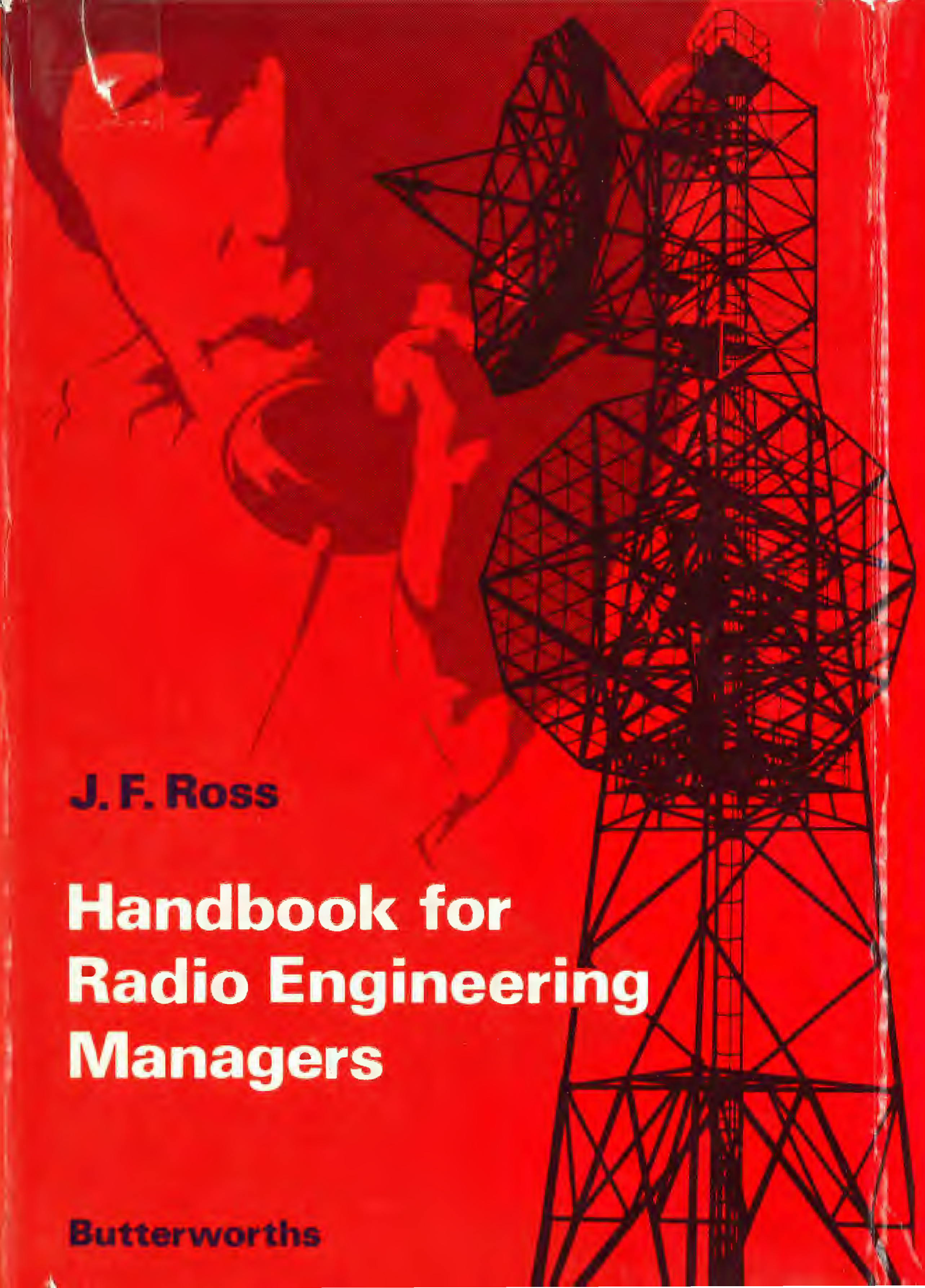
Ross

Handbook for Radio Engineering Managers



J. F. Ross

Handbook for Radio Engineering Managers

Butterworths

This Handbook is designed to help everyone associated with the management of radio projects, services and facilities from the large complex radio stations and networks down to the small station.

The book describes managerial factors and aspects associated with the design, installation, commissioning, operation and maintenance of radio engineering services and facilities with particular emphasis on efficiency, productivity, budgeting, organization, safety practice and environmental obligations.

The text is entirely practical in its approach with a minimum of complex mathematics and management theory. A unique feature of the book is the extensive use of illustrations, graphs, tables, worked examples and case studies taken from a wide range of real situations.

Cover illustration courtesy of Thomson – CSF

Handbook for Radio Engineering Managers

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Preface

The need for excellence in radio engineering management has never been more important than it is today. The difficult managerial and technical problems which have compounded as a result of the application of highly advanced technology to major projects and operational facilities involving high cost, profitable operation, tight schedules, rigid specifications, high power, stringent safety procedures, extreme complexity and environmental considerations focus attention on the man most responsible for their solution–the radio engineering manager.

For decades the engineer accepted the role of technical expert whereby he analysed the technical problem assigned to him and prepared a functional design for solution of the problem. However, in more recent times he has become closely involved in the management decision making processes. The requirements of most new works projects or system operations offer a choice as to the action to be taken and economic comparison studies, cost benefit studies and evaluation of the alternatives form an important responsibility of the engineer. He has to take these into account in recommending to management the course of action which should be followed.

The practice of radio engineering has reached a high standard throughout the world and the rapid development of many newly formed nations has been due in no small measure to the skill of radio engineers in establishing internal and external communications employing such facilities as broadcasting, television and radio communications particularly in the case of the latter of broadband microwave radio relay links and earth station satellite systems. The design and economic provisioning and operation of these facilities requires the application of efficient management techniques and many engineers have expressed the need for a book which might serve the dual purpose of a practical reference handbook for practicing radio engineers and a textbook for students.

In preparing this Handbook the author makes no claim to originality of the subject matter in the text. It has been drawn partly from published and unpublished records of many major organisations, partly from the experiences of others and partly from the author's own records and experiences in radio engineering spanning more than forty years. No attempt has been made to deal with the technical aspects of design and measurement or the theoretical side of management and organisation as these are already well covered in a multitude of excellent publications.

The content and arrangement of the subject matter has been chosen after considerable thought, discussion and correspondence with colleagues but the main task has been the selection of essential information which is not readily available to the average engineer, the extensive use of examples, photographs and case studies taken from real situations and the compression of these into a single volume. It has been divided into six Sections, each Section being complete within itself.

The First Section covering Management and Organisation deals with project management, project control, project programming, design programmes, planning and tender schedule stages, external and internal plant programmes, site installation and construction, PERT/Cost techniques, trend analysis, productivity and efficiency, engineering budgets, costing and organisation.

Engineering Economy, the second Section, is concerned primarily with economic choice and in particular with economic studies, capital costs, maintenance and operating costs, retirement, depreciation and includes worked examples prepared for economic comparison purposes.

Safety Practice, a subject of considerable importance to the radio engineering manager, comprises the third Section. The main topics are philosophy and plans, staff responsibilities, aids and facilities, electrical and radio equipment, mechanical plant, radiation hazards, maintenance of masts and towers, designing for safety, installation of equipment and plant, protection, and installation and construction hazards.

The fourth Section deals with Fires in Radio Installations covering fire hazards, organisation, equipment and buildings, detection and facilities, electric shock hazards, the transformer problem, lightning hazards, lightning protection and includes case studies of fires at transmitting stations and studios.

The important features of Environmental Aspects in Radio Engineering are outlined in Section 5. Features covered include reliability, performance of materials and equipment, corrosion, failures of structures, environmental obligations in mast and tower design and radio frequency spectrum management.

The final Section covering Specifications and Contract Administration covers specifications, including examples of typical radio engineering specifications, inspection and acceptance tests and contract administration.

Although many of the practices mentioned throughout the book were developed for large or medium size projects or stations the methods are, when sensibly applied, equally valuable for other smaller works and for small stations with only a few technical people. The control and management of a project for adding a new studio or an additional low power transmitter for example, has all the operational features—and most of the difficulties—of building a multimillion pound long haul radiocommunication relay network, high power international broadcasting station complex, earth station satellite system etc. Also the loss by fire due to inadequate protection of a low power commercial broadcast or television transmitter can be just as crippling to a small business as the loss of a strategic radiocommunications post may be to a military group. Safety practices, too, are just as important at a small station as at a large station where some hundreds may be employed.

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Section 1

Management and Organisation

Introduction

No major radio engineering project can be properly initiated, or carried to a successful completion, without adequate consideration of its technical and economic ramifications. The emergence of engineering management as a necessary feature of present day broadcasting, television, radiocommunication and radar planning, installation, maintenance and operational projects, and the adoption of the systems approach in place of the former unit approach to problems, reflects the rapid development of management science as a necessary radio engineering discipline.

The initial stages of any project entail research, feasibility study and economic evaluation, and these must be carried out in depth before a decision to proceed is reached. In this Section, it is assumed that the project has been proved to be viable and that positive steps are to be taken towards its implementation.

Project management from this point onwards will be concerned with initiation of the planning and design stages, establishment of controls, staffing supervision of the contract or installation work and other fringe activities, planning for commissioning and ultimate handover to operating and maintenance staff.

All activities associated with a project must follow a logical sequence. Decisions must be reached at the appropriate time and competent management during the early stages will establish a sound basis for all subsequent steps. Many difficult decisions may have to be made during the early phases and the temptation to proceed with some fragments of the project at the expense of the development and application of managerial concepts should be resisted.

Programming of all detail planning, design, construction, installation and commissioning activities, especially the necessary co-ordination between building, civil, mechanical, electrical and radio requirements of many projects, is becoming ever more important with increasing size, complexity and the demanding time schedules applicable to large multi-discipline radio engineering projects. On such jobs it may be necessary to have staff fully devoted to programming and associated resource scheduling of engineering, manpower and plant resources.

Sound financial control is necessary for successful project management. The organisation must provide an appropriate cost control system to provide accurate, up to date cost information. This system needs to highlight financial problems as soon as possible for management attention. Regular realistic estimates of the cost to complete the works are also necessary to provide the overall financial control required.

A sound organisation is fundamental to the success of any project whether it be new work, maintenance or operations. A soundly based organisation plan enables changes in staff and technology to be made as the need arises, particularly those changes associated with expansion. The organisation must have stability and cohesion in order to ensure corporate working, so that all efforts are directed towards a common objective.

Chapter 1

Project Management

We are living in an age of increasing specialisation in all engineering disciplines and this trend is likely to continue and to intensify. The radio engineer challenged by larger and more complex project tasks is confronted with a continuing stream of potentially difficult problems and there is a paramount need for the application of sound methods in engineering management. Without the use of modern radio engineering management techniques the engineer will almost certainly be faced with shortfall between achievement and programme. The old traditional intuitive practices which placed heavy reliance on experience must give way to calculated reason and logic. Furthermore, with rapidly advancing technology, and with increasing size and complexity of many radio engineering projects, this relevant experience is seldom available.

Project management embraces planning, programming, progress control, installation, commissioning and operation of the station, system or facility and in order to carry out a programme of work efficiently, economically and to a tight schedule, management must be provided with a means of assembling high quality information based upon measurement rather than estimate and facilities for speedily analysing this information. This is necessary in order to provide a realistic programme in the first place and to provide accurate information on the progress or status of the work to enable quick effective action to be taken if deviation occurs.

FUNDAMENTALS OF PROGRAMME MANAGEMENT

When decision has been made to proceed with a project, it is necessary to ensure that the work will be carried out in the way contemplated when the estimate, schedule or tender was made out, and that all the items and processes will be completed within the time allowed and within the expenditure provided for, in the budget. A programme is therefore required to ensure that the various processes are followed through as planned and the rate of progress, as budgeted, is being achieved.

The conditions of contract for most large radio engineering projects require that the tenderer submits a programme with the tender. The programme and tender should be compiled together; indeed it is difficult to understand how it is possible for the tenderer to build up a competitive price without a programme. The object of the programme is to show simply and clearly the expected position of the work at fixed times from the time the contractor takes possession of the site, to the time the system is commissioned and handed over. If the programme as submitted with the tender is not acceptable, the parties should confer to enable agreements to be reached on a programme, with final acceptance of the tender being dependent on the tenderer's willingness and ability to meet the conditions of the contract. A prospective contractor who is unsympathetic or unco-operative at this important stage would probably be yet more so, after the contract has been placed.

The adoption of programme management techniques provides a valuable method of setting down the logical sequence of activities and of showing their inter-relationship in a form suitable for monitoring. The fundamental meaning of programme management is the communication of facts, problems, ideas, processes, time elements and resources. In this communication, quantity is no substitute for quality, and proper communication is established only when a response is evoked; in other words, monitoring is valueless unless corrective action results from it.

All the parties concerned with the project must be committed to the one programme. It will often be in broad outline form during the early stages of the project and will be developed and expanded within this framework as progress is made. Certain schedule dates will have to be revised during the development of a programme and this must be done in a controlled manner. The project master programme will become too large and too complex to be used by every organisation and person associated with the project. The master programme should therefore be broken down into simplified forms for different levels of management, and also for specialised operations in the various project phases. In order to produce simplified programmes, the schedule dates should be analysed in relative order of importance, introducing the concept of first order, second order and third order schedule dates.

The following fundamental points of project management are of particular importance:

(a) Programme management procedures require a high degree of discipline by all parties in decision making. General acceptance of the need for effective programming and monitoring throughout the life of the project will impose a discipline upon management and engineering decisions, and should ensure the proper integration of the various sectional interests.
(b) Pre-project planning and studies must be performed in sufficient depth and in adequate time if the master programme is to be reasonably realistic.
(c) Adequate flexibility must be built into the master programme so that the most effective use is made of the resources available to the principal and the contractors.
(d) Standard engineering programmes have limited value in view of the importance of the non-standard aspects of many radio projects.
(e) The procedures for monitoring work progress and expenditure should be simplified in order that management at all levels can be supplied with the appropriate amount of detail.

DESIRABLE ATTRIBUTES OF A PROGRAMME

Any programme may have to be modified during its life because of unforeseen problems, and the use of modern programme management techniques may not always help to obviate these problems. Nevertheless, these management techniques should be of value in deciding the best course of action to be taken, if and when such problems arise, and this strengthens the justification for their use.

In any event, a programme to be of much use to management must have the following attributes:

(a) It must provide one master plan and schedule for the entire project whether the nature of the work be design, installation, construction or maintenance. The presentation should be such that every person associated with the project can clearly ascertain his role in the programme. The master plan should be capable of condensation for top management and be capable of providing a lift-out of information for the various sections of work for the information of the resident engineer, foreman etc. The extent of detail reported should be appropriate to the manager or supervisor to whom the report is directed.

(b) It must indicate, whether time schedules of the programme are being met, whether costs incurred at the time of reporting are within the budget or contract cost, and whether the specifications of the work are being met. Management echelons are primarily concerned with whether time schedules, costs and the technical specifications are being met, since a successful engineering project must satisfy all these three objectives.

The programme must disclose those critical activities which may cause problems. For example, it should point out when a change in the delivery or manufacturing schedule, even for a small activity, may have a major impact on the project as a whole. One pre-requisite for any control system is the provision of adequate means of measuring the effect of any commands given. The information so derived can be fed back to the sender, in order that errors may be corrected.

(c) It must reveal whether there are trends which indicate that time schedules, costs and specifications will not be met, and also the extent of such deviations. Once the project programme has been approved, management decisions should be required only to correct departures from the accepted plan and schedule. It must facilitate management by exception, i.e. it must report to management only those items or activities which require action to correct a deviation. At the same time the system must assure management that the unreported items or activities are proceeding according to plan.

(d) It must permit ready modification of schedules to keep up-to-date with changed conditions or the introduction of amendments.

Data must be stored in such a way that easy access is provided to all who require information.

(e) It must be economical to operate.

Economy is one of the basic reasons for employing control systems but it is not an easy matter to place a money value on all system benefits as many are intangibles and difficult to evaluate. The economic aspects can only be properly assessed particularly when dealing with operation and maintenance activities, by comparing the cost of operation in times when no formal system of control was used, against the cost when a control system is used.

SCHEDULING

Upon completion of the plan, it is necessary to affix times on which individual parts of the plan will take place. This dating or scheduling, consists of the assignment of specific jobs to the resources (manpower, machinery, etc.) and the assignment of specific starting and finishing times to these jobs. To do this, account must be taken of all the inter-relationships between operations or activities.

The proper scheduling of project work is both an art and a science and considerable experience is necessary to become skilled in the work. One of the objects of network techniques is predicting problems, and many factors enter into the associated time estimates. These include:

(a) The complexity and nature of the work.
(b) The skill and number of engineering personnel involved.
(c) The ability of outside sources to meet their obligations.
(d) Consideration of technical side effects due to new or modified designs.
(e) Pressures from political, and other areas to meet certain in-service dates.
(f) Special factors unique to a particular situation.

The engineer must be sufficiently experienced to take into account all of these considerations and to come up with realistic and reasonably accurate end dates.

If activities are subdivided into short, controllable elements and one activity gets out of hand because of faulty estimating or any other reason, management will generally be in a position to act before the condition spreads and endangers the complete project. Bad estimates on small works or sections of a work, are often not as dangerous as bad estimates on which jobs extend over a long period of time because the problem may not be apparent until the project falls into serious difficulty.

Scheduling has often been confused with planning which is an entirely different and separate function. Planning is the process of setting down the separate activities which must be carried out in order to fulful the objectives of a project and the establishment of the sequential relationships between these activities. The planning operations must be performed before the project can be properly scheduled. Scheduling on the other hand is the determination of the time requirements of each activity. The scheduling function is a process for formalising the planning functions and for some projects, a certain amount of re-scheduling is often required during the progress of the work.

PROJECT ACTIVITIES

Each project must be handled as a separate entity having its own technical objectives, schedules, method of achievement and of course its own cost structure. For large radio engineering projects, many organisations generally select one of their staff as the Project Engineer or Project Manager with the responsibility and necessary authority to carry out the programme of work to conclusion.

Because of the complexity and size of many of today's radio engineering projects, many different kinds of professionally trained people may have to be organised to carry out the work. For example, for a long haul broadband radiocommunication relay link through a dry inland region there may be requirements for experts in the fields of air conditioning, structural, civil, electrical and radio engineering. This may introduce interface problems in some situations but basically the work involved in carrying out one project is very little different from another. For a typical large project, activities involved may be as follows:

(a) Establishment of the organisation arrangements to allow the programme of work to be carried out.
An organisation is necessary in order to establish a basis on which to carry out the work, and also to clarify responsibilities of individuals in the group, delegations and authority.

(b) Preparation of specifications for the project.
Specifications vary from documents defining the required project system in detail, to performance documents which merely describe the end use of the system without defining the method, means or design concepts to be used. If the tender documents do not detail the technical specifications, these must be prepared by the project group.

(c) Formulation of the parameters for the technical performance, characteristics and configuration of the station, system or facility and the development of control systems to monitor these parameters throughout the life of the project.
The accomplishment of the objective involves communication of the proper instructions to the responsible parties, communication of corrective instructions and information among all parties concerned with the project, and a follow-up system of developments and proposed changes.

(d) Development of reliability requirements for the system.
The project group must be cognizant of the reliability requirements of the system, or facility, and implement an adequate programme to achieve the reliability objectives. The implementation of reliability is usually accomplished by a special reliability and quality control group where a large project is involved.

(e) Preparation of design programme.
The programme should set down the design objectives at particular stages of the programme, the detailed activities which should be achieved by each group, section, department, or contractor, and what aspects of the design are to be considered or require approval at each stage.

(f) Preparation of the project master programme network.
The network should cover the essential requirements of the whole of the project from the period commencing with its allocation to the project group, to the completion of the work, and should include all activities related to the development and execution of the project within the influence of the group.

(g) Preparation of installation and commissioning programme.
Where the contract involves installation or site establishment of the system, this should be properly planned and programmed. In some cases subsequent operation and maintenance of the system may also form part of the contract, and these matters would require appropriate consideration during formulation of the plan.

(h) Manufacture and evaluation of prototype units.
The manufacture of prototype units which may be the result of a development and engineering effort, involves special planning. The programme schedule, which is usually critical, may require that manufacture be accomplished piecemeal as the required information and drawing are released for manufacture.

Evaluation begins with the completion of the prototype. This may be a series of tests that determine the ultimate capability of the system, or the prototype may be placed as a pilot model in an operational situation, and observing the performance. Recent prototypes have included solar cell power systems for broadband radio relay systems, automatic monitoring equipment for unattended television and sound broadcast transmitters, remote control and tuning of programme receivers and automatic production line testing of television receivers.

The project group has the task of setting the objectives for these tests, the organisation of them, participating, and finally evaluating the outcome.

(i) Development of control systems for the project management processes. The systems are to be used for maintaining surveillance of the expenditure, time scheduling, profitability and technical performance of the work throughout the life of the project. They are also to provide the basis for the preparation of regular management reports and discussions with the principal or customer. The smooth conduct of a project depends to a large extent on how effective the links with management and the customer are monitored.

(j) Scheduling tasks and subcontracting for system items which have to be procured.

When the organisation for the project and the schedule for the accomplishment of various tasks have been established, tasks are assigned to the various groups. Factors which influence decisions regarding sub-contracting for items are, contractors capability, relative cost, scheduling, experience and the principal or customer preference.

(k) Preparation of handbooks and drawings.

The preparation of handbooks detailing the system installation, operation and maintenance is a specialised task, and in some cases has represented the largest single side item of the contract. The amount of detail, drawings, photographs etc. will be dictated by the system specification.

(l) Provision of operational support equipment items.

The selection of spare parts, test equipment and other support equipment would be made after joint discussion between the contractor and the principal following system design completion. The guide to what items or units should be provided as spares or test units would depend to a large extent on life expectancy, costs, long term availability and availability of alternatives.

(m) Provision of support for system installation, maintenance, operation and staff training.

For a turnkey project the contract may require that the system be fully installed and commissioned, and that the contractor provide a training programme to enable the principal's staff to become fully conversant with the equipment.

Even after the system has been delivered and installed there is often a continuing role for the project group for a considerable time. Many matters requiring attention from time to time include settlement of claims, guarantees, maintenance liaison with the principal and analysis of field reports. Field reports may indicate shortcomings in the design of units or inadequate components, and if a maintenance guarantee period forms part of the contract, a redesign and field replacement may be involved.

MANAGEMENT INFORMATION

Whatever his level in the organisation, the manager is faced with both strategic decision making tasks and those which involve organising and controlling the implementation of those decisions. Each level of management requires certain basic information in order to make a correct decision. Network techniques and computers play an important role in this regard.

A common objection raised by many managers to network techniques such as PERT, Critical Path Method (CPM), Line-of-Balance (LOB) and others, is that the process of assembling information, constructing a network diagram, and the breakdown of the work into packages etc. tends to become too complex and involves excessive administrative manpower effort. It is agreed by many people that this is a difficult part of the network approach in management, but it is through this very process of assembling the information and constructing the network diagram that the greatest advantages of these methods are realised. In the preparation of the network diagram, the planner must be thoroughly conversant with the work required. Unless he is, he cannot break down the work into the packages or operations required for the network compilation. This can be construed as an analysis of the estimating and planning procedures, as inadequate attention to details, errors etc. will be shown up by inconsistencies and incompleteness in the network diagram. The significant aspect of a network analysis system is the planning and control it makes possible, and not the methods used in collecting and processing information.

In conjunction with network techniques, computer systems provide top and middle management with far better means of directing large scale complex projects. Management can measure cost, time and technical performance on an integrated basis, and better assess the tradeoffs involved in putting an 'off-target' back on line. An examination of many large radio engineering projects which over-ran cost and schedule targets, revealed that many were plagued by a common problem, namely, inadequate management information. The information was inadequate, not in the sense of there not being enough, but in terms of relevancy for setting objectives, for shaping alternative strategies for making

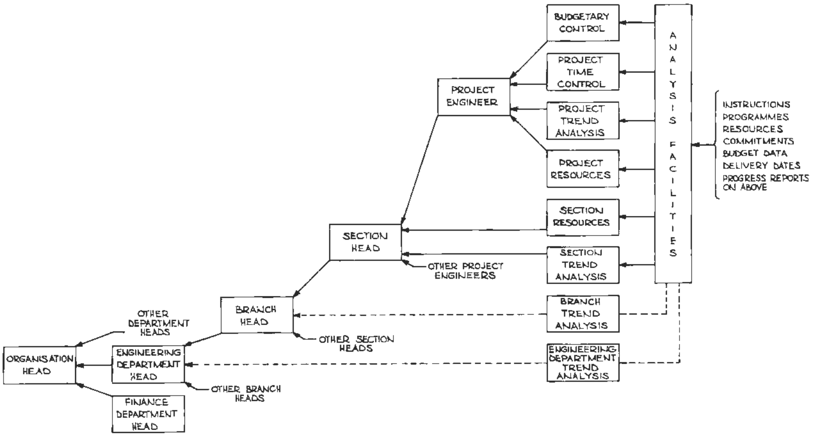

Figure 1.1 Typical management information flow diagram

decisions and for measuring results against planned goals.

However, it has to be recognised that none of the network analysis techniques is universally applicable. Too many organisations have looked upon CPM, PERT and others as techniques which could be installed without adaptation to the particular working method and requirements of the organisation. Very few organisations are identical in character, and a particular system used by one organisation would not necessarily be suitable for another without some change. Modification of the system will often be necessary in order to be integrated into existing management information systems and the requirements of the organisation. For the system to be successful it is important that it be a practical and meaningful tool for the management environment and suited to the problems of the particular organisation.

The chart of *Figure 1.1* illustrates diagramatically the information flow and control information needed by various levels of management for the proper

Table 1.1 MANAGEMENT INFORMATION REQUIRED FOR DECISION MAKING

Level of control	*Area of delay*	*Information required for decision making*
Group or Resident Engineer	Section of the installation work	Detailed installation or contractor's programme Analysis of the progress to date Site resources Analysis of the project position
Project Engineer	Contract delay in either design or installation	Report from Resident Engineer Detailed design or installation programmes Contract programmes Analysis of contractor's progress Analysis of project position Resources of contractor Project programme
	Works programme delay	Report from Resident Engineer Project programme Analysis of progress of project Contractors' programmes which are in difficulty Contractors' resources which are in difficulty Financial situation Project resources
Section Head	Specified project	Report from Project Engineer Project programme Analysis of progress of the project Contractors' programmes which are in difficulty Contractors' resources which are in difficulty Financial situation Project Engineers' resources and commitments
	Section annual works	Section commitments Section resources Programmed completion dates for all projects, of the Section Financial situation of the section

Table 1.1 *(continued)*

Level of control	*Area of delay*	*Information required for decision making*
Branch Head	Specific major project	Report from Section Head Programmed completion date Situation of critical contracts Trends and performances of manufacturers in difficulty Financial situation of the project Section resources
	Branch annual works programme delay	Report from Section Head Section commitments Section resources Completion date of all Section projects Financial situation
Engineering Dept Head	Major project delay	Report from Branch Head Estimated completion date Progress analysis giving position of critical contracts Financial situation of the project Branch resources
	Engineering Branch annual works programme delay	Report from Branch Head Branch commitments Branch resources Target dates for all Branch projects Branch financial situation
	General delay in the Engineering Dept annual works programme	Report from Branch Head Estimated works completion dates Branch trends Installation trends Manufacturing trends Overall financial situation
Organisation Head (Principal)	Major project delay	Report from Engineering Dept Head Estimated work completion date Progress analysis of critical contracts Project financial situation Engineering Dept resources
	Engineering Dept annual works programme delay	Report from Engineering Dept Head Estimated completion dates Engineering Dept commitments Engineering Dept resources Installation trends Engineering Dept financial situation

control and co-ordination of a number of projects. *Table 1.1* shows the basic information required for decision making purposes, by various levels of management from the Resident or Group Engineer through the Project Engineer, Section Head, Branch Head, Engineering Department Head to the appropriate Vice President or Head of the organisation.

RELEASE OF INFORMATION

The control of any contract by the principal is substantially weakened once the contractor is able to claim fairly that he is held up for information. It is therefore first of all necessary to negotiate or, if submitted with the tender, agree on an overall contract programme based on the schedule dates showing a phased issue of information to the contractor. If the design planning has been done properly and provided that work is on programme, it will then be possible to release working drawings as required. A control system should be set up to ensure that details required are provided when required. This should be in the form of a periodic, usually monthly, scheduling of areas for which information is required, the schedules being prepared at an agreed period in advance of the requirement, and they should show the detail and extent of the information required.

CONTRACT PAYMENTS

Many large radio engineering projects involve considerable investment of contractor's capital and by the time the project is completed, profits may be considerably reduced or even nullified by interest payments on the capital, particularly if the work over-runs the original schedule. Because of this, many contracts allow for progress payment clauses in order that the contractor is not required to have the whole capital cost of the work invested before payment is made by the principal.

Progress payments for the project may be made on the basis of specific work being accomplished, for example, completion of tower foundations, or it may be on the basis of the delivery of specific equipment or plant, for example, tower steelwork. Another arrangement which is sometimes agreed to, between principal and contractor, is for the progress payments to be made at regular intervals with the amounts paid being governed by the actual work accomplished.

A third contract payment arrangement which is sometimes used involves a straight line budgetary control curve. This method increases the project engineer's financial control during the site phase of the project. In some cases a high proportion of the contract price is related to the cost of manufacturing and materials, leaving only a relatively small proportion of the total to cover a long period of site construction and installation activities. A straight line curve simplifies payment procedure as it is understood from the outset of the contract, that payments are to be made in accordance with this principle providing the contract progresses in accordance with the programme. Also it is far simpler to adjust the straight line curve than an 'S' type curve.

Some contract administrators object to the straight line curve on the basis that it is not necessary under a system of retention of money, and that payments in the early stages of the work for more work than has been carried out, is contrary to the principles of budgetary control. They also believe that timing of payments does not condition the rate of progress by the contractor, that is, it does not provide an incentive to better and faster work.

Contracts associated with radio engineering construction works differ somewhat from those concerned with material or equipment supplies. The main difference is that no product is to be delivered but rather the product has to be constructed on site in accordance with plans and specifications to meet a requirement. Because of particular site and job requirements each construction work may differ considerably from any other, even though the end products may be the same. For example, it would be most unusual for a contract involved in the construction of a large broadcast station at Site A to be identical in every respect with that for Site B. Some differences may on the surface appear to be minor but the differences may be of importance as far as payments are concerned, and a tenderer may require a change in previous payment arrangements.

COMMERCIAL CONSIDERATIONS

Programming should not be considered only from an engineering point of view. Economic and commercial considerations should also be borne in mind. When minimum and optimum programmes based on engineering capability are prepared, they should be adjusted to become also the commercial optimum. This may involve changes in the time scale to improve competition among prospective tenderers.

The cost of delay in commissioning of a microwave radio relay system on a high traffic telephone route might be enormous in some cases, and if the delay could be minimised or eradicated by steps taken in the early stages, the commercial gain might be great, and would vindicate the earlier sacrifices. Experience has shown that large projects for which inadequate preparations had been made in the early stages, tended to require substantially longer periods to commission than programmed. In one project, a capital investment of several million pounds laid idle for one year before being placed into service because of delays in site clearance and building construction. The over-riding consideration in developing project programmes is to construct plant so that it is commissioned and is capable of full commercial output by the programmed date. This applies particularly to broadband radiocommunication links which are required to meet increased telephony traffic.

ENGINEERING RESOURCES

One of the major limiting resources for major projects is engineering personnel. As the pace of radio engineering development has accelerated with the rapid progression in circuit handling capacity of radio relay systems, earth satellite stations, automatic control of high power television and broadcast transmitters etc., the demand for engineering effort of high quality has increased enormously.

The degree to which engineering is a limiting resource will depend on the nature of the particular project work and consequently it is not sufficient to state without qualification that it is the major limiting factor. There is no doubt, however, that it figures prominently in most radio engineering project fields involving design, installation and commissioning activities.

Where several projects are involved plans must be made to ensure that suitably, experienced and qualified staff are available in order to meet the project needs as they arise. The traditional organisation of engineering and drawing office staff may not be suitable for some projects. Frequently these resources have to be reorganised to provide for the rapidly changing and intensive effort necessary to launch many of the modern day large scale projects and to deal with those in the future.

Senior engineers with special expertise in particular fields should be deployed to make maximum use of their expertise, experience and judgment. It is equally important to establish versatile junior engineers with the basic radio engineering knowledge so that they may be redeployed as project circumstances demand. Experience has shown that the greater the degree of specialisation, the greater is the need to counterbalance this by versatility at junior engineer levels so that by redeployment, excessive overloading and underloading of different sections or groups of engineers is avoided.

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Chapter 2

Project Control

The requirement of project control necessitates the provision of a facility for both reviewing the Project Master Programme as a whole, and reviewing separately all the programmes related to it, whether these are in the form of networks, bar charts or simply lists of scheduled dates. A requirement of management in practically every engineering programme of work is that positive and uniform control and monitoring be applied throughout all phases of the programme to ensure that all the commitments of cost, schedule and technical performance are met. Also, optimum programme performance will result when these three programme factors are in proper relationship with each other, and in proper balance with such factors as total system planning, resource allocation etc. Continuous operations analysis and corrective action at the appropriate time will ensure a balanced relationship.

The closeness to which the operation is to conform to the plan, the extent to which restraint is exercised, and the direction over resources to ensure that this occurs, will indicate the degree of control required.

CONTROL SYSTEM BASICS

The extent of the control exercised on a project will of course depend on its magnitude, complexity, cost and importance. A relatively minor project may require only a few simple indicators to show whether the cost, schedule and technical performance conditions are being met. On the other hand, a major project like a long haul radio relay network may require an elaborate monitoring and control system for administrative purposes. For any project, however, irrespective of its size and complexity, there are certain basics required of a control system. The control system must:

(a) Be in a form which is understood by all who are expected to use it. A less refined system of control operated with the acceptance, confidence and co-operation of the workforce will prove superior to a sophisticated system which is badly run.

(b) Have the full backing and support of all the groups associated with the project. This can be helped by not attempting controls which are too stringent at the outset.

(c) Indicate trends in deviation to allow corrective action to be taken by the controller or management before the deviation reaches a point of major concern.

(d) Indicate the rapidity at any point in time with which the divergence from the plan is taking place, that is, it must portray the rate of change.

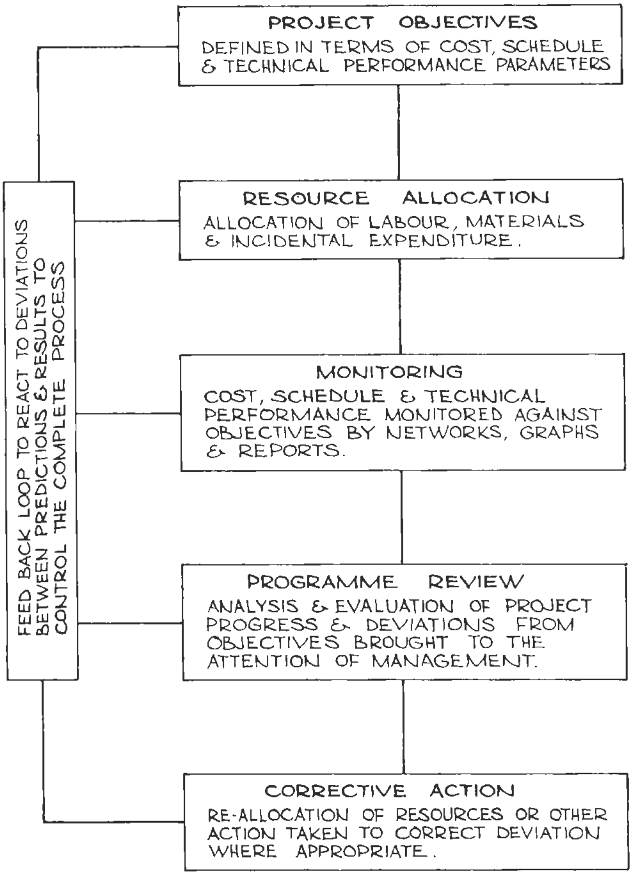

Figure 2.1 Major processes involved in project management

(e) Indicate the form of corrective action necessary to correct a deviation.
(f) Set standards, markers or indicators at strategic points for control operations.
(g) Be sufficiently flexible to allow for changes in plan and scheduling that may occur during the life of the project.
(h) Allow ready identification of areas where effort can be reduced.
(i) Provide information in a form which can be stored for future reference.

Figure 2.1 shows the major processes of management associated with the control of a typical radio engineering project. Sequenced in logic-dependent order, the processes form a classical control loop.

PROJECT OBJECTIVES

Objectives must be set for every project whether design, installation or operation types. They would normally cover a specific period of time and would be spelled out in measurable, definite and concrete parameters. In nearly all projects, the objectives are specified before the plan is prepared. After all, the plan is simply the course which has to be charted in order to achieve the objectives. More often than not, there is a hierarchy of specific objectives covering each element of the whole project. The objective set at subordinate levels of management must be within the bounds of the objectives set at the immediately superior level. The setting of objectives for the project is important because:

(a) They assist in the determination of the basic organisation structure, and establish the functions necessary for achievement of the end results.
(b) They set standards and indicators against which to measure performance.
(c) They stimulate unity of purpose, efficiency and morale of the workteam.

If the technical objectives are such that a new system has to be engineered, the approach to translating the objectives into work assignments may involve the specification of inputs and outputs, performance characteristics, and other features and technical requirements judged to be appropriate. The work may then be divided into site engineering, systems engineering, component engineering and research, and the parameters of the system or facility as set down in the reference design would place certain demands upon the characteristics of the site facilities, subsystems, component ratings and performance.

However, for large projects, the development of a programme of tasks based on a generalised set of technical objectives may be quite complex. Parallel efforts may be required in some cases to ensure that the project can be completed on time and the preparation of tasks may require the participation of many groups or sections of the organisation.

It must not be forgotten that there are other objectives besides the project objectives. If the project objectives are considered to be specific objectives then there are what may be called key objectives and general objectives. The key objectives are the long standing objectives set by top level management to guide the continuing operation of the organisation. The general objectives set out those things which must be done to accomplish the key objectives. Each branch such as engineering, accounts, stores and contracts etc. should have its own general objectives. Objectives must be set for the organisation as a whole for all levels of management and for each major project undertaken. They provide guidelines throughout the organisation and become the standards against which progress can be measured.

ALLOCATION OF RESOURCES

The next step is the allocation of resources. This means taking action to ensure that everything is procured, funds are allocated and labour is available to carry out the project work. This step may be the responsibility of a project engineer; on the other hand part of it may be delegated to another person or many other persons. It may require the purchase of expensive equipment and materials, the hire of plant, the erection of buildings, site works etc. It may also call for engaging new staff and re-training existing staff. It is at this stage that the schedule becomes important because all these activities have to be meshed into a final completion target date.

MONITORING

Having put the plan into action, management will naturally want to know whether the work is going according to the plan. In other words, they want to monitor the work in order to compare the actual with the planned objectives. Monitoring of the project is necessary to provide information for decision making and to provide a means for people at various levels to report on the project status. It will be appreciated that effective control of the work and its consequent expenditure will only be possible if the right information is forthcoming through the monitoring facilities, so that divergencies are promptly revealed.

The monitoring of progress and cost are essential elements of project control. Information regarding the work progress is the primary ingredient necessary to ensure that objectives are attained or at least that progress is being made toward the attainment of the desired objectives.

PROGRAMME REVIEW

It is a general practice for reviews to be made of each project at regular intervals. The review is often carried out on a monthly basis to coincide with the submission of management reports. The purpose of the review is to compare the progress of the project work with the programmed plan and to establish:

(a) The effectiveness of the project management.
(b) The extent to which the specific objectives of the project have been achieved at the time of the review.
(c) The current financial situation of the project.
(d) The extent to which top level management should participate in the event of deviation from the programme.
(e) Whether any changes are necessary in the project manager's authority to make technical and business management decisions required by the project.
(f) Whether the priority allocated to the project is adequate.

The project manager presents the status of his works programme in terms of accomplishments or deficiencies as related to schedule, cost and technical performance, using the Project Status Reports as a basis for the submissions. Where action is necessary to solve problems or expedite a particular phase of the work, appropriate steps can be taken by management.

The main advantages to be derived from programme review may be summarised as follows:

(a) It keeps all levels of management informed of the progress of each project.
(b) It improves communications between the various group leaders associated with the project control.
(c) It helps to mould a more effective team by improving the understanding of the objectives of various programmes.
(d) It highlights areas in the engineering organisation which may need support or additional backing to cope with a particular work.
(e) It helps to develop a greater awareness of the responsibilities of the various leaders involved in the work.

(f) It helps to develop a greater awareness of the need for problem area recognition by group leaders.
(g) It provides a means to assess activity performance for assigned areas of responsibility by comparison with standard performance or trends of performance.
In the standard performance case, the work performance is compared with the standard time, i.e. the time required by a workman of reasonable skill to carry out the work while working to a reasonable value of output. In the trend of performance, a comparison of current performance is made with the performance on previous occasions.
(h) It allows management to determine the effectiveness and adequacy of delegations vested in the various levels of line management.
(i) It effectively brings to the attention of top management of the organisation, high performance or work of merit of individual staff on the project and areas of high productivity.

Experience has shown that there is a relationship between the detail which can be reviewed by the management of a project, the normal term of which may be of relatively short duration, and the frequency with which such reviews can be carried out. Historically, the practice has been, for new works, to make a basic assessment of project installation and construction progress at monthly intervals, and most organisations and practices are directed to this need. Whilst in the ultimate, a high speed data processing facility might be capable of giving an instantaneous review of any particular situation, in practice an assessment of some arbitrary interval of time, such as one month, seems to be a reasonable requirement for as far ahead as it is possible to look from the present.

Whenever changes in programme dates or failure to achieve programme target dates occur in a contract programme, it is, as a result, frequently necessary to review the Project Master Programme, recognising these changes and taking account of them in a critical path method run. Experience has indicated that in any large suite of programmes such as envisaged for control of a large complex project, there is an advantage if the transfer of data is carried out automatically. The problem of data transfer between separate programmes is in fact a similar problem to that which exists in any suite of programmes which are separately reviewing sections of a composite whole. Basically it can only be resolved by clear identification of common events and recognition of the compatibility of one programme form with the other. Indiscriminate identification of events must therefore be avoided by a precise system of coding. If attention is not given to this aspect, the problem of storing and subsequent retrieval of data will inevitably give rise to errors in subsequent processing and reporting.

CORRECTIVE ACTION

The first four steps—setting objectives, allocating resources, monitoring and programme reviewing—are really preliminary steps in control. They may be performed with a high degree of efficiency but no control results unless all this checking has some influence on those carrying out the project work. Corrective action is necessary before any real control of the work can take place.

Analysis and evaluation which takes place during the programme review stage will highlight any deviation from the objectives or predicted results. Where deviation does occur, action can be taken to correct the past action or more likely, to ensure that the course of the project is placed on the desired target. For corrective action to be meaningful, a framework of standards or indicators at strategic points in the project must be set, and the actual performance measured against these standards or indicators.

The type of corrective action taken will depend on the extent of the deviation and the nature of the project, and may include:

(a) Re-allocation of resources.
Many deviations from the predicted course are often the result of unexpected obstacles in the work situation such as technical problems, wet weather, breakdown in supporting plant and shortage of tools.

(b) Revision of the plans.
Often work is affected by wet weather, high winds, late delivery of materials, non-availability of local labour and other external forces which cannot be corrected by management action, and a change in plans may be necessary. If the revision reveals major problems, the plans may have to be reformulated to cope with the deficiencies which have been revealed.

(c) Review of directions.
Sometimes failure to meet objectives can be traced to inadequate directions to project staff. It may be necessary to review the objectives with the project team to ensure that there is no doubt about what is wanted and how they should go about accomplishing them. In other words, goals must be specific and the course must be set.

(d) Planning for future works.
If the present measurements indicate variations in estimated rates of productivity or performance, action should be taken to ensure that future programmes and schedules take account of these facts.

PROGRAMME COMPARISONS

Apart from environmental conditions, the programming requirements of certain categories of radio engineering works such as broadcast station, earth station, television station, radiocommunication station and radio relay repeater projects, do not within the particular category change fundamentally in terms of the permissible installation sequence. What does change however, particularly as a result of differing environmental conditions and availability of supporting resources, is the duration of the associated activities and therefore the timing of programme events.

Management is based upon comparison, and comparison implies a standard or programme against which that comparison can be made. It is therefore important that results provided for management should be prepared with a view to showing the divergence from the normal programme rather than the haphazard recording of whatever may have occurred within the precise limits of the period under review. If therefore, the task of management is to be made easier, so far as the presentation of facts and figures is concerned, some basis of comparison must be found which will enable managers to visualise what is going on, without having to make calculations or mental adjustments of their own.

Charts and graphs play a very important part in the presentation of information to engineering management. A much clearer mental picture of the position can often be obtained by examining a chart or graph than by reading a detailed statistical report, especially if the people concerned are constantly requiring information about a number of large projects. By means of up-to-date charts and graphs the manager can have an overall picture of the current status of all of the projects and so be able to give speedy attention to those areas where action is required, as recorded by difference between the anticipated programme and the actual progress. It is not always possible to assess the true position accurately at a moments notice, from normal statistical information supplied by the accounts department or costing section.

Whatever form of management aid is used, the system should assist the project manager in accomplishing his responsibilities for:

(a) The co-ordination of project planning.
(b) The assessment of project status.
(c) Reprogramming as a result of technical difficulties or changes in scope, schedule, resources or policy.
(d) The co-ordination of progress data, by integrating multiple source progress information into a single easily understood form.

COMPUTER PROGRAMS FOR NETWORK ANALYSIS

The use of a computer in network analysis has many advantages over a manual system. The most important of which are:

(a) The greater speed by which calculations can be performed allows updated information to be made available to management and project leaders much earlier.
(b) The greater accuracy of computer calculations minimises errors in data calculation.
    Repetitive manual corrections to written achievement entries on cards and sheets often result in a set of excessively worn and untidy documents with a high error risk.
(c) A computer can be programmed to carry out any required variations to the basic analysis.
(d) The idea of relying on an automatic easily changed file in the computer's store is preferable to manual updating on written sheets and cards.
(e) Calculations of immense complexity can be undertaken.
(f) Management is provided with clear and easily identified network activities and events.
    A computer will invariably accept a full alphabetic description of each event and activity and print these along with the numerical identification. It can also edit the report, discard unwanted information, print column headings etc., the whole analysis being neatly laid out for use by project management.

The point at which computer assistance becomes economic or otherwise desirable is not determined solely by the magnitude of the project, although this will be a significant factor. The size and shape of the network may not be the main factor in determining computing costs. The output data may be sorted in various ways, by listing activities in order of increasing float, or events in the order of their expected times. Further sorting, by sections for instance, may yield very useful sets of output data; it will also add to the cost of computing. To employ a computer as a sorter could speed up the output unnecessarily at an unjustifiably high cost.

An important point is that the preparation of the network is basically a non-computer exercise. It depends upon visual observation and analysis of the project to be carried out, and the experience and intelligence of the network compiler is an important factor. Also, by the manual preparation of the network the compiler can exercise his judgment and control over each separate action.

The question of computer utilisation involves many considerations, the main ones of which may be summarised as follows:

(a) Whether integration with an overall management control system is proposed and, if so, the expected frequency of analysis and revision.
(b) Whether cost optimisation, probability analysis, resource scheduling or other advanced computations are desired.
(c) The desired format and quantity of reports during the progress of the project.
(d) The availability and cost of a computer service with an adequate facility programme.
(e) The availability of trained staff to program a problem for computer solution.

It is not a simple matter to determine the precise cost of installing and using network analysis in relation to the project cost, because there are many side benefits which are derived by management generally, and to which it is difficult to fix a price. However, an analysis of four large radio relay station projects showed that the cost of operating the system varied from 0.25 to 1.5% of the total project cost. About one third of this arose from direct computer charges; the rest was staff time.

The time and expense involved in writing a network analysis computer program is often considerable and it is prudent to make use of prepared programs which may be available from the libraries of computer service bureaux. An examination of the various specifications will allow determination of their suitability for the particular project in hand. It is important that the specification of a particular program be fully known before it is applied to a problem. Its capabilities must be thoroughly understood.

Computer programs which have been developed for network control recognise in the first instance, the requirements of being capable of carrying out a critical path review in order that the earliest and latest start and finish dates for principal events can be established and thereafter, meeting the need for reviewing the schedule dates. Any changes to the program which do not directly arise from these needs must be examined with caution, otherwise there is a risk that the basic advantages of an essentially simple program, which will provide management review data, in both physical and financial terms, as well as offering a convenient progress statement on the situation of both the project and its supporting contracts, may be lost.

COMPUTER PROGRAM FEATURES

There is a wide range of computer programs available to the engineer from various sources. The range and extent are being constantly expanded. Facilities most widely used by radio engineers include:

(a) Event and activity reports and resource analysis.
(b) Float and slack analysis.
(c) Scheduling and forward scheduling dates on events and activities.
(d) Three time estimates and probability calculations.
(e) Automatic network checking.
(f) Calculated results for events, activities and calendar date conversion.
(g) Print outputs of events, activities, interface activities and number of copies.
(h) Management summary reports.
(i) Cost optimisation and control calculations.
(j) Bar chart scheduling without dependencies.
(k) Resource scheduling.
(l) Resource analysis and control.
(m) Project progress control.

Float and slack analysis (b) is of particular interest in new station or system projects. Float is the measure of free time available to the completion of an activity. It is the difference between the activity duration and the maximum interval between the occurrence times of events at its start and finish. The terms usually associated with the process of float analysis are total float, free float and independent float. Total float is the maximum float time available to an activity, free float is that portion of the total float which, if absorbed in the operation of a particular activity will not affect the amount of float available to any successive activity and independent float is that portion of the total float which is available only to a particular activity.

Since float is the difference between the activity duration (t_e) and the maximum interval between the occurrence times of events at its start and finish, total float can be calculated from the formula

$$\text{Total float} = (T_{Lj} - T_{Ei}) - t_e$$

Convention in calculating float is to designate expressions referring to the start of an activity by the symbol 'i' and expressions referring to the completion of an activity by the symbol 'j'. T_{Lj} is therefore the latest time the activity can be completed and T_{Ei} is the earliest time the activity can commence.

Slack is a term by which the free time associated with events is measured. It is the difference between the two times of a given event, calculated during the forward and backward passes through the network. Slack time is the extent to which an event may be delayed without affecting the timing of the critical path and is expressed by

$$\text{Slack} = T_L - T_E$$

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Chapter 3

Project Programming

A primary requirement for successful project achievement is that, when the project is taken over by the project group, there is a reasonable chance of completing it by the programmed date. The project must therefore be appropriately developed at the take-over stage and sufficient time must be available for the design, installation and commissioning to be completed by the programmed dates with the resources available.

In some large communications organisations the initial stages of development of a project are the responsibility of the Planning Branch who carry out a feasibility study, economic study and sometimes field survey and site selection work. Collaboration between the planning engineers and the project group is essential, and should start at an early stage of the project development. To ensure that the project is sufficiently developed when taken over by the project group all the activities in the initial stages need to have been properly programmed and completed. Due to the nature of the projects during the initial stages, the programme for these activities must be much more flexible than would be thought desirable for a formed project. This calls for a close monitoring and reporting system, particularly during the period of collaboration between these two groups.

Programming of design and installation demands complete understanding of all activities, a determination of the critical path and a proper assessment of the duration of each activity. When these requirements have been met, project management has a reasonable chance of completing the project as programmed, provided that use is made of the best techniques to programme the activities and to control the project by careful monitoring of progress, and the application of corrective actions whenever significant deviations occur. The use of a Project Master Programme in network form for programming each project, and of a computer for monitoring project programmes and for automatic periodic reporting, by computer print-outs, on project progress and expenditure for control purposes are important requirements for large engineering projects.

THE PROJECT PROGRAMME

Whilst most radio engineering project programmes all have a basic similarity, the detailed timing of a particular project programme will be dependent upon such factors as the following:

(a) Type of station, such as, television, frequency modulation, radar, radio communication, earth satellite, medium or high frequency broadcast, mobile network, paging station.

(b) Power, frequency, number of transmitters or receivers and antenna system types.

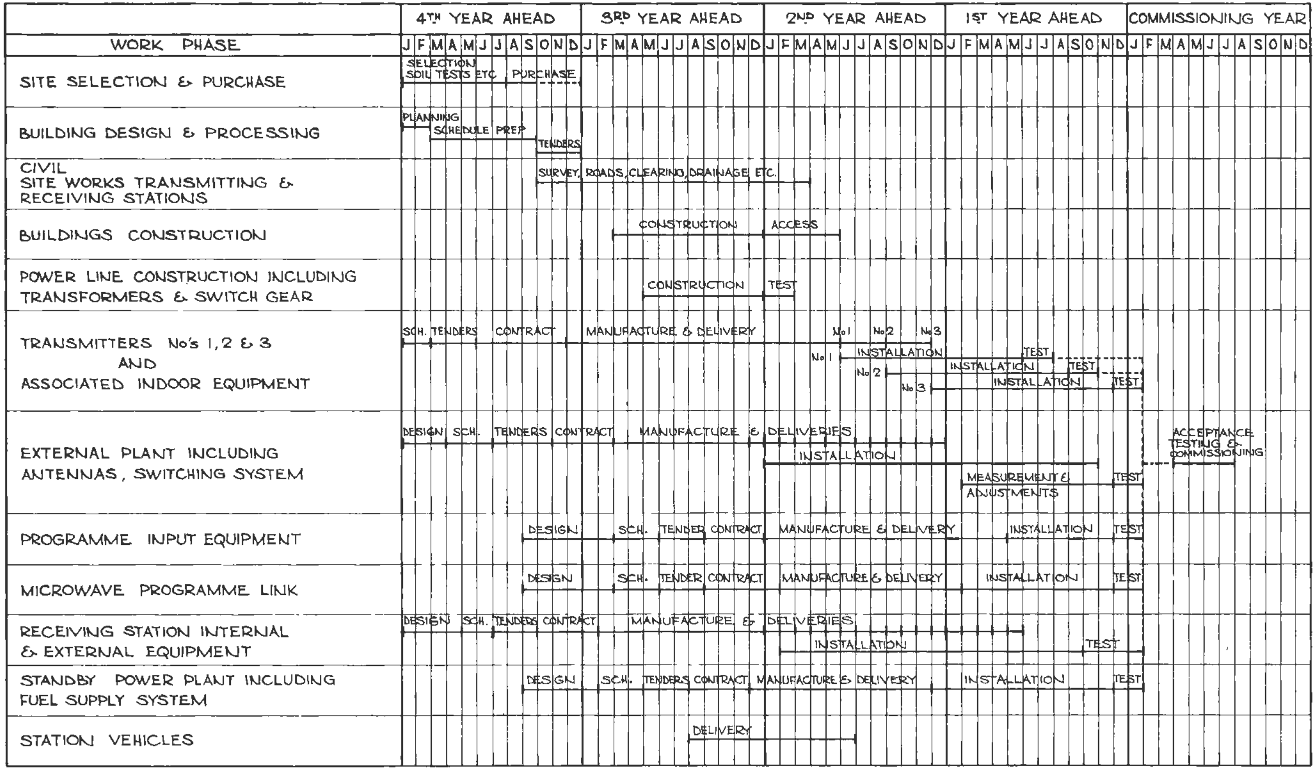

Figure 3.1 Project programme, high frequency relay station

(c) Peculiarities of the site, for example, areas subject to cyclonic disturbances, difficulty of access, foundation problems for masts and towers etc.
(d) Availability of local materials, labour, mechanical aids and specialist services such as surveyors, soils engineers.

For each project programme, there will be a critical path which will establish the shortest possible time for completion of the project. As an example, a study of a typical medium frequency broadcast station project would probably show that the critical path lies through the areas of site selection, equipment specification preparation, building design, building construction, equipment installation, transmitter tests and overall station acceptance and commissioning tests.

A one month period is a generally accepted typical allowance, after date of equipment and plant installation, for fully commissioning a broadcast station comprising twin 5 kW transmitters and a directional antenna system. Two weeks of this time are required for overall testing and completion of commissioning of the station as a whole. This allowance has been found from experience to be essential for all the adjustments and performance measurements necessary from time to time and for the successful settling down of all the station equipment and plant in operation. Wide variations in acceptance testing and commissioning periods are necessary for the larger high power broadcast station installations, a long haul broadband microwave radio relay system, a tropospheric scatter link and an earth satellite station.

Many modern radio installations are extremely complex, and projects costing £5 million and more are now common place. In these programmes a period which allows for contingencies should be built-in, since large and complex installations are invariably subject to factors over which the engineer has little, if any, control. Factors such as defective materials, interface design difficulties, unusual environmental weather conditions, labour difficulties, site access problems and others, are bound to affect the probability of completion being achieved by the due date in a programme which does not allow for such factors. Although some form of accelerated action can often be taken in specific parts of a project, such action can seldom be completely corrective in many cases.

Experience has shown that contingency allowances between ordering of the radio equipment including transmitters, antennas, switching system etc. and the testing operations, are invariably consumed without necessarily altering the completion date of the project. In a typical programme for a broadcast relay station comprising three transmitters, a receiving station, antennas and interconnecting microwave programme link system shown in *Figure 3.1*, a contingency allowance of up to two months in the Project Programme extending from the programmed test date to the beginning of the period allowed for acceptance testing and commissioning may be programmed to absorb the effects on the programme test date of uncontrollable factors, such as those previously mentioned. No contingency allowance for these factors is made in the earlier stages. A period of two months has been found to be a reasonable period for projects of this nature taking four to five years to complete.

THE CRITICAL PATH

The critical path is defined as the sequence of interconnected events and activities between the start of a project and its completion that will require the longest time to accomplish. This longest path is the shortest time in which the project can be completed. It may further be defined as the sequence of events in which the delay in one operation would force the delay in completion in the entire project or conversely, a saving of time in any single operation within this path would result in a saving of time for the overall completion of the project. However, if the critical path is shortened, the sub-critical paths may become equal to it and therefore critical. The involvement of a critical path in the work situation is one of the greatest benefits derived from network programming techniques and is the basis for a very important predictive feature, and represents its contribution to the principle of management by exception.

Figure 3.2 shows the critical path on a small network associated with the installation of a 50 W television translator station. The time taken to complete this particular project is comparatively short, but for the main transmitting station which would probably involve studios, buildings, towers, links, transmitters etc., the network would be much more complex and may involve work extending over one or more years.

On any project it is possible that the critical path will change if circumstances have a serious impact on the project. In fact the principal reason for using networks is to determine the critical path and whenever a critical activity is threatened with delay to determine where effort should be concentrated to rectify or at least to minimise the effects of the delay. There would be little purpose in networks if it could be guaranteed from the beginning that the critical path was inviolate and would be maintained in line with the programme up to the completion date.

There are many advantages to be gained in knowing the critical path of a network. For instance, if the principal or customer requires a completion or delivery date earlier than normal processing, installation, construction and commissioning practices would dictate, it is not unusual when network techniques are not used, for all phases of the work to be expedited. A network diagram will indicate, however, that only a few items are critical and which need to be expedited. It would be unnecessary for instance, to expedite or put men on overtime to test spare parts, remove spoil from the mast base etc. Even in a very large engineering project involving some thousands of network activities, the number of critical items would seldom exceed one hundred. Economies can be achieved by giving particular attention to those items which will reduce the overall project completion time. Similarly, if the work is held-up because of wet weather, high wind, delays in delivery of material, shortage of skilled tradesmen, it is not necessary that every one of the project activities be expedited. Some approaches, and examples which can be used to shorten the critical path without substantially increasing the direct costs are:

(a) Design changes.
Sections of a mast fabricated in the factory can be erected faster than individual members.

(b) Greater use of sub-assemblies.
An antenna coupling network completely mounted and assembled in the factory or workshop would require less manpower than if assembled on site in the coupling hut.

(c) Change in commencing time relationships.
The assembly of the bottom section of a mast may be carried out on the

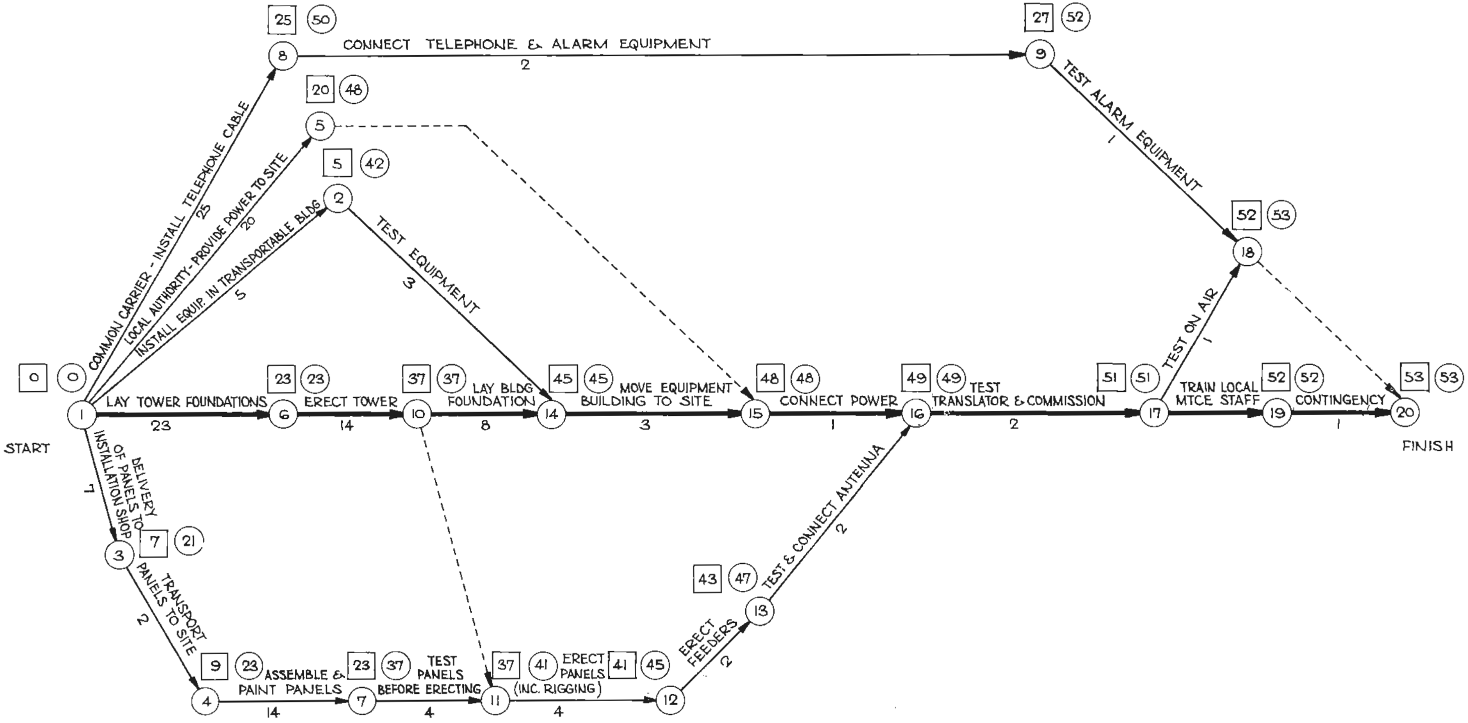

Figure 3.2 Critical path in network for installation of low power television translator station

ground, say the first 30 m, concurrently with foundation works so that mast erection can commence as soon as concrete has cured.

(d) Activities carried out concurrently rather than sequentially.
Installation of the earth mat and erection of a mast could be carried out concurrently when weather is suitable and resources are available.

(e) Change in the construction approach.
The use of ready mixed concrete, for mast foundations may be more economical than mixing on site, if ready mix services and transport are available.

(f) Use of larger work units.
Many large excavations are required for the foundations of a tall mast and the employment of more men on this work would allow several holes to be excavated concurrently. The work would be completed in a shorter time without appreciable reduction in efficiency.

(g) Employment of new erection or construction techniques.
Many masts of triangular cross section have been erected in fast time by employing three separate erection cranes, one operating on each leg of the structure with its own riggers and winch, and the whole work proceeding concurrently.

Although the critical path through a project is fairly constant, all contracts not on the critical path should be programmed in detail because many often have little slack and require careful supervision. Because availability might make timely placing of non-critical contracts important, this again may put pressure on non-critical contracts through an early use of their slack. The overall trend of the project could thus be watched, if properly programmed.

PROGRAMMING METHODS

A programme may be considered to be a list of work to be performed over a future period and its purposes may be summarised as follows:

(a) To enable forecasting of future requirements of resources such as manpower, material, mechanical aids, incidentals, services and funds.
(b) Optimisation of the resources and services to enable the best use to be made of them.
(c) To indicate likely future deviations from the plan and to facilitate reorganisation to correct the deviations.
(d) To provide a systematic allocation of work to the workforce so that it is passed down in a controlled manner.
(e) To act as a bench mark or indicator against which progress of the work can be gauged.
(f) To give an overall picture of the work which has to be carried out to fulfil the planned objective within the desired time-scale.

Until recently many engineers relied solely on bar charts for presenting project programmes and on manual updating for monitoring progress. The increasing complexities of modern radio engineering projects have demanded more advanced methods and sufficient experience of the use of network programmes and computer monitoring and analysis has now been gained to realise the benefits of their application for the better understanding of programme requirements and project management functions.

When the bar chart method is used it requires considerable experience in the work to be undertaken and a reasonable time of concentrated thought to decide what action should best be taken. Normally the person who can do this most effectively is the engineer in charge of the project. Should the work fall behind, it may be difficult for the engineer to find the necessary time for proper concentration on this task. When using a critical path method, he need only suggest the compression of one or more likely activities. The programme can be analysed and the results returned to the engineer who will either accept them or suggest other compressions. He will thus be free for the many other managerial and technical duties which will require his attention.

The nucleus of project control is the Master Network Programme. In a very large and complex project a family of associated programmes may be developed to serve particular purposes, for example milestone, key event, site installation, contractor and design-decision programmes. By a process of shredding, specific information can be compiled into programmes for various levels of management.

The master programme covers the essential requirements of the whole of the project from the period commencing with its allocation to the group to the completion of the project and includes all activities related to the development and execution of the project within the influence of the project group. The form of the master programme should be a network and supporting detailed programmes should be in network form, except perhaps certain equipment manufacturing phases where bar charts may sometimes be preferred. The detailed programmes should be consistent with the master network and capable of readily yielding updated information for it.

The master network should show all the work necessary to complete the project and should have the minimum number of activities consistent with adequate control. The supporting programmes should be detailed and be keyed in to the master network. Changes to the logic of detailed programmes should have no effect on the master network because of its simplified form and such changes should not disrupt the flow of information.

MASTER NETWORK FUNCTIONS

The Master Network has two main functions:

(a) As a logic network, it shows how all the various activities are inter-related and where there are restraints between activities. A full understanding of all the processes is therefore required to draw up such a network.
As different projects have great similarities in fundamental logic, it is possible when commencing a new one, to take the network used on a previous one, and with modifications for any peculiarities of the new project, adapt it to form a suitable outline for the new project. In this way the experiences of the previous projects can be used to the benefit of the new project to ensure that an increasingly higher standard of network content is available at the outset. This network should be produced by the installation group as soon as possible after taking control of the project and thereafter, developed as knowledge of the project grows, but within the frame of the work of the schedule or target dates.

(b) To form a programme with a time scale related to each activity and indicating the critical paths.
In the early stages of nearly all major projects, the detailed timing of many activities will be impossible as they often depend on how the design develops, site conditions, the type of contracts yet to be placed and other management decisions. It is therefore helpful first to schedule some milestone dates within the network concerning the important events spread throughout the project, and which are carefully chosen to indicate complete sections. The engineers doing the scheduling should select schedule dates to lie between the earliest date and the latest date for each milestone event. The margin available should be carefully allocated throughout the project programme so that the schedule dates in the early stages will be closer to the earliest dates and those towards the end of the programme will be closer to the latest dates. Typical milestone events for a television transmitter installation network are shown in *Table 3.1.*

Table 3.1 TYPICAL MILESTONE EVENTS FOR TELEVISION TRANSMITTING STATION INSTALLATION

No.	*Event*	*No.*	*Event*
1	Project commenced	26	Architect briefed on building
2	Site selected	27	Tower or mast contract placed
3	Equipment specified	28	Feeder contract placed
4	Antenna type and pattern specified	29	Operational staff positions advertised
5	Staff requirements determined	30	Antenna manufactured and delivered
6	Studio-transmitter bearer planned	31	Building design and documentation completed
7	Building planning completed	32	Tower erected
8	Installation drawings prepared	33	Installation staff briefed
9	Tower or mast specified	34	Antenna panels erected
10	Tenders called for antenna	35	Operation staff selected
11	Tenders called for transmitter equipment	36	Contract placed for building
12	Building proposal studied by installation group	37	Antenna cable erected
13	Building brief prepared	38	Transmitter equipment contract placed
14	Staff proposal prepared	39	Antenna power dividers installed
15	Tenders called for tower or mast	40	Installation materials assembled and miscellaneous equipment manufactured
16	Antenna feeder cable specified	41	Building constructed
17	Bearer equipment tenders called	42	Operation staff transferred to station
18	Equipment manufactured in workshops	43	Antenna cable tested and power dividers adjusted
19	Contract placed for antenna	44	Picture input and control equipment installed
20	Building proposal studied by Chief Officer	45	Transmitter and miscellaneous equipment installed
21	Tender called for antenna feeder	46	Transmitter tested and adjusted into dummy load
22	Approval operational staffing proposal	47	Antenna radiation pattern checked
23	Bearer cable equipment installed	48	Bearer aligned and tested and test transmission completed
24	Transmitter equipment tenders assessed	49	Acceptance testing and commissioning completed
25	Installation materials ordered	50	Field strength survey completed

Table 3.2 LIST OF TYPICAL MASTER NETWORK SECTIONS FOR BROADCAST STATION INSTALLATION

Section	*Work*	*Major items*
1	Station buildings contract	Transmitter, power house, administration buildings, and residence (where applicable), fire protection etc.
2	Civil engineering contract	Site clearing, roadworks, drainage, water supply etc.
3	Electrical engineering contract	Mains extension, sub-station, power house plant, building earth systems
4	Mechanical engineering contract	Gantries, air conditioning, ventilation
5	Transmitters contract	Transmitters, including installation materials, spare parts, dummy load
6	Auxiliary equipment contracts	Programme input equipment, test equipment, control desks, batteries, emergency programme etc.
7	Antenna systems contracts	Antennas, matching equipment, slewing switches, transmission lines, dissipative lines (where applicable)
8	Switching system contract	Switch equipment including remote control equipment
9	Support facilities contracts	Station vehicles, mechanical aids, workshop plant, tools etc.

For a major radio engineering project it will often be impracticable and unnecessary for the project Master Network Programme to appear on a single drawing sheet, although it will be processed by the computer and analysed as one programme. The programme is for convenience divided into sections suitable for use by the specialist engineers concerned with particular areas of the work. A list of typical sections for a large high power broadcast station is shown in *Table 3.2.*

NETWORK APPRECIATION

The necessity for advanced forms of programming is appreciated by all concerned with the management of projects. However, some senior engineers have often pointed out difficulties associated with the apparent complexity of some large networks because of the limited time available to study those networks.

Experience has shown that detailed understanding by senior engineers, of the network principle and the significance of interlocking within a given network, is a pre-requisite to the effectiveness of such programmes. There have been cases where substantial changes have taken place in the critical path during the course of the project and those involved had not fully appreciated at the outset of the project that such changes could occur. It therefore appears highly desirable that a senior engineer should at the very beginning of a major project be responsible for carefully working out the parameters which form the basis of the Master Network Programme. All project engineers should be provided with simplified print-outs and be given clear guidance on the significance and operation of networks and print-outs. However, with the ever increasing tendency for improved processing methods with resultant greater information output, it is

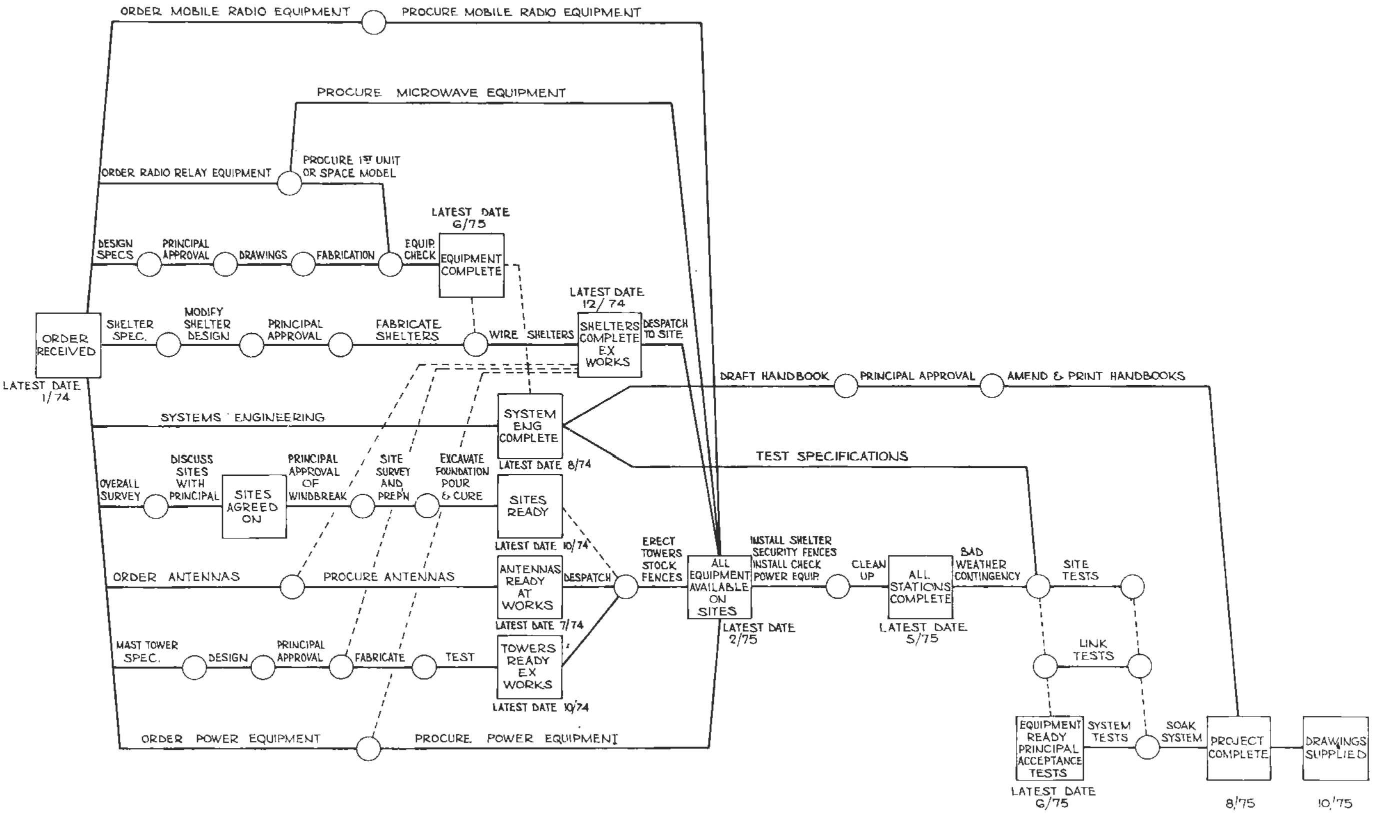

Figure 3.3 Draft programme for radio relay industrial control system

important that engineers remember that their primary function is an engineering one. On radio engineering projects, programmes are indispensible to the engineers involved to resolve conflicts, improve understanding and avoid duplication, but advanced programming techniques and methods of processing information should not be allowed to distract engineers from their primary function. The extent to which top managers become involved in engineering depends largely on the extent to which programming applications are successful. Their intervention in project management becomes necessary, generally speaking, only when major problems arise, usually because proper decisions had not been taken at the appropriate time in the programme. Programmes and information should be treated as aids to progress engineering work and not too supplant the authority of the engineer. Any notion that the computer is a substitute for decision making is fallacious.

Network programmes should be formulated by staff experienced in radio engineering and the requirements of the project for which the programme is produced. This will ensure incorporation into programmes of past experience of network preparation and operation. The accumulation and use of experience are keystones in the improvement and development of the master network. In order to ensure that the requirements of the project are covered it is general practice in many organisations for an engineer to first produce a draft programme and then discuss it with the senior engineers of the project management. Where the draft does not conform with the requirements of the project, the programme can be modified accordingly. *Figure 3.3* illustrates a draft programme for a radio relay system installation of an industrial control system comprising telemetry and mobile radio units.

Network programmes and procedures should not be regarded as a solution in themselves to construction problems. They constitute advanced techniques for the aid of management and are ineffectual without proper management control and adequate resources. Contractors have to recognise their own capabilities for fulfilling contracts and should not accept contractural commitments which they are aware they cannot fulfil or are unaware whether they could fulfil. An admission by a contractor at the outset that dates as set down in schedules are impossible to meet because of inadequate resources would establish an initial understanding and place a project on a far more satisfactory footing than the later discovery of such difficulties.

MONITORING THE PROGRAMME

Having prepared satisfactory types of programmes to allow full understanding of the requirements of the project, a service has to be instituted to provide management with progress information quickly, so that deviations can be monitored early enough for corrective action to be taken before delays build up and affect the completion of the project. It is important to monitor all the activities in the project Master Programme and all the individual contract activities interfaced into it, preferably by use of a computer which will also analyse the effect of any deviation from the programmed time of activity. It should be remembered however that the computer used to monitor and analyse the programmes acts only as a labour saving device and does not perform any superhuman function. The engineer's skill, knowledge and experience still play an important role.

The normal control principles which apply to all installation and maintenance projects are included in critical path programmes but it must be accepted that no matter how great the knowledge or how detailed the information, there will always be many activities which contain assumptions. Other activities may be affected by factors not subject to control. For example, certain assumptions must be made regarding repair of a large modulation transformer which may have failed in service. Such assumptions with many others, may differ considerably from the actual conditions encountered when the core is removed from the tank to perform the repair task. One obvious factor beyond control is the state of the weather particularly if the transformer is part of an exposed power vault installation.

Variations between planned performance and the actual performance must be properly documented. The programme requires revision at appropriate intervals after which it is re-issued to all concerned. The control function cannot be too haphazard because too frequent checks and revisions may serve no useful purpose, and are therefore an unnecessary waste of money and manpower. On the other hand, if some vital state is reached and passed without assessment, the opportunity for corrective action may be lost.

As each control point is reached the programme is reviewed. This is done by reducing the duration of all completed activities to zero. Partly completed activities are reassessed and given new durations which are the estimated times for completion from the time of the review. Activities which have not commenced remain unchanged. The information is then processed by the computer and an allowance is made for the time which has elapsed from the commencement of the programme. A new programme is obtained, and the critical path is again indicated. Any variation in the total duration of the critical path is immediately evident. If this duration has increased beyond the original time, action will be required to correct the position. The critical activities are therefore examined and proposals for compressing suitable activities are prepared.

The compression of time may be obtained by extending working hours, subletting some contracts, employing additional staff, greater use of mechanical aids and any other suitable means. The programme with the revised durations of the selected activities is again referred to the computer and a new critical path is obtained. This may have returned to the original estimate and can then be accepted as satisfactory. Should it still be unsatisfactory the process must be repeated until a satisfactory answer is obtained. From this final answer the computer will print the necessary information for the engineers and supervisors controlling the various phases of the project work. The controllers will then know the new starting dates and duration of their tasks to meet the revised programme necessary for completion of the total task by the original planned date.

General practice on many large projects is to up-date the computer stored information each month, although bi-weekly intervals may be necessary in some cases. The return from contractors and others may be in the form of computerised questionnaires and the completion is a relatively simple task. The print-out gives a retrospective analysis of the work progress situation. Appropriate measurements of slack can be reported together with the earliest and latest completion dates and where appropriate, the scheduled date. Because of the detail contained in these print-outs, it would normally be expected that they would be directed to the working level associated with the particular area of work and in order to provide the most suitable type of information to management levels, some form of shredding or selection has to be carried out.

Figure 3.4 shows the elements of a typical programme review system. The project engineer assists the EDP group who in most cases control the computer facilities, in networks and obtaining time estimates. The network with its associated information is entirely the responsibility of the engineering group. Information to up-date the networks is given on a monthly basis, or whatever time basis is desired, and the information is put in the proper format for sending to the EDP group. After processing by the computer, a series of print-outs is then made available to project management and to those key managers and supervisors who are responsible for some particular phase of the project work or monitoring. Project management analyses the computer outputs and reports to senior management. Copies also go to those contractors who may be required to submit analyses of their programmes as part of the contract management arrangement.

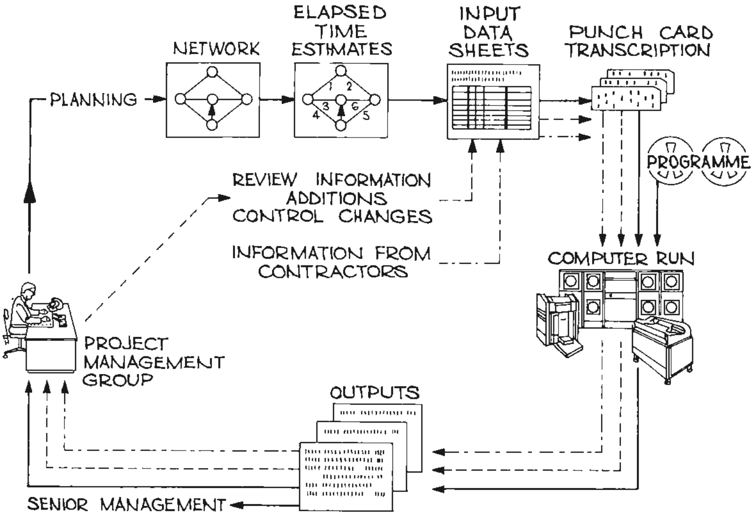

Figure 3.4 Typical programme review system in operation

PROGRESS REVIEW

Some organisations hold conferences for the periodic review of projects and the project engineer may personally present the status of the project to the group. These discussions generally require the compilation of charts, graphs etc. which constitute excerpts from the formal status report documents. Reports may include Management Summary Report, Manpower Loading Diagram, Cost Prediction Report, Schedule Prediction Report and others. *Figure 3.5* shows the management organisations involved in a project for the provisioning of a radio relay system and mobile patrol units for an industrial control system, and highlights the need for proper monitoring of the work of the many sub-contractors.

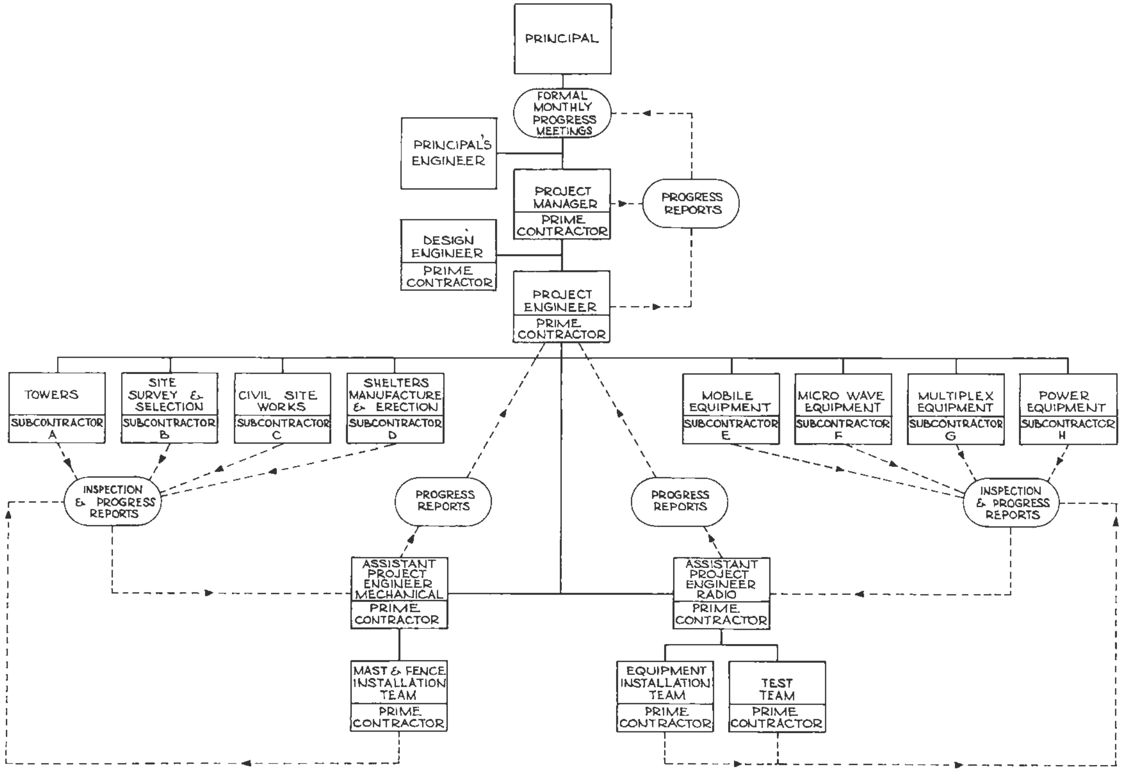

Figure 3.5 Management organisation for industrial control radio relay system

Experience by project engineers has shown that there are two main problems which tend to develop in some projects:

(a) Information takes too long to reach the various levels associated with decision making. Each level analyses the data before sending it on to higher level, and in the process defensive interpretations of the data sometimes results.
(b) Information is adjusted to agree with the budgets of the organisational function and is not necessarily in accord with the character of the work.

It may be necessary therefore in some cases to arrange for information flow to cut across the function lines of activities and to focus upon programme objectives. The ideal is a system of information which has its roots in the projects and which can be drawn off at the various levels of the organisation without destroying the command structure necessary for effective management.

PERT AND CPM

The two most popular network planning systems used for many years for radio engineering projects are PERT (Programme Evaluation and Review Technique) and CPM (Critical Path Method). The use of either system enforces rigorous planning of the work and enables the forecasting of realistic target dates for completion or commissioning of new stations or systems. They permit an objective analysis of alternative plans in relation to the scheduled target dates and facilitate the consideration of any limitations in the availability of resources.

The results of the analyses in the PERT system are expressed in terms of events or milestones of progress while the results of CPM calculations are shown in terms of activities or operations to be performed. PERT can therefore be considered to be event orientated, while CPM is activity oriented. Another difference is that in the case of CPM, planning is separated from scheduling, and time and costs are directly related. However, there is a further important difference between the two systems and that is the procedure for estimating the elapsed time. It can best be described as deterministic and probabilistic.

In the PERT system, probabilistic time is used, each activity being expressed with multiple time estimates, these indicating time uncertainty. The reason for using the probabilistic approach is that a more realistic evaluation can be made as three estimates of time are made for each activity. These times, called the optimistic time, the pessimistic time and most likely time are converted to a single time estimate and a statistical variance, and these are used to calculate the probability of achieving the project scheduled dates. The practice is designed to introduce a more objective attitude concerning the inherent difficulties and variabilities in the activity being estimated. The estimator has to identify all those factors which have to go right for the optimistic estimate and assume that they will go wrong. This gives the extremes and the situation is then firmly bracketed. Within the extreme range the time, all things considered, that the task is most likely to take to complete is selected, and at that point there is available a good time estimate, together with a measure of the uncertainty involved. This time is the probabilistic time used in the PERT system. In the normal PERT system, costs are not taken into account.

In the CPM system, management is provided with an integrated summary picture of total progress of the work and the progress outlook. It is based on the premise that project duration can be shortened by incurring additional expenditures, thus management can justify methods improvement by relating time schedules to cost. The estimated time of carrying out an activity is the same as the most likely time in the PERT system and so may be considered to be a deterministic method of arriving at the completion time. It requires that both the time and cost be estimated with a high degree of accuracy. The system produces least cost work schedules for each of several project durations by introducing normal and crash situations and goes on to calculate the project duration which gives the least project cost. This system, the deterministic method, allows costs to be considered as a controlling variable and may be applied directly without introducing optimistic and pessimistic times.

Table 3.3 COMPARISON OF PERT AND CPM NOTATIONS

PERT	*CPM*
Network	Arrow diagram
Event	Node
Activity	Job
Scheduled time	Duration
Expected time	Earliest start
Latest allowable time	Latest start
Primary slack	Total float
Secondary slack	Free float

The two systems were independent developments and because of this the notations are different. A comparison of the notation is shown in *Table 3.3.*

LINE-OF-BALANCE

The Line-of-Balance technique (LOB) is a systematic method of collecting, summarising and presenting planning and progress information to management. It highlights the elements where the rate of progress is inadequate to meet the schedule by checking each operation against a target. Operations that fall short of the target are identified for further analysis.

Based on the management by exception principle, Line-of-Balance graphically portrays information involving three steps:

(a) Delivery schedule.
This chart presents the cumulative delivery schedule for the entire project. It shows the estimated delivery schedule for the complete period together with the actual delivery schedule as at the end of the reporting period.

(b) The programme progress chart.
This chart has two sections, what should have been done for each operation and the actual progress on each operation. It is a bar chart which shows the cumulative quantities processed at control points at a given time. This information can be calculated manually, or obtained from computer print-out.

(c) Analysis.

Analysis of the programme progress chart is the main feature of Line-of-Balance. It pinpoints out-of-balance operations and allows investigations to be made in terms of area of responsibility and source. In cases where the overall chart is very large it is often convenient to prepare supplementary charts to cover particular areas or phases of the work.

The Line-of-Balance technique can be applied to almost any type of radio project but has found greatest application in monitoring production programmes involving factory or repetitive manufacturing type work. It is a dynamic technique when properly applied, as it highlights deviations while the project is being worked.

A few years ago a technique which is a combination of PERT and Line-of-Balance was developed to handle the awkward transition stage of a project from the planning and development to the production phase. PERT is ideal for planning and development type work, while LOB is ideal for the production phase, and a combined technique known as PERT/LOB is often used to handle a complete turnkey project which involves all work from preliminary planning and development stages through to final production and fielding of a given quantity of items. The PERT/LOB technique provides this life-cycle management capability. In work areas which involve non-repetitive type work, PERT/LOB may be considered to be equivalent to standard PERT and where the work is of a repetitive character it may be considered to be equivalent to standard LOB. In the transition area where the repetitive and non-repetitive works intermingle, the integrated PERT/LOB technique allows effective control of the work. In effect it integrates the planning elements of PERT with the control elements of LOB. Several earth station antenna systems were developed and manufactured using this technique.

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Chapter 4

Design Programmes

The design phase of a project is probably one of the most difficult phases to programme and is extremely difficult to control. Design is a creative process and therefore it is mainly a personal matter. No flow diagram could be expected to give the procedures on the thought processes followed by a particular individual. Design is a bringing together of information for decision making. The main steps of analysis, conception, engineering calculations and economic considerations are relevant to practically all designs. *Figure 4.1* shows a typical flow chart used in the design of a tower to support antennas associated with a microwave radio relay system, and illustrates this point.

Many practices used in design programmes in the past have proved inadequate for controlling the design stages of many large and complex radio engineering projects. The design programmes were not prepared sufficiently early and many were of poor quality. Also, there had been a lack of proper machinery to ensure implementation. The development of many of these programmes has lagged considerably behind the development of programmes for manufacture and installation. Many of the design/decision programmes have been prepared with a lack of real appreciation of the inter-relationship of events, and there has often also been a poor appreciation by many managers of the delays resulting from late decision making.

REQUIREMENTS OF A DESIGN/DECISION PROGRAMME

The requirements of a design/decision programme may be summarised as follows:

(a) It should clearly set down the design objectives at particular stages of a project.
(b) It should specify the detailed activities which should be achieved by each group, section, department or contractor.
(c) It should show what aspects of design are to be considered at each stage.
(d) It should indicate the acceptable tolerance on information at each stage.
(e) It should be in such a form that it can be monitored and analysed to produce a good management information service.
(f) It should show who makes a decision or initiates information.

Machinery should be set up to ensure that when decisions are made they are not modified or altered without consideration by the appropriate level of mangement. Delays are often engendered on a project by changes of mind or changes of design which theoretically may result in minor increases in efficiency. The effects of these changes on schedule dates are not always fully appreciated. Minor changes by junior engineers and others may have far reaching effects on

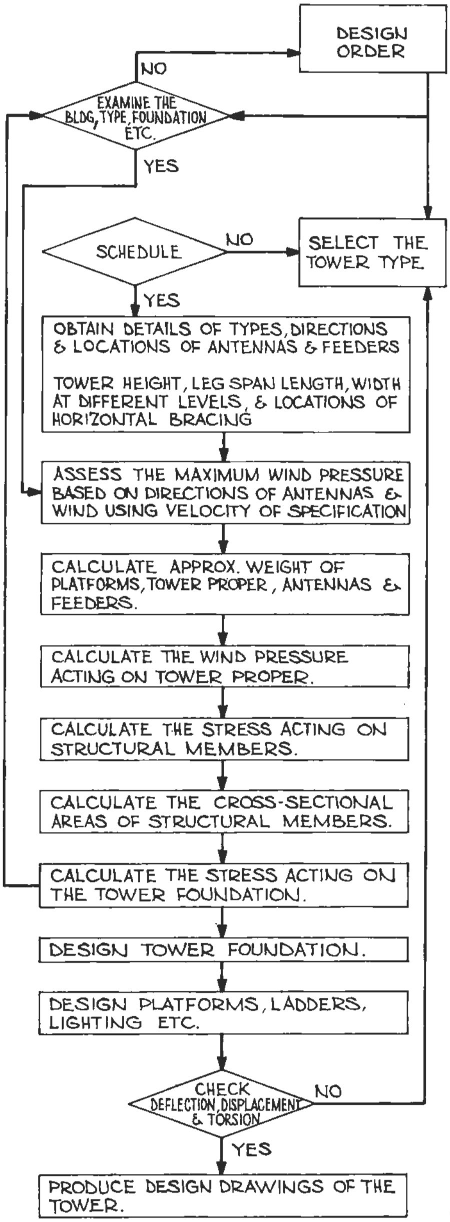

Figure 4.1 Typical flow chart for tower design

the programme in some situations. Design programmes indicating clearly to review management, and throughout the organisation, the times allowed for specific stages of work, must be available. Awareness by management of the consequences of not meeting such programme dates considerably facilitates the task of the project engineer.

DECISION MAKING

All design activity requires a plan. The plan is called the design process and is a series of steps or stages through which the design will pass before it is completed. The design process or activity can be programmed, monitored and controlled by management because it involves actual work. The act of decision making on the other hand is carried out by management and although it can be programmed and monitored it is extremely difficult to control. The control exercised on intermediate management is by higher management but the control on the higher levels of management is to a large extent, personal discipline. All that can be done is to ensure that each level of management has the data it requires or alternatively the data which is available at the time and that management is aware of the possible sequences if it is lax in making a decision. *Figure 4.2* shows in block diagram form, the process of decision making by management and *Figure 4.3* shows a practical situation involved in the design of a large inductor associated with an antenna matching network. All the steps in this inductor design process can be readily programmed, monitored and controlled but on the other hand, the process of decision making is difficult to control.

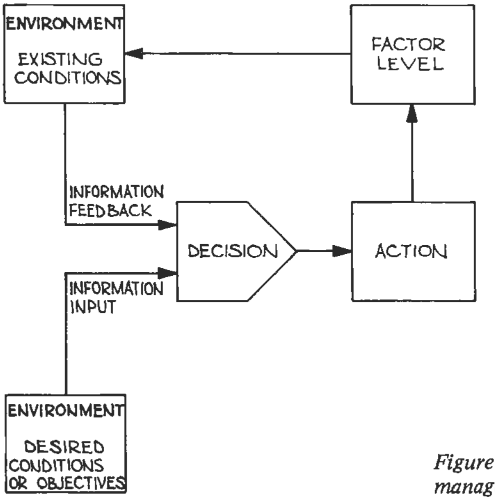

Figure 4.2 The process of decision making by management

Some decisions which arise during the course of a design are more important than others. Some are of a minor nature and the influence on the design relatively small. Others, however, may be critical, in that they have a major impact on the design. For example, a change in attachment arrangements of a parabola may have relatively negligible effect on the wind loading of a tower but a change in location of the parabola from a low level position to a higher level may have a major impact on the design of the structure.

Morris Asimov, in his book '*Introduction to Design,*[1]' classifies the theory of making critical decisions in engineering design as follows:

(a) "A critical decision is formal, and is assumed to be final. When one of the proffered set of possible solutions of the design problem under consideration

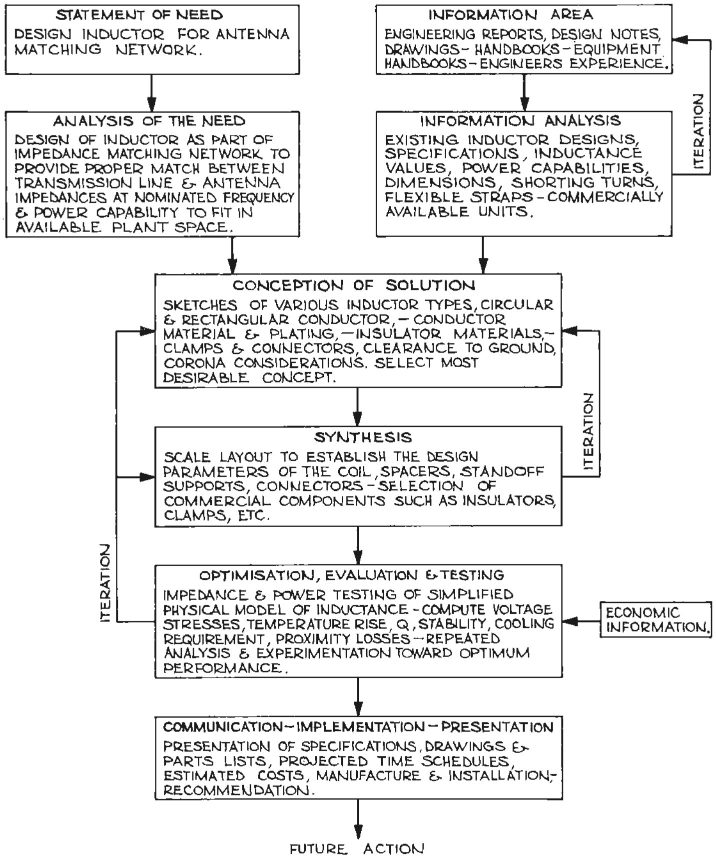

Figure 4.3 Typical steps in design process for inductor associated with high power m.f. matching network

is formally chosen, important commitments are made by the management of the project. Design effort is released to proceed from the preliminary explorations of the particular concept to a final state of physical realization. Such paralleling sub-projects in other parts of the design as need to be co-ordinated proceed on the assurance that the particular concept shall be realized. Only under the most compelling circumstances is the selected concept retracted and a substitute introduced, for the penalty of such a virtual failure is usually very high in terms of its effects on both the direct and indirect design work committed by the decision for that concept."

(b) "A critical decision rests principally on a comparison of advantages and difficulties associated with each of the proffered solutions. The advantages may be evaluated in principle on some utility scale. The difficulties generally emerge as sub-problems that must be resolved if that particular concept of solution is to be capable of physical realization."

(c) "Design work is constrained by a budget of time and money. Actual budgets are usually set for the major phases of the design project. In some projects where tight control is maintained, time and money budgets are set for each of the major problems as it is recognized. In others only time-targets are set for such problems so that the project as a whole can be co-ordinated. Even where budgets are not set, it is assumed that the design work will be done within the limits of a reasonable budget."

(d) "A critical decision depends on the levels of confidence held for each of the contending solutions. We assume that any physically possible concept could, with probability *one*, be developed into a physically realizable design if an indefinitely large budget of time and money is allowed. However, the budget is always limited either by edict or by a sense of the reasonable. The level of confidence, as used here, is a subjective probability that the design work required to bring the particular concept to a state of physical realizability will fall within the limits of a decreed or assumed budget."

(e) "The level of confidence is affected by evidence. Initially, we develop a level of confidence in each of the alternatives by an internal reaction, tempered by experience and the similar reactions of others. We try to anticipate the range of sub-problems that will appear when the concept is pressed toward a realizable design, and we consider the inherent difficulties in their solution. All of these preliminary activities combine to form an initial level of confidence. Some of the alternatives may be dropped after this cursory study. The principal contenders may require further evidence, which is obtained by analysis, by experiment, by consultation, by searching relevant literature, or by exploring personal and group experience. This evidence, reflecting on a particular concept, augments the initial level of confidence."

(f) "Critical decisions emphasize levels of confidence early in the design project, shifting to costs of design work as the project progresses. In the early stages of a design, the concepts are more abstract and therefore further from physical realization. Close cost estimates of design work are difficult to make. When advantages are more or less equal, critical decisions hinge on relative levels of confidence for the competing concepts. The chosen one will reflect emphasis on the level of confidence on which it can be realized. In the late stages where physical realization is easier to assess, only concepts with a high level of confidence are acceptable; and when advantages are similar, critical decisions rest on the relative design costs (that is on the confidence limits of the budget). If advantages are equivalent, that concept which requires the least design effort will be favoured."

(g) "Critical decisions take account of the severity of the penalty resulting from the failure of a chosen concept to attain to a state of physical realizability. If the penalty in re-doing committed design work, or in failing to meet a time target, is very severe, the selection rule will require a high level of confidence. If the penalty is mild, the level of confidence can be relaxed correspondingly."

(h) "A critical design decision should be made by a person at that level of administration at which he could be properly required to bear the responsibility if the chosen concept failed."

PROBLEMS OF DECISION/DESIGN

The main problems encountered in the area of decision/design may be summarised as follows:

(a) The lack of definition of individual responsibilities.
It is important to ensure that all controlling engineers and managers concerned with decision/design know when the design work has to be completed to meet the programme and at what stage decisions are required to be made. Inadequacies in these respects sometimes lead to relatively junior staff initiating modifications to design which could have a serious effect on the programme.

(b) The time delay in the transfer of data from one person to another.
Laxity or delay in transfer of information can often be attributed to the originator not co-operating because his internal organisation may not be geared to handle the specific request, partly to the recipient demanding too precise information at too early a date, and partly to the principal not being specific in his requirements.

(c) The delays which occur in the making of decisions.
Substantial delays are often encountered as a result of lateness in reaching major decisions. There are usually very good reasons why these decisions are delayed but methods should be introduced to ensure that the possible results of these delays are more readily anticipated. The design/decision programme should be such that major decision points are clearly visible to management and some form of machinery should be instituted to ensure that decisions are made in time or that management are aware of the resulting delays.

(d) The changes in design which frequently occur at a late stage of the work. Many project controllers have insisted on freezing of designs by certain dates. Design changes, the desirability of which is a matter of opinion only,

Table 4.1 SOME TYPICAL ALTERNATIVES IN MICROWAVE RADIO RELAY SYSTEM DESIGN

Sub-system	*Alternatives*
Radio equipment	
Power	0–Infinity (Watts)
Frequency	0–Infinity (Hz)
No. of channels	1, 2, 3, 4, 5, 6. . .
Modulation	AM, FM, AM-SSB, FM-SSB, digital etc.
Type tubes	Diskseal, triode, klystron, magnetron, travelling wave etc.
Multiplexing	Frequency division, PAM, PDM, PPM, PCM etc.
Receiver	Transistor-mixer, diode-tunnel, diode-paramp, cooled paramp etc.
Antenna	
Type	Parabola, horn, slot array, lens, lens in horn, cassegrain etc.
Size	0–Infinity (metres)
Material	Aluminium, steel, copper, expanded metal, plastic etc.
Feeder	Coaxial cable-circular, rectangular, elliptical waveguide etc.
Reflectors	Rectangular flat, curved or chopped-elliptical flat or curved
Power plant	
Capacity	0–Infinity (Watts)
Primary system	Diesel-generator, petrol-generator, wind-generator, mains supply, thermoelectric, solar cell etc.
Secondary system	Battery, fuel cell, none
Protection system	
Diversity	Polarisation, space, frequency
Combining	Variable gain, equal gain, optimal switching etc.
Signalling	Dial pulsing, revertive pulsing, panel call indicator, multi-frequency pulsing etc.

should not be allowed to interfere with programmed freeze dates, but if the desirability is supported by substantial established facts, the merits of changes in relation to interference with established programmes should be properly evaluated. New ideas are imperative for advancement of state-of-the-art and if total freezing is adopted as a matter of policy it could lead to total stagnation.

(e) The variety of alternatives facing the engineer in the preparation stages. Different approaches to the same design problem both within project groups and departments of the organisation, creates difficulties for manufacturers and contractors. Whilst the principle of progressive development is accepted it is considered by many engineers that greater standardisation of radio component and unit design would be highly beneficial. Standardisation of design can allow many tasks to be expedited without retarding design/development.

Alternative approaches must be identified and evaluated and the optimum chosen. This usually involves theoretical and simulator studies together with cost and time analysis. *Table 4.1* indicates some typical alternatives which may be available in a microwave radio relay system design study.

(f) The presentation of the programme in a form suitable for analysis of the progress on a project.

CO-ORDINATION WITH OTHER GROUPS

Within a large organisation there are often many decisions made on a project by groups, sections, branches and departments outside the orbit of the project group control. Many of today's radio engineering activities require such a wide range of detailed knowledge of various facets of engineering that no single group can encompass it. Therefore, many tasks are carried out by teams, each of whose members have a basic understanding and expertise in at least one specialty area. In some projects, teams composed almost entirely of engineers and support technical staff may be sufficient to carry out the project work. However, in an increasing number of the larger complex projects, experts in the arts, economics and social fields may have to be involved. This is seen particularly in product design, aesthetic considerations of masts and towers, and many other areas.

It is essential that the draft design/decision programme should show the proposed commitments of these other bodies. It follows that this programme should be submitted to these bodies for discussion and their agreement. The bodies concerned would then detail their own programme of work and allocate their resources. Subsequently it may be necessary to establish impersonal objective machinery for the reporting of delays when these bodies fail to meet their accepted commitments.

In many cases of design work, it is difficult to prepare a programme which has fixed periods because of the very nature of design activities. The design process is not a one-way single pass effort. It may often be necessary for the designer to retrace his steps. Feedback and iterations may occur at any stage. If, at the analysis stage, undesirable responses are discovered and resynthesising cannot correct these, then perhaps a new concept may be in order and if no suitable concept can be formed, the problem may have to be redefined. Where alternatives include novel features, the engineers concerned must ensure that sufficient time is allowed to develop these features. Design, manufacture and construction times

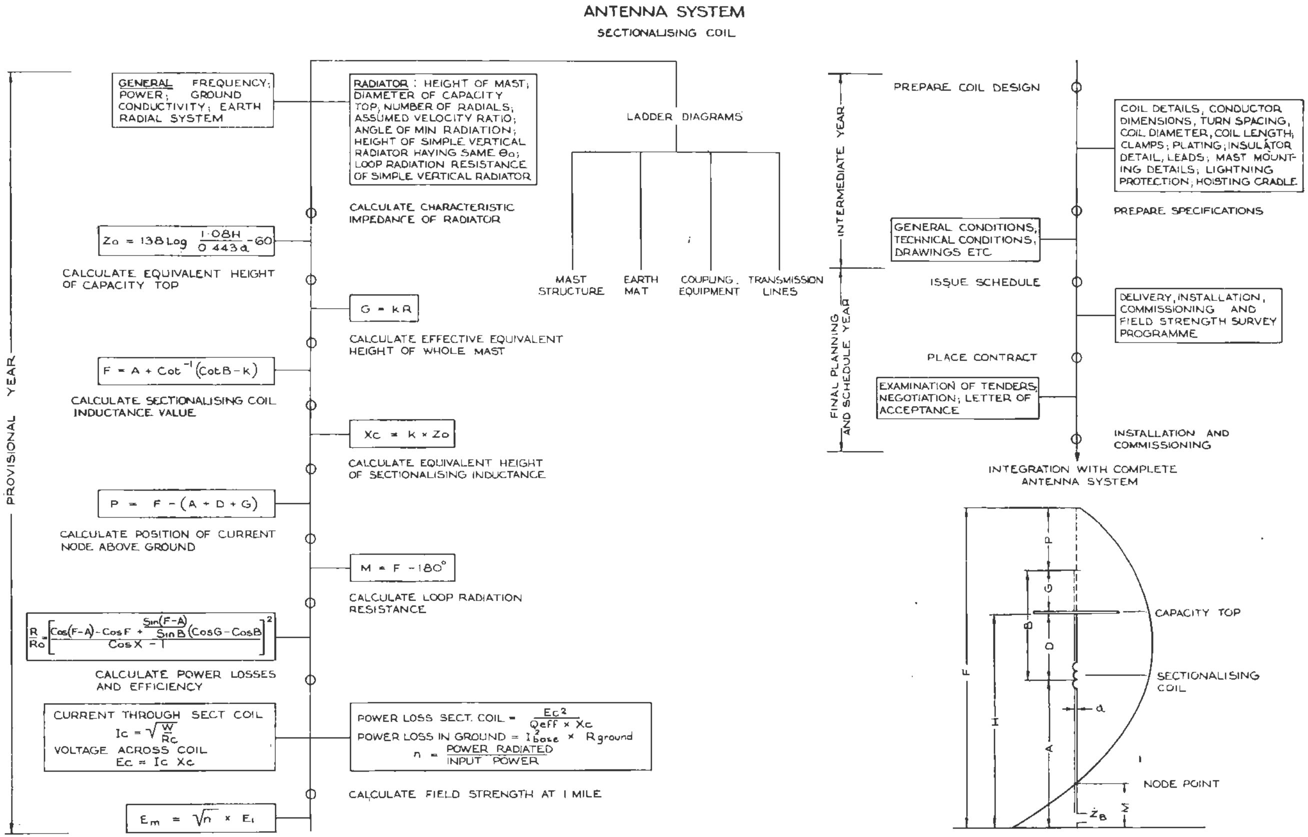

Figure 4.4 Typical design ladder chart for antenna system

for novel designs will normally take longer than the time required for an extrapolation of an existing design.

Nevertheless, if the project group is to maintain control of the project as a whole, then it is fundamental that it monitors all items which appear on the design programme, regardless of who is responsible for the action or the nature of the design/development work.

PREPARATION OF DESIGN/DECISION PROGRAMME

Many attempts have been made to produce a standard programme to cover all contingencies of a design programme but although it is feasible to produce such a programme, provided that the necessary resources are available, it would be so complicated that it may be impracticable. In principle, a design programme should be a progressive programme which is developed up to the stage where contracts are placed in any particular area and after that, the design flow should be controlled from the design programme.

Although there is some advantage in having the design programme in network form it is apparent, even after a preliminary investigation, that a logic network in full detail showing all the passages of information is not a practical proposition. It has to be recognised that a design programme cannot be produced in one operation, it is a progressive exercise and therefore the master programme should contain sufficient information to stipulate when major decisions are to be taken. As the decisions are made the early part of the master programme can be infilled with design flow data. Making a decision releases a further area of work which, up to the time of the decision, could only be covered by the outline of the time required for the longest alternatives. If this infilling was carried out to its logical conclusion the result would be a highly complex impractical programme. The infilling should therefore be carried out to the point in any work area where the contract is placed, after which, the design programme for that area can be developed as part of the contract programme. In this manner the design programme can be developed in specialised areas and executed by the engineer responsible for that area.

It is fairly obvious that the space would not exist on the master programme, due to the physical limitation of the paper, to accept the detailed infilling described above. Also it would be difficult for any one group or body to extract its commitments from such a diagram. A method of presentation which has been found useful in large radio works is a series of ladder diagrams with a ladder for each group, work area or contract. On each ladder is clearly identified the milestone, key date and decision events extracted from the master network along with the detailed passage of information. The complete diagram may take several sheets but each group would receive its commitments on one sheet. *Figure 4.4* shows a typical ladder diagram for antenna system contracts involved in a high power medium frequency broadcast station project.

DESIGN FREEZE

In theory, after an item has been designed properly and released for manufacture or other action, no engineering changes should be required. In practice, however, changes or modifications do often become necessary. These may be due to a desire for performance improvement, a more economical product, a safer method of carrying out a work, changes in requirement by the principal or customer, a shortage in supply of a component, a design error or deficiency brought to light by manufacture, testing or field service.

The proper evaluation of the need for an engineering design change must be considered with the utmost care and skill. Changes should be kept to an absolute minimum, as frequently many other groups may be affected by such changes, causing disruption to schedules and increased costs. The engineering change advice system used by many organisations is in itself an expensive administrative burden.

Delays are often caused by changes in design which theoretically may result in minor changes in efficiency or a small reduction in overall cost. The effects of changes on the completion of a project may not always be fully appreciated. They may have a far reaching effect on an installation or a manufacturer's works programme. Design changes, the desirability of which are a matter of opinion only, should be carefully examined and evaluated before approval is given to make the change. Sometimes re-design of some part of the work may be necessary because of design errors in the first place. Many of these are often the direct result of undue haste, inexperience or crash programme action introduced when the project is running late or an earlier finalisation date is required. Under normal circumstances, drawings and design calculations would be carefully checked and, in some important cases, prototype or models may be constructed. However, occasionally these desirable precautions cannot be put into practice.

Where design changes are initiated by the principal, there is some compensation for the contractor as he would normally recover the cost even though they may disrupt the smooth flow of logically planned work. Where, however, the contractor finds it necessary to introduce designs because of shortcomings in his own original work or assumptions, these represent a direct charge against the project and have to be carefully controlled.

It is not always appreciated that the total cost of a design change can greatly exceed the straightforward estimate attributable to the change itself. Factors such as interest charges, space utilisation and extra overhead and administration charges are often overlooked.

The recording of actual costs associated with a design change is not always a simple exercise. If a piece of equipment or plant has been completed and commissioned and a design change is introduced, there is little difficulty in determining the actual cost of the change. If, however, the change is introduced, say midway through a complex work, a different situation is encountered. Large cable forms may have to be opened to incorporate additional wires and remove others, terminations may be changed, components may be added or removed and many other such variations may occur in the work. As the inspection, testing and commissioning would not have been completed, they would be affected in both scope and complexity and it may be extremely difficult to determine accurately that part of the work which is directly attributable to any particular change.

CHANGE PROCEDURE

The problems and side effects of design changes in large and complex projects may be far reaching and it is prudent to ensure that proposed changes receive proper attention in order that the full effects can be predicted as reliably as possible. A formal design change procedure which examines the following aspects is considered to be essential:

(a) The estimated cost of carrying out the design change after allowing for credit of uncompleted work involved in the change.
(b) The cost break-up between principal and contractor of the cost associated with the change.
(c) The effect of the change on the schedule.
(d) The need for, and advantages of, the change.
(e) The effect of the change on the performance, safety and reliability of the facility, equipment or system.
(f) The cost and effort required in documentation such as manuals, charts, drawings etc.
(g) The flexibility of the proposal.

Design changes can be classified as being either essential or desirable. If they are essential, there is very little choice in the matter, and the decision whether to proceed would be determined by the flexibility of the proposal put forward. If the change is considered to be desirable, then this is a different matter and requires close examination. Many proposed changes, particularly those associated with improved efficiency or performance, have often turned out to be of less benefit than the original claims offered. Also, little can be said in favour of a change which may save a few pounds in parts cost, but which adds considerably to the ultimate cost and schedule timing because of delays in obtaining or fitting the parts.

DEGREE OF UNCERTAINTY

The degree of uncertainty in a project end date can be assessed from the standard deviation on the end event, and if a scheduled date has been applied, the probability of achieving it can be deduced. Due to the multiple time estimates, optimistic, most likely and pessimistic, the actual project completion date may occur before or after the scheduled date. In analysing the three times estimate, it is clear that the optimistic and pessimistic time should occur least often and that the most likely time should occur most often. Thus it is assumed that the most likely time represents the peak value of a probability distribution.

However, an examination of activity elapsed times will generally indicate different spreads between the optimistic and pessimistic times. If the estimator is 100% sure of completing the activity in a particular time, there would be no spread. In fact, the extent of the spread is a reflection of the degree of certainty of completing an activity within a specific time. The graphical representation of the chances of completing an activity in any of the elapsed times can be represented by a normal probability distribution curve. In the case where the spread is large, due to a high degree of uncertainty, the curve would flatten out but where a high degree of certainty exists the curve would be narrow.

On the basis of the central limit theorem, it can be concluded that the probability distribution of times for accomplishing a work consisting of a number of activities may be approximated by the normal distribution and that this approximation approaches exactness as the number of activities becomes great. The

Table 4.2 NORMAL PROBABILITY DISTRIBUTION

Positive values			*Negative values*		
x	Probability	Probability %	x	Probability	Probability %
0.00	0.5000	50	–0.00	0.5000	50
0.05	0.5199	52	–0.05	0.4801	48
0.10	0.5398	54	–0.10	0.4602	46
0.15	0.5596	56	–0.15	0.4404	44
0.20	0.5793	58	–0.20	0.4207	42
0.25	0.5987	60	–0.25	0.4013	40
0.30	0.6179	62	–0.30	0.3821	38
0.35	0.5368	64	–0.35	0.3632	36
0.40	0.6554	66	–0.40	0.3446	34
0.45	0.6736	67	–0.45	0.3264	33
0.50	0.6915	69	–0.50	0.3085	31
0.55	0.7088	71	–0.55	0.2912	29
0.60	0.7257	73	–0.60	0.2743	27
0.65	0.7422	74	–0.65	0.2578	26
0.70	0.7580	76	–0.70	0.2420	24
0.75	0.7734	77	–0.75	0.2266	23
0.80	0.7881	79	–0.80	0.2119	21
0.85	0.8023	80	–0.85	0.1977	20
0.90	0.8159	82	–0.90	0.1841	18
0.95	0.8289	83	–0.95	0.1711	17
1.00	0.8413	84	–1.00	0.1587	16
1.10	0.8643	86	–1.10	0.1357	14
1.20	0.8849	88	–1.20	0.1151	12
1.30	0.9032	90	–1.30	0.0986	10
1.40	0.9192	92	–1.40	0.0808	8
1.50	0.9332	93	–1.50	0.0668	7
1.60	0.9452	95	–1.60	0.0548	5
1.70	0.9554	96	–1.70	0.0446	4
1.80	0.9641	96	–1.80	0.0359	4
1.90	0.9713	97	–1.90	0.0287	3
2.00	0.9772	98	–2.00	0.0228	2
2.50	0.9938	99	–2.50	0.0062	1
3.00	0.9986	99	–3.00	0.0014	1
4.00	0.9999	99	–4.00	0.0001	1

probability can be calculated by adding the standard deviations which are direct functions of the spread and relating the difference between event earliest date and scheduled date. The probability is dependent upon the distance, usually weeks, between respective dates and the square root of the summed variance of the individual expected times along the critical path.

The procedure in calculating probability may be summarised as follows:

(a) Determine the spread of each activity leading to the scheduled event.
(b) Calculate the variance (standard deviation squared) for each activity.
(c) Total the variances and obtain the standard deviation by taking the square root of the sum of the variances.
(d) Substitute values in the following formula to derive factor x.

$$x = \frac{\text{scheduled time} - \text{earliest time}}{\text{standard deviation}}$$

(e) Select the probability for the x factor from *Table 4.2* of the normal distribution function.

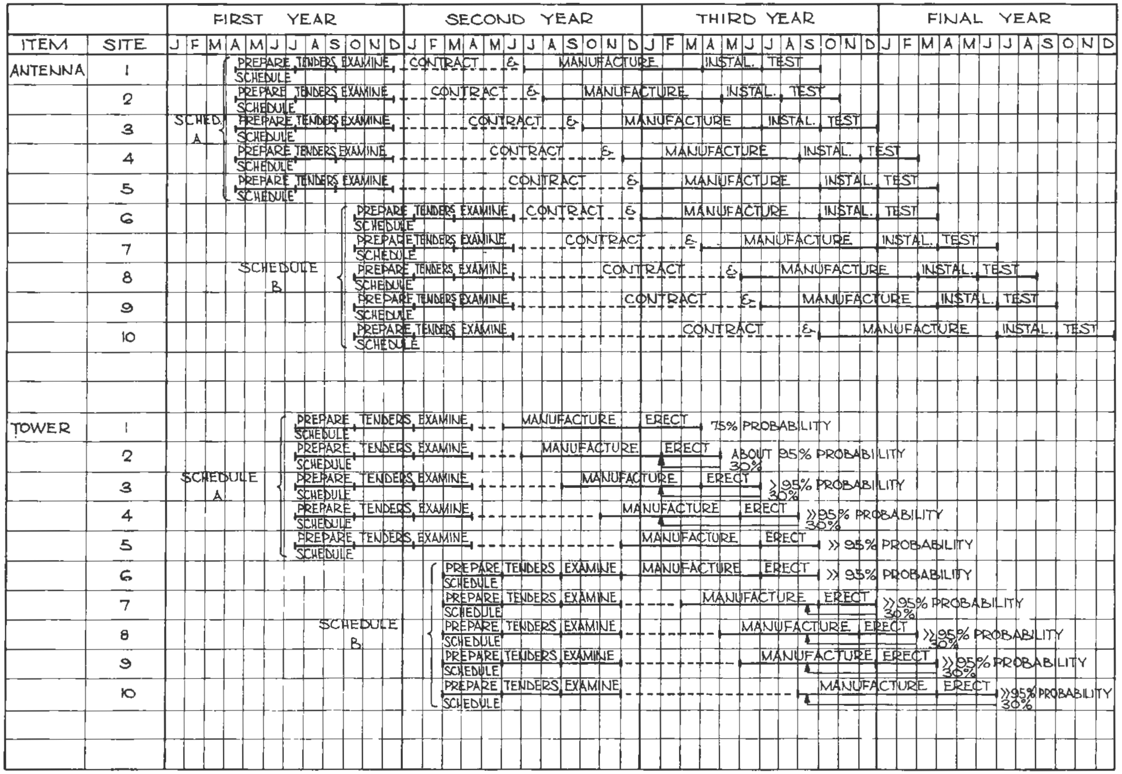

Figure 4.5 Probability application for a television antenna and tower expansion programme

In calculating probability values it frequently happens that the network gives more than one most critical path to the event having the scheduled date and giving different values of standard deviation for each path, even though they may be of equal length. In these cases, the lowest of the alternative values of probability is used.

Figure 4.5 shows a typical application of probability associated with the provisioning of antennas and towers for 10 television stations forming part of a major network expansion programme.

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Chapter 5

Planning and Tender Schedule Stages

An examination of reasons for failure in achievement of many radio projects has highlighted the fact that insufficient attention had been given to the proposals during the planning and tender schedule stages. Many projects showed that a co-ordinated programme, covering the whole range of activities, had been lacking. Proper planning is essential, otherwise it may be found that insufficient time is available for adequate consideration of the many inter-related issues. The planning and tender schedule stages fix the direction, and have considerable influence on the success of nearly every project. These stages should be programmed and monitored in the same way as the activities associated with the installation, construction and commissioning stages.

The profit on one project was reduced considerably when the tenderer failed to properly consider interface problems between a large tropospheric antenna dish and the support structure. The contractor designed and built the dish but purchased the structure from a sub-contractor who did not have a proper appreciation of the loading and purpose for which the structure was to be used. Considerable on site work was necessary to correct problems that should have been evident during the planning and design stage.

AIM OF PLANNING OPERATIONS

The need for proper planning by any organisation arises simply from economic considerations and the availability of manpower resources. The attainment of objectives is a process involving the allocation of these available resources. Once this basic concept of resource allocation is recognised the need for planning to achieve the best compromise of alternatives becomes evident. The aim of planning operations should be:

(a) To set down specifically the objectives of programmes.
(b) To analyse systematically and present for management decision, possible alternatives and programmes to meet these objectives.
(c) To properly evaluate and set down the beneficial results and costs of programmes.
(d) To determine the complete cost estimates of programmes including the ultimate operation and maintenance expenditures where new works are involved.
(e) To set down a schedule of expenditure and accomplishment during the various years of the life of each project on the programme.
(f) To indicate to management, future requirements of manpower, funds and other resources necessary for its future operations.

(g) To promote better communication between all parties concerned with development plans.

Planning is always carried out with a specific aim in view. At every level at which plans are made, there is a need for an objective because planning not only implies, but involves, action. The main point of any plan must be the achievement of the objectives which have been established. Frequently, planning is on a continuing basis, as for example radio communication systems carrying public traffic. These are invariably under continual study and analysis. The objective, in this case of satisfying the demands for service, requires an exacting solution in order that the service/cost balance, is maintained.

The objective of planning is the development of an over-all plan of accomplishment and identification of all the necessary tasks to the degree of detail relevant and the use to which they will be put. When planning is based upon sound estimating, coupled with a realistic concept of the time required to accomplish the work, then maintaining schedule is largely a matter of regular comparisons between actual and scheduled progress, with corrective action being taken by management wherever and whenever deviations occur.

BENEFITS OF TIME/COST SYSTEM

One of the principal management aids used in the planning and tender schedule stages of a project is the time/cost system. Its main benefits are that it assists in:

(a) Assessment of the relative merits of alternative approaches to a problem.
(b) Definition of the total scope of the schedule and identification at an early stage of individual tasks and works which have to be done.
(c) Identification of key decision points and the associated deadlines for these decisions.
(d) Determination of funding requirements for the project and the rate at which funding build-up will take place over the life of the projects.
(e) Establishment of the critical areas of an effort and the assessment of effects on these areas of additional resources on parallel efforts.
(f) Definition of those tasks which must be started immediately.

THE NEED FOR MONITORING AND REPORTING

To make sure that the benefits to be gained from working to comprehensive and properly planned programmes are not lost by failures of implementation, procedure for monitoring and reporting progress on all planning and tender stages must be set down. This procedure is an essential safeguard to ensure that a project develops in a proper manner in accordance with the planned programme. In the case of a large radio station or a long haul broadband microwave radio relay system, two to three years of planning and schedule work may be involved, and decisions on new stations or link systems may have to be taken up to seven years ahead of the operational requirement date.

Key events which are crucial to subsequent phases of a project should be monitored so that all responsible for these phases know the progress position. In areas where flexibility is obtained, and the need for this in planning is well recognised, programming of certain stages is all the more important. The intention is not that planning events should be scheduled to occur at the same time for every project but that a programme for these events should be established early for each project, so that it fits in with the programmes for the subsequent design, manufacturing, installation, construction and commissioning events. This planning programme should be monitored and reported on, in order that the effects of any variations on later stages would be known as soon as possible.

PLANNING STAFF

Since the project engineer and his staff are responsible for achieving the objectives, it is reasonable to expect that they should plan and measure their accomplishment. However, there is some merit in having a group specifically assigned to planning and scheduling work. The advantages of having such an establishment may be summarised as follows:

(a) The exchange of information about various projects can be easily and simply organised because all the planning staff are physically located together.
(b) The planning engineer can maintain an objective viewpoint of the proposal.
(c) Personal growth is provided for the planning engineers by giving them a greater breadth of experience in the organisation activities.
(d) A high degree of skill can be achieved by the planning staff, since they are generally not given time consuming administrative chores to the same extent as project staff.
(e) Projects phase in and out, and planning staff are easily moved from project to project.
(f) Emergency or high priority works can be handled more readily because of the greater concentration of staff.

The planning stage is an important stage in any project and the work calls for staff with the broadest background. Not all engineers are trained in the fields of economics, statistics and marketing but nevertheless the work could hardly be performed by specialists who may be trained in these fields if they are unqualified in the technological aspects.

Experience by several organisations involved in large international turnkey projects has shown that the best staff for planning and scheduling work are those drawn from field project areas. As planners, they are more aware of the problems of project engineering, and establish better rapport with the field staff. If project staff do not assist the planners in making the initial breakdown of the project, they should be consulted in the next step, to confirm the logic of the breakdown and to prepare estimates of resource requirements. It is important that all levels participate in the planning, to the extent of their responsibilities. Mutual planning in this manner will result in many benefits, some of which are:

(a) The direct and personal involvement of planning and project groups at the planning stage.
(b) Development of a common understanding of the goals.
(c) An appreciation of the contributions of other groups.
(d) A realisation of the need for clear communication between interacting groups.

ENGAGEMENT OF CONSULTANTS

Many medium and small size organisations find it necessary and desirable to engage the services of outside radio engineers to help with the planning, design and installation of major projects. The project is very often an activity incidental to their main goals and as project management is not part of their main business, they cannot afford to divert time and attention from their chief responsibilities, where they are efficient, to the specialised job of project planning and management where they are likely to be inefficient. For instance, management of a commercial broadcast station may decide to replace their conventional single radiator with a multi-element directional antenna system in order to increase coverage in certain directions or to meet changed requirements of the licensing authority. The system design, preparation of specifications, technical analysis of tenders and general management of the project would generally be beyond the capacity of the normal station operations staff.

Another important factor in favour of the engagement of outside consultants is the objective and impartial viewpoint of the outside engineer, especially in the early or preliminary study stages of the project. He is able to devote full attention to the specific problems associated with the project without being continually interrupted or detoured to deal with the normal day-to-day engineering mangement activities. If the organisation is to use an outside engineer, the greater advantage will be gained by it when it calls him in at the very beginning to help with the preliminary study rather than after they have contracted to purchase certain equipment or plant.

TYPE OF CONTRACT

The requirements to achieve an adequately planned programme for the development of a project through its planning and tender schedule stages must have regard to the type of main contract to be placed. The two main types may be classified as:

(a) Equipment or plant contracts.
(b) Station or system contracts.

Equipment or plant contracts involve the provision of major items for a station or a system. For a broadcast station the equipment may include such items as transmitters, antennas, power plant etc.

Station or system contracts on the other hand involve the provision of a complete station or system and may include major building and civil engineering site work.

It is usual to refer to contract plant or equipment as being of a standard type or a prototype. The standard type refers to items or units of a particular size and design for which contracts have been placed previously and for which specifications are readily available such as transmitters of various outputs. Nevertheless, it is often necessary to modify specifications as a result of development, experience or geographical location or environmental consideration but the so called 'repeat' station units can be included under this category from the specification and design aspect.

Prototype equipment or plant refers to equipment or plant of a size or design for which no contracts have previously been placed. With the rapid changes in technology, prototype equipment is being installed to an ever increasing degree on contract. Realistic scheduling for prototype facilities requires an appreciation of the work involved and problems likely to be encountered. Typical equipment in this category has been broadband microwave radio relay equipment where technology has enabled the channel capacity to be gradually increased in steps from 300, 960, 1200, 1800, 2700 to 6000.

PROGRAMME STAGES

For a large project which may take two or more years to complete from the date at which a contract is placed, up to three years of planning and tender schedule work may sometimes be necessary. The pre-contractual stages are generally referred to as the Provisional Year, Intermediate Year and the Final Planning and Tender Schedule Year. The development of these stages for a typical high power television transmitting station is shown in *Figure 5.1*.

In setting down the programme, the aim should be to select rational timings for the key stages, which if adhered to, would ensure that the contracts are placed with a satisfactory relationship to the completion date of the station or system. Good management requires that a project proceeds through its full cycle of activity as planned from its first listing in the draft preliminary proposal. Departure from this cycle by the introduction of crash programmes is undesirable and is likely to lead to excessive expenditure.

THE PROVISIONAL YEAR

In many organisations, preliminary proposals for the year's development plan are prepared by the Planning Branch at a particular time each year and the plan introduces the proposals for a new year, the provisional year. If the project is a very large one which may require five years to commission after placement of the contract, then the provisional year would be about seven years ahead of the commissioning date. These preliminary proposals may be referred to other Branches or Departments when information relating to them is required for a specific purpose, for example, the associated capital investment estimates.

Preliminary studies of proposals invariably revolve around four main questions:

(a) What is physically required for the station or system?

This involves an estimate of the types and sizes of the various equipment and plant, such as racks, control desks, cubicles, power plant, ancilliary equipment and antenna, also site requirements, buildings, utility facilities etc. If the installation is of a type that is well established and already in operation elsewhere, for instance, a broadcast or television station, then the work in this phase will comprise mainly sizing up or down of equipment and utilities, and keeping in mind physical changes of antennas etc. with wavelength change. Innovations and improvements which have emerged since the last installation would also be taken into account.

An analysis of various alternatives may be necessary. In the case of a large high power transmitting station these alternatives may include:

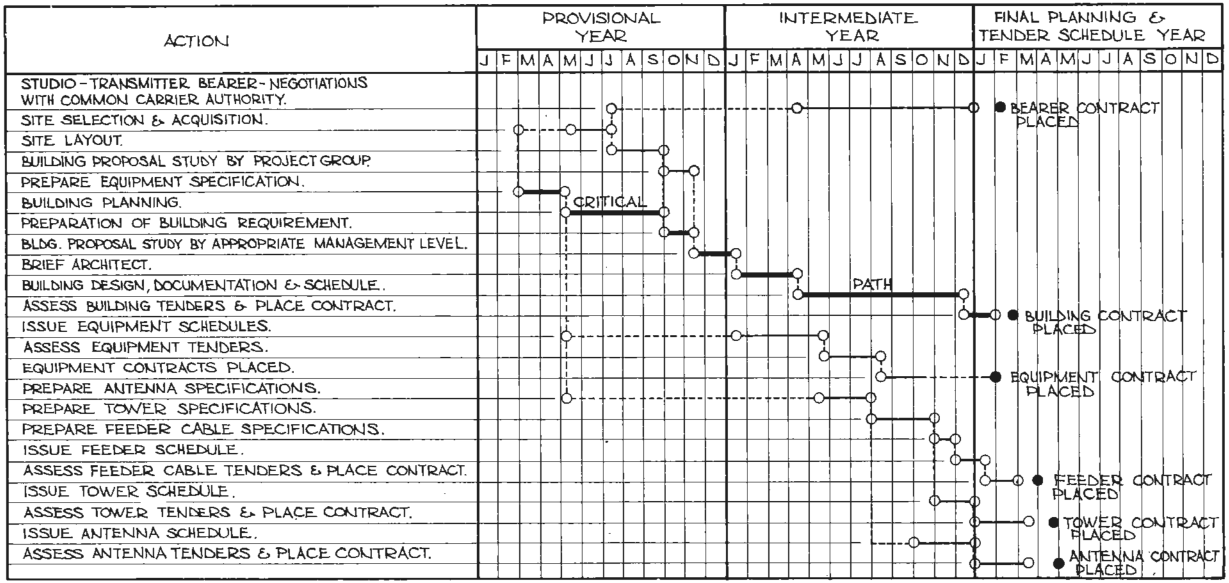

Figure 5.1 Programme for planning and tender schedule stages for typical television station project

  (i) external type vault equipment versus internal type requiring covered building space;
  (ii) automatic or remote control equipment requiring complex equipment but less staff and less overall building accommodation, versus a manual control and staffed situation;
  (iii) extension of commercial mains versus local generation of power;
  (iv) erection of staff houses on site as against payment of special allowances for travel from a distant town etc.

(b) What is the station or system installation going to cost?

This aspect involves a cost estimate of the physical requirements together with the cost of installation, erection and commissioning. All costs associated with buildings, site purchase, site civil engineering works, access roads and overhead charges would be included in this exercise. The adequacy of this phase of the work will rest directly upon the analysis of (a), accessibility to reliable up-to-date prices of equipment, materials, plant, transport, hire of plant and labour.

Estimates of varying quality based on design information of several degrees of completeness may be required during successive stages of the study. The main estimates normally applicable are:

  (i) Economic study estimates.

  The simplest and most convenient method of estimating the capital cost of a task is from curves of capacity versus cost. These costs are plotted from experience with plants of various capacities, preferably of identical type. Many curves are available showing for example, costs per channel kilometre or per station for typical radio relay and tropospheric scatter systems, costs per kW of m.f. and h.f. transmitter installations, costs per channel for satellite systems, costs per kW for diesel generating plant and costs of masts and towers for various heights.

  (ii) Comparative design estimates.

  The capacity versus cost curves are not suitable when it is necessary to compare one design against another. However, it is often too expensive to price from complete detailed designs. One approach frequently used is to prepare comparative estimates from partial designs. Design effort is concentrated on a few key items, determining all other costs by statistical relationships between these key items and other elements of the project cost. For a radiocommunication repeater, the key items are the radio equipment, power plant, shelter, and tower. These items not only represent the greatest percentage of the cost, but they also establish requirements for the other elements.

  (iii) Detailed estimates.

  These estimates are based on firm project definition and should be sufficiently accurate enough so that the complete work cost will not vary significantly from the estimated cost. Many organisations require that the final cost of the project should deviate no more than ± 10% from the estimate on which funding was approved. This degree of accuracy requires extensive records, considerable field experience and a thorough analysis of interfacing problems including those influenced by site conditions.

(c) How long will the work take to complete?

Practically all project works are undertaken on the basis of completion within a definite period after commencement of the work or signing of a contract. Such a condition can be fulfilled only by the most careful planning in advance and by the smooth meshing of the tasks of all groups associated with the complete work. The degree of success in meeting an agreed upon time period will depend upon the skill and understanding with which the time table or schedule is prepared, and also the earnestness with which it is observed during the progress of the work.

The proper preparation of an accurate schedule requires familiarity and considerable experience in handling radio engineering projects. Many groups may be involved in a large project and each group will, within reasonable limits, invariably want as much time as possible for the phase of the work for which it is to be responsible. This may be more than management is prepared to accept, and a series of conferences of all involved groups may be necessary in order to prune times to acceptable periods which can be met with the resources available.

(d) How much will it cost to operate and maintain the station, facility or system?

In determining the cost of operation and maintenance it is necessary to estimate the cost of the power consumed by the system, maintenance parts, labour for maintenance and operations, and administration and other overhead charges. Finance charges including interest, rates, taxes and insurance would also be included in the total cost.

Actions to be initiated in the three years of the planning and tender schedule stages will depend on the nature of the project. In many radio engineering projects, early field strength or path survey work will be involved in order to determine such matters as station location, area of site required and type of building. There are so many conflicting factors that each project must be treated separately when preparing a programme. A standard programme is often out of the question. For example, in the case of a medium frequency broadcast station there may be aviation restrictions concerning the erection of masts, local authority planning and building restrictions and many other local factors. It may well happen that in a given locality the prohibitive price of land, the cost of preparing the site, erecting buildings, construction of access roads or installing the equipment, outweigh consideration of technical superiority.

All these factors and many others make it necessary for considerable engineering effort to be involved in each major project during the years prior to the contract stages. As an example the main actions required in the planning of a typical high power television station in the provisional year are as follows:

(a) The site should be selected and the necessary steps taken to arrange its acquisition. Because height is a primary consideration for a television transmitting antenna, much of the preliminary work can be resolved from an examination of contour maps in the office. The site layout which would closely follow the site selection or which may even be carried out in parallel with it will be an important factor in determining the amount of land which has to be acquired. In many instances no special road works are required for site access but in others costs may be high or even prohibitive. In some mountain sites chair lifts may be required.

(b) Preparation of the equipment and plant specifications is one of the earliest actions required in the provisional year because the equipment and plant have a critical bearing on the building requirements. Also the antenna system has considerable bearing on the tower and its foundations and area requirements. Most programmes will show the equipment specification as being on the network critical path at a very early stage.

(c) The planning of the building can be commenced when the important equipment features have been resolved. Issues which have an effect on the building requirements include, operational staff numbers, air conditioning or ventilation, floor loading, ceiling heights, type of equipment, means of receiving programme from the studios, i.e. by microwave link or rental of coaxial cable from the common carrier authority and any special requirements such as brick construction or aesthetic considerations imposed by local authorities. During preparation of the building requirements prior to briefing of the architect, it would be normal for the planning engineer to discuss the proposal with the project engineer or group who would eventually carry out the installation of the station technical facilities.

(d) At the end of the year or other suitable period dictated by local procedures, the building proposal would be submitted to the appropriate management level for approval in principle before briefing of the architect, and formally calling tenders for the equipment.

After management has agreed upon the overall broad plan and schedule for the project, the detailed aspects of the planning and scheduling can be undertaken. The work must be broken down into packages and placed in the correct sequence in which they will be accomplished. The amount of manpower for each phase of the work has to be determined as part of the exercise. Often the detailed work will show up important aspects which have been overlooked in the broad overall plan. The detailed examination may reveal manpower requirements considerably in excess of the original estimate in which case management may have to reconsider the desirability of proceeding with the proposal. On the other hand the examination may reveal techniques or ways of achieving the objectives more economically and/or at an earlier completion date.

INTERMEDIATE YEAR

The intermediate year is involved in clearing the major activities to allow placement of contracts in the final year. In some cases, where long manufacturing times are involved, it may be necessary to place some contracts in this year. However, many organisations consider this is the year where firm prices are obtained in order to seek financial approval in the final year.

A matter to be cleared early in the intermediate year is the briefing of the architect to allow building design and tender work to proceed. In the majority of installations, the building is on the critical path of the network and details should be finalised as soon as possible, to allow tender prices to be obtained before the end of the year.

The equipment tenders should be issued early in order to obtain prices and to confirm estimated delivery times. In many cases these delivery times may be long, particularly if the manufacturer is heavily committed for other works and it may be expeditious to place a contract or at least forward a letter-of-intent, ahead of the programmed year. External plant such as antennas and towers are also items with long lead times and tenders should be called sufficiently early to allow completion by milestone dates. The studio-transmitter arrangements for the programme bearer should be finalised early in the year. If a microwave radio relay link is to be used, the path will have to be surveyed and tenders called for the radio equipment and the towers. If on the other hand a coaxial cable bearer is to be rented from the common carrier authority, then negotiations should be conducted early in order to allow the authority to proceed with any necessary work.

FINAL PLANNING AND TENDER SCHEDULE YEAR

As early as possible in the final year or immediately the first contract has been placed the project group should be issued with the necessary authority to proceed with the work. Many organisations, however, involve the project engineer at a much earlier stage than this. If the project engineer is involved early in the life of the project he will have gained acquaintance with the background of the task which will in its later execution promote a smoothness that can hardly be recaptured by a person called in after all major decisions have been made. The documents issued to the project group should include all the relevant design data, schedules, specifications, tender and contract papers, negotiations with local authorities and environmental bodies, any restrictions to site access and all other matters associated with performance of the work.

If the task concerns the installation of a station complex, the project group should carry out a detailed investigation of the site to confirm that the proposed layout is the optimum arrangement and proceed with pegging out and establishment of the station reference bench mark. They should also take action to ensure that all materials and facilities which have to be provided for the contractor in accordance with the contract are on site or readily available.

As soon as the project group is satisfied that it can proceed in accordance with its authority, it should involve the relevant specialist groups such as power plant, reliability, structural etc. If subsequent operations and maintenance are to be performed, the maintenance and operations group should also be a member of the group. This involvement should include such detailed aspects as:

(a) Basic details of the project.
(b) Site, buildings, access arrangements, equipment and plant layouts.
(c) Work site logistics.
(d) Power supply arrangements.
(e) Unusual installation, operating and maintenance features.
(f) Expected reliability and extent of maintenance and servicing.
(g) Programmed commencing, testing and commissioning dates.
(h) Staff training arrangements.
(i) Spare parts, mechanical aids, vehicles, handbooks, drawings etc.

CONTRACT STAGES AND ACTION REQUIRED.

Reference has already been made to the two main types of contracts:

(a) Equipment or Plant Contracts.
(b) Station or System Contracts.

Broadly each type of contract requires the planning of the following set of operations:

(a) Preliminary research and design work.
(b) The preparation of the specification including drawings and tender schedule documents.
(c) The printing of the specification and the completion of other documents associated with the calling of tenders.
(d) The calling of tenders.
(e) The preparation of tenders by the manufacturers and service suppliers.
(f) The examination and assessment of the tenders and preparation of the recommendation.
(g) The procedural requirements of the organisation which have to be followed before the contract can be placed.

There are a number of less important procedural stages leading up to the various key stages and experience has shown that an appropriate time interval should be left between the key points to accommodate the intermediate points. For example, before a recommendation is submitted to the Contracts Department it may require the approval of Branch and Engineering Department Heads. When the overall programme has been agreed by the design and project groups, it is the responsibility of the latter to arrange the programming of these minor stages for their particular contracts and to fit this programming into the agreed co-ordinated plan.

The programme usually leads to the placing of all contracts, with the exception of the site purchase, early in the financial year. This timing allows for the project to be submitted for financial approval early in the year, as all the major contract prices should be known at that stage. If the receipt of tenders is spread over the year, it makes it difficult to prepare an accurate summary of the total project cost at an early stage. Funds approval should be sought in sufficient time to allow payment of materials and services when they become due in accordance with the terms of the contract.

In the case of antenna, feeder cable and tower schedules, it is sometimes advantageous to allow a good time margin as economies may often be obtained if one contractor carries out the work called for under the various schedules. Not all manufacturers are in a position to supply all items, and it may be necessary for them to seek quotations from other suppliers or prospective sub-contractors.

The programme shown for a typical television station can only be taken as a guide and the programme for a specific project contract should be drawn up to suit the requirements of that contract. The only firm requirement which must be applied to all contracts is that all preliminaries should have been completed so that contract prices are obtained early in the final year in order to seek a firm financial allocation for the project.

Tenderers should be required to support their proposals with networks and resource estimates to assist management in the analysis and evaluation of the proposal. This will assist in the proper assessment of all proposals during the examination stage by providing:

(a) A common base or structure for comparison of time schedules and resource estimates submitted by the various tenderers.
(b) A discipline which communicates the logic and reasonableness of the proposed time schedules and resource estimates.

(c) A reassessment, if necessary, of target dates and resource requirements for completing various phases of the project as estimated by planning engineers prior to calling of the tenders.

PROGRAMMES FOR STANDARD EQUIPMENT

Improvements and proposed variations to the last issued specifications will generally be a continuing process as suggestions are fed back from project groups, maintenance or operating groups, and consequently no specific time would be shown on a programme for this stage of the work. The redrafting of some of the specifications will start immediately after approval of the development plan or very early in the provisional year. In some large projects a period of 18 and in some cases 24 months may be necessary on the programme for the preparation and printing of specifications, the issue of the schedules and the preparation and return of the tenders by the competing tenderers.

The programme time to be allowed for assessment of tenders will vary with the type of equipment, plant and magnitude of the work. The examination and preparation of a technical report for an antenna coaxial feeder cable would be a relatively simple and straight forward exercise and should normally be completed within a few weeks. However, a directional antenna system for a television or medium frequency antenna may require considerable analysis perhaps by computer program and would take much longer. Also, considerable time may be occupied in seeking and obtaining additional technical information from the tenderer on his proposed design.

Following nomination of the contractor, a programme period of four to six weeks is often required to complete negotiations with the selected contractor or to clarify any last details of delivery or costs, and for contract finalisation by the Contracts Department.

The capital cost estimates for the project will have been in course of preparation over the previous six months or so with a view to submitting the proposal to the appropriate management level for approval.

PROGRAMMES FOR STATIONS OR SYSTEMS

As in the case of standard plant or equipment, improvements and proposed variations to the last issued specifications will be a continuing routine process and no set time for this work would normally be shown on the programme. The operations required to obtain tenders and place a contract for a complete station or system do not differ from those required to place a conventional equipment or plant contract, except in the time periods allowed for the different stages.

The time programmed would of course depend on the nature and magnitude of the project. For instance in a broadcast or television station programme a period of 2-3 months may be sufficient time for selection of a site, but for a high capacity long haul radio relay system a period of 6-9 months may be required to select all sites on the route. Also, the design of a complex directional antenna system with an unusual pattern would take considerably longer to detail than one for a standard omnidirectional radiator.

The procedural stages prior to placing the contract follow the same pattern as for conventional contracts.

PROJECT PROPOSALS

On completion of the initial planning phase of a proposal, management approval has to be obtained for engineering concurrence and the allocation of funds before the work can proceed. Tenders can then be called for the work by the issue of a tender schedule or a manufacturing order can be issued to put the work in hand. In addition to securing approval for allocation of manpower, funds and other resources, it can also be considered to be a guide line for subsequent development or planning activities.

The method of obtaining this approval varies from one organisation to another and the most common names used for the document are Project Proposal, Work Proposal or Project Summary. Invariably, a separate submission is required for each proposal although in some cases of relatively minor works top management may allocate a lump sum for these proposals, with the approval for individual proposals being vested in a lower level of management.

To allow a proper appreciation and examination by management, all major project proposals should contain the following basic information:

(a) The objective which the proposal aims to fulfil.
(b) An outline of the problem and how the proposal will bring about a solution. This should include details of any systems which the proposal will supersede and the reasons why the work should be carried out in the time scale planned.
(c) An introductory functional description of the system proposed, outlining how the objective will be fulfilled, the need satisfied and how it will match the environment under which it is to function.
(d) The estimated cost of the work including materials, labour, incidental expenditure and administration or overhead charges. Where the work extends beyond one financial year, expenditures for the various years should be set out.
(e) The value of the system proposed should be fully explained and supported with data or the expected demand, profits, savings, operating and maintenance costs or whatever are the primary measures of success of the system.
(f) Economic comparison studies of alternative schemes should be outlined, giving reasons as to why the recommended proposal was chosen and the order of preference of other schemes studied.
(g) Where the project is one involving a large manpower effort, the most desirable build-up and decay of these resources should be indicated.
(h) Special environmental factors which influence the design or cost of the work. Typical factors would be social (shortage of operating or installation manpower), physical (difficult mountain top site condition) and economic (system of high capital cost but lower annual operating costs).
(i) Constraints which may be applicable to the proposal.
(j) References to files, reports and official correspondence which may have initiated the planning work.

Promotion of the proposal to top management is necessary to obtain their approval to proceed with the work. It should be written in a style and manner which will present a clear and concise picture of the work proposed. It should be expressed in simple understandable language and set out the advantages to be obtained by carrying out the work. It is most annoying for management to receive a proposal that is prepared in such a manner that they have difficulty in understanding what the proposal is all about. Management cannot be expected to approve a scheme which it cannot readily understand, regardless of its inherent merits. It may have to be referred back to the originator for clarification or additional supporting information. It is important also that the technical attractiveness of the proposal is not rated ahead of profitability, except in special circumstances, such as work to be carried out to improve safety aspects. The profitability aspects of a proposal are of vital concern to management. Although a technically attractive proposal may result in a profit, its profitability, that is the ratio of profit to investment, may be small.

FURTHER READING

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Chapter 6

External Plant Programmes

External plant designs are seldom truly repetitive. For example, a mast design is influenced by the site on which it is placed to the extent of variations in wind loading, ice loading, soil conditions, contours which affect guy lengths, the extent of atmospheric corrosion and several other factors. Experience with many projects has shown that the majority of large external plant works have run into programming difficulties for several reasons at nearly all stages of the work. One factor which has led to lost time in the early programme stages is the method of handling the basic design work.

There are two generally accepted methods of handling basic design:

(a) The detailed design scheme.
In this approach, considerable time and effort is spent on working up a design in detail before submitting a tender.

(b) The sketch design scheme.
In this scheme, a sketch design is produced in a relatively short period, sufficient only for pricing and selecting a contractor. The selected contractor would be given a letter-of-intent to work up the design in detail by joint consultation. The firm contract would then be placed after agreeing on the worked-up design.

The advantages of the sketch design scheme are briefly:

(a) There is a saving, both financially and in terms of effort in abortive design.
(b) There is often little problem in paying for a series of worked up designs.

The disadvantages of this scheme are:

(a) There is considerable difficulty and risk in quoting a fixed price on a design for a complex project that has only been worked to the sketch stage.
(b) It is extremely difficult to make a proper technical assessment of an undeveloped sketch design. It could lead to an error of judgment in making the best choice.
(c) The release of important information on which to develop the station design may be delayed pending the work-up of the sketch design.

THE DESIGN PROGRAMME

Four critical areas are usually involved in large external plant projects. These are masts and towers, antenna systems, transmission lines and the line switching system. If these areas are properly programmed the rest of the site work can be made to fit into the network with little difficulty. However, in considering a station design as a whole, civil engineering works such as clearing, roadworks, drainage and switch-house could well prove to be critical factors during the period between the plant design and its erection or installation, especially if site access is difficult.

A typical design programme developed around a detailed design scheme may have several phases. The programme may start with the issue of a tender schedule covering the broad concept of the project. The design would be developed in consultation with the principal and prospective sub-contractors. At the end of the design development period, the basic plant layout will have been agreed, so that the principal may proceed with the design of site access roads to the antennas, clearing and other associated works. The time necessary for this tender preparation work would be fixed by the principal but would be governed by the size and complexity of the works. Nine to twelve months is a typical period for a large project. A tender examination period of two to three months is generally adequate when close liaison has been established during the tender compilation stage.

As soon as the contract is placed, detailed drawings must be produced in order that manufacturing details and ordering can proceed. Often the lead time of basic raw materials such as steel for masts, copper for transmission lines and antennas, steatite insulators etc. are variable depending on demand and resources. Many manufactured items may also have long lead times. For example, a 500 kW line switching matrix may involve a period of 18-24 months between ordering and on-site delivery dates. The implication of this is that drawings forming part of the material or plant should be completed as quickly as possible.

It is not an easy matter to determine the degree of planning a tenderer should be expected to carry out before submitting his tender. The planning of the external plant works developed from the Master Programme will have ensured that the tenderer has clearly specified completion dates for all areas of work, on which he can plan. Any restrictions on his working will have been stated. Thus, having ensured that the tender schedule is based on a reasonably final design, it may well be appropriate to ask tenderers to include information in tenders which demonstrates clearly the amount of planning done in preparing them. Tenderers could be asked to state details of rates of working such as wire laying for earth mats, transmission line and mast erection and to include in their tenders programmes based on the schedule dates, together with plant location and movement charts. This information would assist in tender discussion and assessment, and ensure a well planned early start to the contract, besides demonstrating the tenderer's capacity to plan properly and to provide and organise adequate resources.

MANUFACTURING PROGRAMME

Manufacturing programmes for external radio plant are generally prepared in bar chart rather than network form, mainly because it is difficult to develop a system of production control. The programme is of necessity a compromise between the requirements of production, inspection and test sections which are in large part multi-contract in nature and of single project control. It has to serve both, and the aim is to produce a programme which is compatible with both the manufacturing detail and the main contract programme. It is usual to commence with

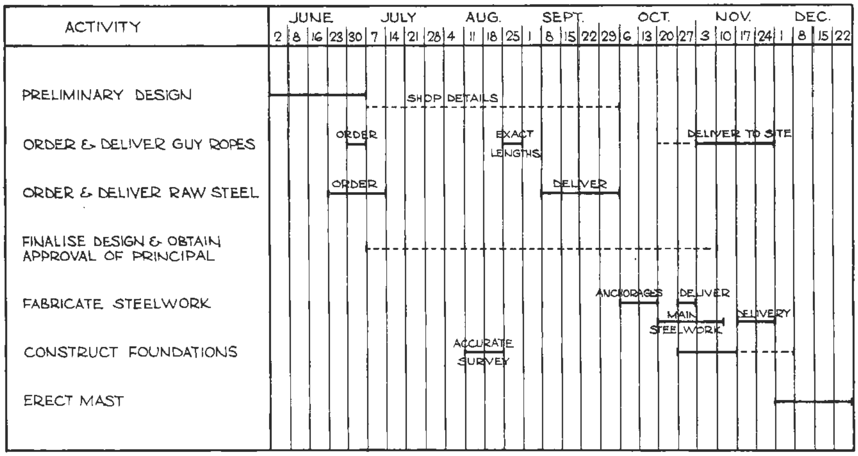

Figure 6.1 Design, fabrication and erection of 150 m mast

development of design for manufacture and end with delivery to site.

Some of the difficulties encountered in programming and controlling manufacturing processes are as follows:

(a) The direct interfacing of the manufacturing programme with the site erection requirements generally lacks any contingency for manufacturing delays.
(b) Time estimates for manufacturing or fabricating processes are prepared in parallel with the development of design and are not placed on a firm specification with the items to be manufactured or fabricated. This is illustrated in *Figure 6.1* which shows in bar chart form, the procedure followed from design to erection of a 150 m mast.
(c) Time estimates for manufacturing processes tend to err on the side of optimism, and pressure from the project programme often conflicts with attempts by the production group and the contractor to revise the forward programme in terms of known work content.
(d) Budgetary control requirements need the support of working level arrangements for the derivation of a realistic incidence of expenditure from a manufacturing programme.

PROGRAMME SERVICING

Having specified the key events in the design programme that impinge upon the integrity of the detailed manufacturing programme, there is need for an information service on their achievement. Prior to the achievement of these key events in the design programme, the manufacturing intentions for each section of the contract represents only a provisional booking of the facilities required. An event reporting service from the design programme would enable positive confirmation of manufacturing intentions to be sought, directly the design clearance of each major section of the contract is confirmed.

The monitoring of the manufacturing programme has many problems, for field staff, and experience has shown that one effective means is by the direct issue to the project group site staff of a copy of a completed manufacturing progress questionnaire to enable updating of the erection programme and supplemented as necessary by a comprehensive tabulation of delivery intentions. *Table 6.1* shows a typical form of delivery intentions of material for a transmitting antenna system comprising four arrays and associated plant.

Table 6.1 DELIVERY INTENTION TABLE FOR H.F. TRANSMITTING ANTENNA SYSTEM
Organisation: AYZ Broadcasters Ltd
Delivery Intentions as at: Sept. 1977
Action Code A = Commence Delivery Material To Site
Z = Complete Delivery Material To Site

Radio Station	*Item*	*Material*	*Qty (sets)*	*Programmed*	*Anticipated*	*Action*
Site A	1	Transmission line assemblies	8	40/76	48/76	A
		2 wire (matrix to antenna)		50/76	6/77	Z
Transmitting antenna system	2	Transmission line assemblies coaxial (matrix to antenna)	8	45/76	46/76	Z
	3	Transmission line assemblies shielded 2 wire (transmitter	3	48/76	3/77	A
		to matrix)		52/76	7/77	Z
	4	Transmission line assemblies coaxial (transmitter to matrix)	3	49/76	3/77	Z
	5	Antenna switching matrix,	1	9/77	12/77	A
		2 wire with support structure		15/77	18/77	Z
	6	Antenna switching matrix,	1	6/77	10/77	A
		coaxial		12/77	16/77	Z
	7	Antennas and matching/feed networks				
		11.0 MHz array	3	50/76	4/77	Z
		15.0 MHz array	2	4/77	8/77	Z
		17.0 MHz array	2	8/77	12/77	Z
		21.0 MHz array	1	12/77	18/77	Z
	8	Antenna support and reflector structures				
		11.0 MHz array	3	51/76	51/76	Z
		15.0 MHz array	2	5/77	8/77	Z
		17.0 MHz array	2	9/77	12/77	Z
		21.0 MHz array	1	13/77	18/77	Z
	9	Installation materials				
		antenna kit	1	50/76	4/77	Z
		Transmission line kit	1	40/76	48/76	Z
		Switching matrix kit	1	6/77	10/77	Z

ERECTION AND INSTALLATION PROGRAMME

There are many problems associated with the erection, installation and setting to work of the external plant facilities. Some of these include:

(a) The availability of labour at a particular site or time, and the risks of abnormal weather which can only be dealt with by making allowances based upon experience of works under similar situations.

(b) Failure to ensure prompt and sequential delivery of materials and the timely

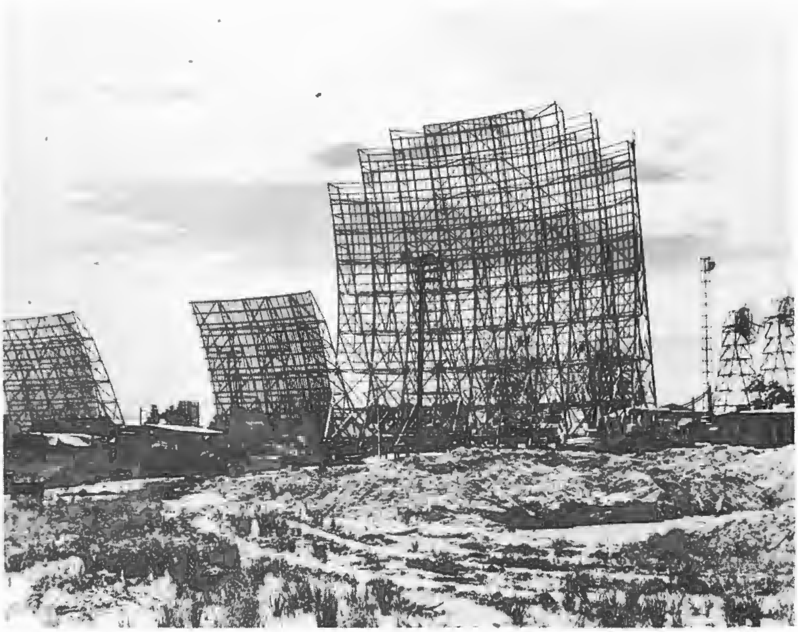

Figure 6.2 Tropospheric scatter antennas (Courtesy Page Communications)

provision of services, such as mechanical aids and supplies by sub-contractors.

(c) Erection and construction methods can be influenced by limitations of site access or access to working areas. This applies in many cases to television and radio relay system towers which may be required at isolated mountain sites.

(d) Acceptance test specifications with respect to measurement, tests and setting to work are seldom available on time.

(e) The suitability of the external plant programmes, particularly the erection and installation programme, can only be determined when they have been joined to other programmes in the Master Programme.

(f) It is often not possible to fix every activity in detail before erection or installation commences and some flexibility must be allowed to take account of changes in the design and manufacturing phases. Also, several different methods of erection or installation may be available and the economies of each has to be properly assessed at the time.

An important aspect of this is the extent to which assembly of a mast or tower can take place on the ground. In some designs a complete section of about 10 m or more can be assembled on the ground or in the factory and hauled aloft by special jury methods. For others such as tropospheric scatter antennas of the type shown in *Figure 6.2* there may be no alternative to erection member by member. It may therefore be difficult to determine erection activity times until the structural design details have been finalised.

(g) The optimum erection and installation programme does not necessarily fit the associated optimum manufacturing programme and close co-ordination is required to produce the best overall solution.

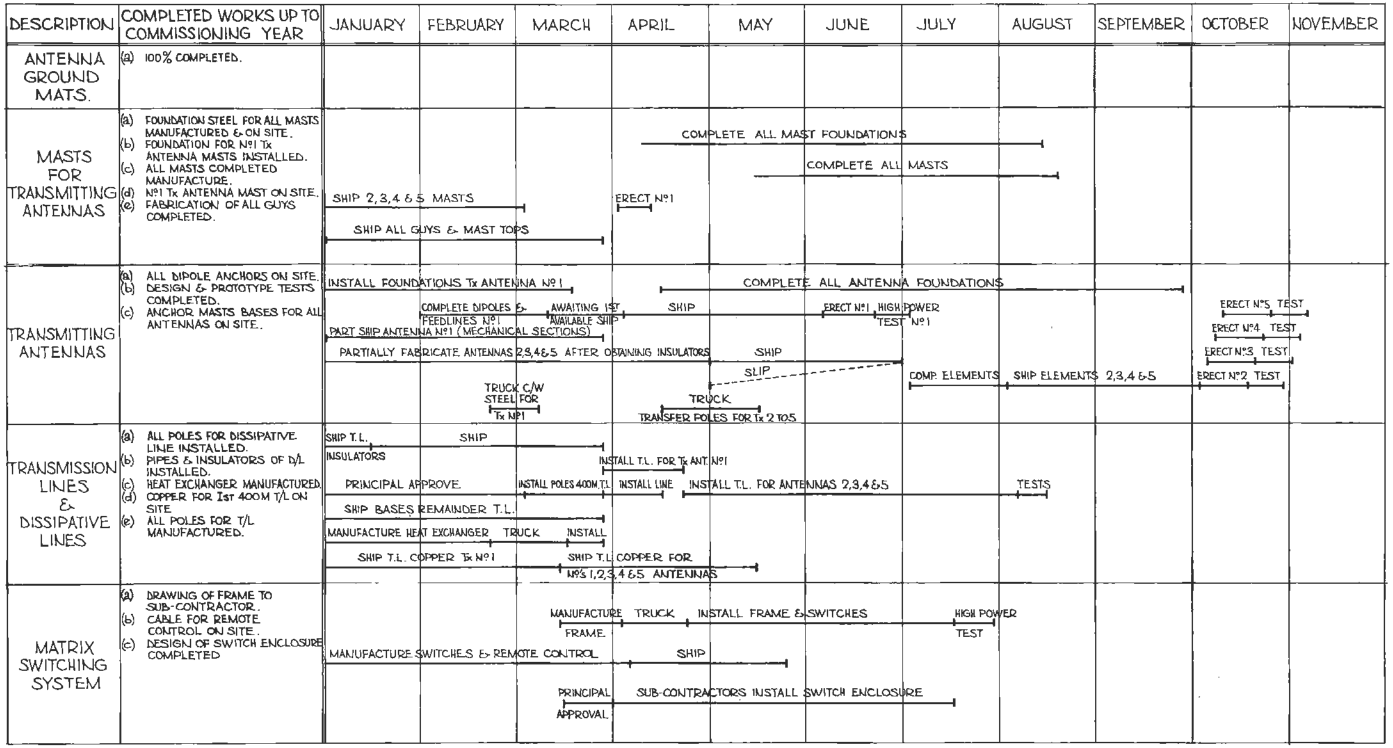

Figure 6.3 Erection and installation bar chart for commissioning year of a transmitting station external plant

Some approaches which have been found by experience to be useful in overcoming these problems associated with external plant facilities include:

(a) Any form of erection and installation programme produced at the tender stage should be constructed by the logical grouping of activities and not by material content.

(b) Construction and erection should be scheduled by type of work for all sections. Concrete work, for example, associated with foundations for masts and towers, counterweights, transmission line poles, rigid coaxial line pillars, manholes etc., should be scheduled so that it will be reasonably continuous for the work as a whole. The same may be said for the erection of structural steel for masts and towers, line switching systems, transmission line anchor towers and so forth.

(c) Manpower estimates prepared in the office should be checked and confirmed by experienced field staff, if possible by the group who will carry out the work. Many specialised erection practices particularly those of a hazardous nature where particular safety practices may be involved, such as mast and tower erection, vary from one organisation to another and even from one group to another within the organisation.

The aim of consultation with the erection group is to avoid a situation wherein the office sets up one method to do the work, completes the programme and then the erection team uses another in order to speed up the process, to make it more economical or because of particular safety requirements or unsuitability of a mechanical unit.

(d) A network built up of grouped erection and installation activities should be evolved during the period from issue of schedule to submission of the tender.

Provided that confirmation concerning essential information and compatibility with other programmes is forthcoming, such a network should be ratified as soon as possible after contract award, and become an expression of intent and thus a working document.

The purpose of the network should be clearly understood. It is to ascertain the contractor's programme intentions and to furnish information for the initial development of the station overall installation programme.

(e) For a large project, a bar chart based on the same grouping principle is frequently prepared shortly after contract award to supersede the tender network programme. This bar chart then becomes the medium of communication and programming review. *Figure 6.3* shows a typical chart for a project in an advanced stage of construction.

INSTALLATION RESOURCES

Many organisations having radio linestaff establishments for maintenance purposes frequently handle their own external plant construction activities by supplementing the maintenance group. However, construction specialists have now entered the field and for many projects can carry out the work much more efficiently and economically. As a compromise some organisations have adopted the principle of using specialist sub-contractors. For example, after delivery of a tall mast from the manufacturer, one sub-contractor specialising in concrete works might be employed to carry out the foundation works while another

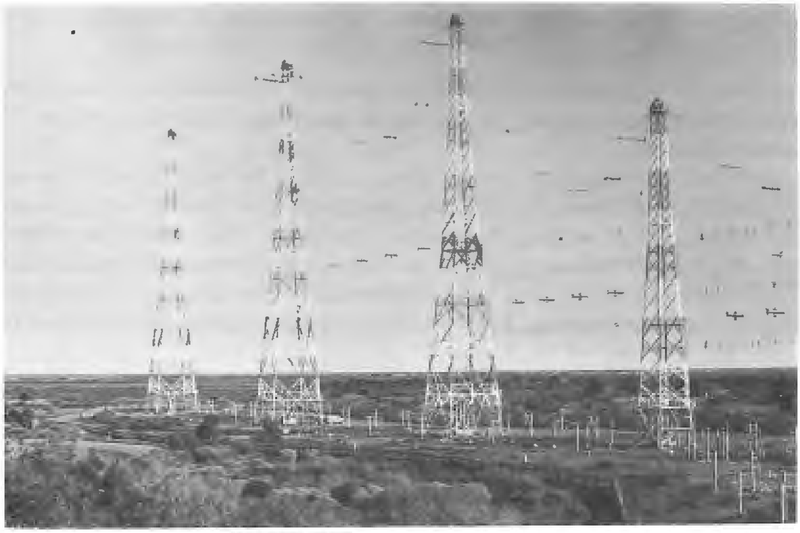

Figure 6.4 Curtain antennas and transmission lines

specialising in structural steel rigging work might be employed to erect the structure and to install feeders, waveguides and antennas.

The most common method, where contractor involvement is used for this type of work, is to employ a prime contractor who handles the complete work. He may carry out all the work himself or he may use sub-contractors. The principal or the customer however is relieved of all the administrative problems in supervising sub-contractors or finding the resources. *Figure 6.4* shows an installation completed under this arrangement for use with a 250 kW transmitter.

PROGRAMME PREPARATION

Programmes for external plant works, or any type of radio engineering works in fact, may be elaborate or they may be simple. The type of programming arrangement used will depend on the class, complexity and magnitude of the work. The simplest form of programming is a tabulation of key events. For a small programme this may be all that is necessary in written form. For clarity and record purposes this tabulated data may be put into a simple bar chart form. Although the bar chart has certain limitations, mainly that it does not show the interdependency of one event on another or it may not be possible to show the time allotted for each particular function, its usefulness can be greatly extended by the use of milestone symbols superimposed on the bars.

A programme prepared in network form will show, among other things, the duration of the work, the earliest and latest completion dates for each activity within the limits of the time span for the work, and the interrelated and parallel activities. Whatever form the programme may take, the following action would be taken during preparation:

(a) Assembly of all the documents associated with the work.

These would include contract papers, specifications, special conditions, estimates, drawings, correspondence to suppliers regarding costs and delivery timing etc.

(b) Definition of the end objectives of the particular work.

(c) Listing of the work into major classifications, divisions, packages, tasks and milestones, and setting these down in regulated sequence.

The main purpose of this operation is to reduce the scope and complexity at each level until a manageable unit for planning and scheduling purpose is obtained. The size and number of these activities will vary and depend upon the size and complexity of the work. When breaking down the work into manageable activities the aim is to show not only the starting and finishing dates of these activities but also the sequence and inter-relationships between the various operations. Careful control must be exercised over the sequential relationships among the activities and operations. Some operations will precede others, some will follow others and some may be carried out at the same time, either in conjunction with another activity or independent of it.

Activities performed by different trades groups such as riggers, radio-technicians, electricians, pipe layers etc. would be placed into separate classifications. Also, work carried out by different sub-contractors would be separately classified. For example, the activity of a sub-contractor employed for the erection of a tower should be kept separate from the activity of, say, a sub-contractor employed to provide the electrical distribution to the matrix switch, slewing switches and tower lighting.

Activities of a similar nature but carried out at different locations should be separately classified. For instance, a project involving repeaters and terminals for a radio relay system may have one contractor for erection of all the towers, but as a different location is involved for each tower, a separate activity should be shown for each site.

(d) Determination of dates on which key materials, services, drawings or specifications are required to be made available or delivered and the latest dates by which orders must be placed or contracts placed for the materials etc. to be delivered on or before the appropriate time.

In establishing delivery dates for materials or equipment, allowance has to be made for the time taken to transport the items from the manufacturer's premises to the site where they are required. On an overseas contract where long sea transport is involved this could amount to several months.

(e) Listing of materials, equipment and plant into major classifications, divisions or sub-divisions. This information would be available from material sheets used in compiling the estimate, however it must be listed by the bill of material process or its equivalent, as estimated quantities are not always accurate enough. The work would be divided with respect to its functional or structural elements. For example for a mast the steelwork would be separated from the guys which in turn would be separated from the concrete anchors and thrust block.

(f) Listing major plant such as cranes and winches, equipment and tools required by the contractor to carry out the work. These items would normally be the property of the contractor and would be recovered after completion of the work.

(g) Determination of site delivery dates for the materials including sand, aggregate and cement, equipment and plant, and dates on which services, such as mechanical aids on hire, are required.

In programming for materials, the method of obtaining them should be ascertained. Some may be purchased from outside sources, some may be obtained from stores stock, some may be obtained from reconditioned or recovered sources, some may be quarried locally–such as sand or aggregate–some may be manufactured on the site–such as antenna concrete counter weights–some may be supplied by the principal or customer, and so on.

(h) Selection of the most economical method of carrying out each activity and determining the time or manhours required for completion. For a network type programme this would be the activity time.

The approximate quantity of work can be assessed from the bill of quantities. The labour manhours associated with that work can be assessed by using the labour element of the billed rate for that particular work activity.

(i) Preparation of the programme based on the information available at the time.

The final programme should show the sequence of operations that is necessary in order that the work may be carried out in the time allotted. It should also show the interdependency of one activity on another.

In a large project involving development work, the programme may be subjected to a considerable number of amendments. These may be caused by design or drawing changes, revised material delivery schedules, changes to specifications and many other factors. For proper control of the work, the programme should be up-dated as soon as possible after the change is known.

EXPENDITURE PROGRAMME

The expenditure programme has an important role as a management brief during the contract period. One of the most difficult problems met by project engineers is that of keeping the cost of the work within the prescribed limits. A radio engineering project involving external plant site works is not like production work in a factory. Conditions cannot always be fully anticipated, and difficulties are almost certain to arise often resulting in increased expenditure. Some typical causes of increased expenditure for external plant works may be summarised as:

(a) Unforeseen site conditons, for example unexpected rock, may be encountered during mast or tower foundation excavation work.

(b) Difficult site access conditions. All-weather roads are not always provided to or throughout a site to give complete access to all working areas, and abnormal rains may result in retardation of the works.

(c) Clashes with other works. Site roads may be designed without proper co-ordination with transmission line pole and other plant layout.

(d) Changes in the design of manufactured equipment after the contract is let. To overcome this problem many engineers insist on freezing designs after a certain date and will only consider design changes where a safety matter is involved.

(e) Failure of material or work to meet the specification. Concrete work for foundations of masts and towers is an example of this problem. The most common problems are failure to provide the required strength and structural failure such as sandy patches, crumbly concrete and cracking.

Table 6.2 FINANCIAL STATEMENT FOR EXTERNAL PLANT CONTRACT

Date of issue: June 1977
Station: Site B

Contract number: 65230
Schedule number: 66/305

Item number	*Description*	*Commitment* (%)	*Budget forecast* (%)	*Costed progress* (%)	*Commitment* (£ × 1000)	*Progress payments*	
						Budget forecast (£ × 1000)	*Costed progress* (£ × 1000)
	Manufacture						
1	Transmitting antennas less towers and foundations	40.93	8.55	8.55	520.750	108.732	108.732
2	Copper earth mat materials	3.03	3.03	3.03	38.500	38.500	38.500
3	Dissipative line including support structures	1.79	1.50	1.45	22.750	19.062	18.427
4	Transmission line materials including support structures	14.93	12.45	11.75	190.000	158.422	149.530
5	Transmission line switching matrix	7.07	2.50	0	90.000	31.824	–
6	Steelwork for antenna support masts	5.70	5.50	5.50	72.500	69.955	69.955
	Erection and installation site works						
7	Provision of concrete foundations for antenna support masts	2.08	0.50	0.50	26.500	6.367	6.367
8	Provision of concrete foundation for antennas dipole anchor points etc.	4.13	1.50	1.25	52.550	19.880	15.901
9	Erection of antenna support towers	2.42	0.60	0.50	30.750	7.622	6.352
10	Erection of transmitting antenna arrays	8.64	1.75	1.35	110.000	22.275	17.182
11	Installation of earth mat systems	2.56	2.56	2.56	32.550	32.550	32.550
12	Installation of transmission lines	3.14	1.00	0.80	40.000	12.736	10.188
13	Installation of line switching matrix	3.58	0	0	45.500	–	–
	Total	100.00	41.44	37.24	1272.350	527.945	473.684

(f) Changes in specialist requirements. Aviation authorities may request painting or lighting of a mast after its erection, even though earlier this treatment was not considered necessary.

(g) Changes in statutory conditions. Amendments to safety requirements for masts and towers may involve rest platforms at greater intervals than original requirements.

(h) Justifiable misunderstandings by tenderers. In the absence of information otherwise, tenderers may assume that installation or erection conditions will be normal but this may not apply when the work is actually being carried out. For instance, the contractor for a building to house antenna matching equipment at the base of a broadcast antenna mast may have completed the building before the mast erection commences and it may be necessary for the mast contractor to provide a protective covering over the building roof to prevent damage from falling objects during the mast erection work.

(i) Accidents during erection. This applies particularly to the erection of masts, towers and antenna systems because of the hazardous nature of the work.

(j) Errors or omissions in the design which may become evident during the installation or testing stage.

Experience has shown that it is desirable to differentiate between the incidence of expenditure that is related to the manufacturing process of the materials, and the site erection. In this way the expenditure programme provides a better basis for highlighting unsatisfactory trends in specific areas of work manufacture and/or site erection, and avoids the need for arbitrary assessment of the proportion of the contract value that is associated with the site works activities.

A typical financial statement for an external plant contract that has been computer serviced is shown in *Table 6.2.* The statement is also useful as a basis for the determination and settlement of interim claims against the various manufacturing processes and erection activities. Adequate records should be maintained throughout the life of the contract so that the financial state of the contract is known at any time. All changes involving costs should be covered by variation or change orders which should preferably be authorised in advance of the work being carried out.

An examination of the extent to which variations or changes occurred in contract work was carried out by one organisation operating a large radiocommunication network and it was found that the number of variations was clearly related to the size of the project. However, as the projects became larger, the proportionate increase in the number of variations became less, but this did not mean that the cost of the variations became less. As a general rule it was found that the net value of variations was not usually a large proportion of the cost but this was not a direct indicator of the financial extent of the change. The gross value of variations showed a proportionately greater percentage of final cost as projects became larger.

From this it may be concluded that variations in large radio engineering projects are far more significant financially than might be expected if account is taken only of the number of variations. It is evident that particular care is justified to ensure that variations or changes are well controlled.

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Chapter 7

Internal Equipment Programmes

The nature of many radio engineering projects whether they be broadcast station, television station, radar station, earth satellite station or radio relay system necessarily involves the synthesis of many programmes. Therefore, in defining the specific programme requirements for an internal equipment contract such as a transmitter contract, consideration has to be given to identifying the interrelationships which may be involved with a number of these programmes, ensuring compatability in form and content with them.

In an internal equipment contract involving for example, several large broadcast transmitters, there may be at least eight basic phases leading to the commissioning of these transmitters:

(a) Tender evaluation and contract negotiation.
(b) Engineering design and planning.
(c) Information exchange.
(d) Parts procurement.
(e) Manufacture and assembly.
(f) Factory test and evaluation.
(g) Shipping and delivery to site.
(h) Installation and commissioning.

All these phases have to be considered sequentially. First, there must be a contract, then taking known measurements of the resources available in each phase, the impact which the load implicit in the contract will have on the resources must be assessed in relation to the existing loads and concurrent

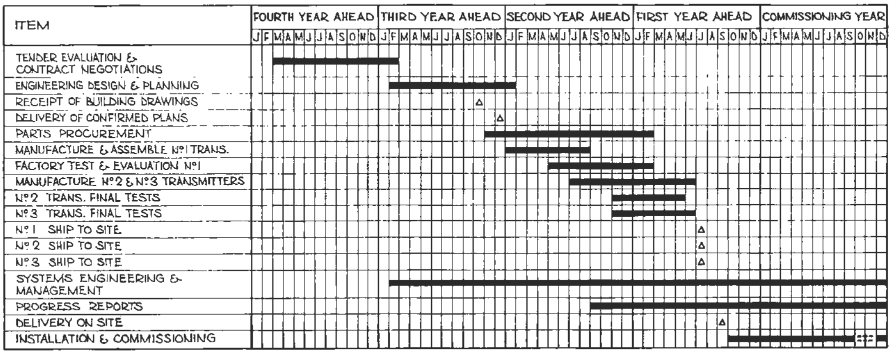


Figure 7.1 Principal phases involved in the provision and installation of a three transmitter project

commitments. From this, a viable programme can be established and at this point a project group may be allocated to the work. *Figure 7.1* shows the principal phases involved in the provision and installation of a new station project involving three 250 kW high frequency transmitters.

THE PROGRAMME

The programme represents a statement of mutual intention by the principal and the contractor. It furthermore commits both parties to a proposed sequence of activities and identifies to a specified time scale, terminal and intermediate events associated with these activities. In its presentation, therefore, it should consider three separate but inter-related situations.

(a) The requirements of the project to which it contributes.
(b) The availability of resources to sustain it.
(c) Its acceptability to management of both parties.

Some aspects of the programme can become critical because of limitations imposed by either of the first two conditions. In its basic concept, therefore, the programme must reflect the best knowledge of the conditions which might obtain throughout the life of the contract.

The programme offers a facility by which both general and/or discrete terms, depending upon specific requirements, can be measured because it identifies activities on a time scale and indicates an intention to achieve certain events by a predetermined time. It is possible therefore to use the programme to state a precise relationship between actual and planned achievement and to provide a basis for considering the implications of any deviation from the programme and the actions, if any, to be taken. If the significant events are clearly indicated, the programme by suitable control techniques can be used as an aid to management in focusing attention on the areas where decisions need to be made.

The objectives of any programme cannot be met unless all those participating are able to exercise satisfactory executive control in their separate areas of responsibility. The principal, the prime contractor and sub-contractors each must be capable of identifying their responsibilities and by appropriate management controls, influencing them in the way required. It is quite fallacious to assume that the act of identifying the existence of any activity, requirement or event, and subsequently regularly reviewing it by an electronic data processing facility is a substitute for basic planning and control of the associated resource requirement.

The need to understand the responsibility for a mangement control by those directly concerned with the contract is very important. Failure on their part to manage or control must prejudice the overall situation. No attempt by the control programme to identify and assume responsibility for the functions of the parties can be effective. The control programme is an aid to management and not a substitute for it.

Also, the management must understand the programme so that they can correctly interpret the meaning, significance and accuracy of the information provided. Unless they have this understanding they can make little or no contribution to further development of the system.

PROGRAMME CONTENT

The internal equipment programme must basically be tied into the project Master Programme. This Master Programme will be in network form with key events identified within the earliest/latest dates obtained from a critical path review of the programme. In essence, the key events of the internal equipment programme would have already been nominated when the project Master Programme was drawn up.

As a consequence an early requirement of the internal equipment programme is to identify these key events. For this purpose, it is desirable to retain the basic style of the programme as a network, with these events clearly identifiable, and supplementary events and associated activities defined to such a degree as to permit a critical review of the project Master Programme on a regular basis.

The main programme content can be listed as follows:

(a) Contract programme.

One of the major problems with contracts for many items of internal equipment, such as large transmitters, is lack of control of programme information at a sufficiently early stage in the life of the project, that is before and immediately after formal contract placing. When a tender is submitted, a programme in network form should be provided. The network should be time scheduled in order that recognition can be given to the best knowledge available of the impact on manufacturing resources during the life cycle of the contract.

Some contracts stipulate that within a given period, usually six weeks of formal contract, the contractor should endorse the tender programme as the contract programme. At this time, bearing in mind the possible lapse of time between submission of tender and contract placement, the activity time scheduling should be re-examined to take account of latest knowledge of the contractor's anticipated resource loading.

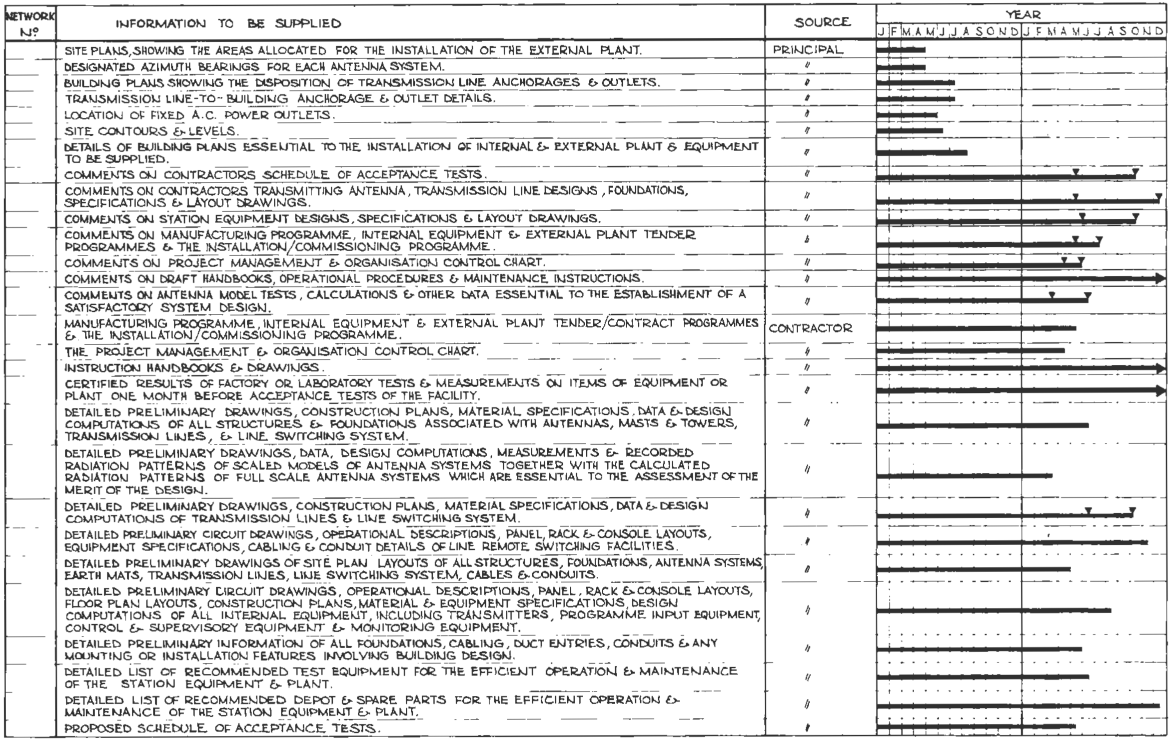
(b) Information exchange.

Practically every project carried out under contract requires the exchange of some information between principal and contractor. This applies particularly where the contract is of a supply/installation nature. In the case of a large transmitter supply and installation task, very close co-ordination is necessary between equipment design and building design staff.

Cardinal events which necessitate a decision on the part of the principal or the contractor should be properly identified in the programme. These events are those which immediately precede the preparation of manufacturing assembly or construction drawings and specifications, any delay in issue of which might affect the subsequent manufacturing assembly or construction processes.

Typical information such as floor loading, equipment dimensions, lead-through cutouts for ducts, transmission lines and cables, louvres, transmission line anchorages, room shielding and buried earth systems would be classified under this heading.

Figure 7.2 shows an information exchange schedule for one high frequency transmitting station involving both external plant and internal equipment activities.



NETWORK Nº	INFORMATION TO BE SUPPLIED	SOURCE
	SITE PLANS, SHOWING THE AREAS ALLOCATED FOR THE INSTALLATION OF THE EXTERNAL PLANT.	PRINCIPAL
	DESIGNATED AZIMUTH BEARINGS FOR EACH ANTENNA SYSTEM.	"
	BUILDING PLANS SHOWING THE DISPOSITION OF TRANSMISSION LINE ANCHORAGES & OUTLETS.	"
	TRANSMISSION LINE-TO-BUILDING ANCHORAGE & OUTLET DETAILS.	"
	LOCATION OF FIXED A.C. POWER OUTLETS.	"
	SITE CONTOURS & LEVELS.	"
	DETAILS OF BUILDING PLANS ESSENTIAL TO THE INSTALLATION OF INTERNAL & EXTERNAL PLANT & EQUIPMENT TO BE SUPPLIED.	"
	COMMENTS ON CONTRACTORS SCHEDULE OF ACCEPTANCE TESTS.	"
	COMMENTS ON CONTRACTORS TRANSMITTING ANTENNA, TRANSMISSION LINE DESIGNS, FOUNDATIONS, SPECIFICATIONS & LAYOUT DRAWINGS.	"
	COMMENTS ON STATION EQUIPMENT DESIGNS, SPECIFICATIONS & LAYOUT DRAWINGS.	"
	COMMENTS ON MANUFACTURING PROGRAMME, INTERNAL EQUIPMENT & EXTERNAL PLANT TENDER PROGRAMMES & THE INSTALLATION/COMMISSIONING PROGRAMME.	"
	COMMENTS ON PROJECT MANAGEMENT & ORGANISATION CONTROL CHART.	"
	COMMENTS ON DRAFT HANDBOOKS, OPERATIONAL PROCEDURES & MAINTENANCE INSTRUCTIONS.	"
	COMMENTS ON ANTENNA MODEL TESTS, CALCULATIONS & OTHER DATA ESSENTIAL TO THE ESTABLISHMENT OF A SATISFACTORY SYSTEM DESIGN.	"
	MANUFACTURING PROGRAMME, INTERNAL EQUIPMENT & EXTERNAL PLANT TENDER/CONTRACT PROGRAMMES & THE INSTALLATION/COMMISSIONING PROGRAMME.	CONTRACTOR
	THE PROJECT MANAGEMENT & ORGANISATION CONTROL CHART.	"
	INSTRUCTION HANDBOOKS & DRAWINGS.	"
	CERTIFIED RESULTS OF FACTORY OR LABORATORY TESTS & MEASUREMENTS ON ITEMS OF EQUIPMENT OR PLANT ONE MONTH BEFORE ACCEPTANCE TESTS OF THE FACILITY.	"
	DETAILED PRELIMINARY DRAWINGS, CONSTRUCTION PLANS, MATERIAL SPECIFICATIONS, DATA & DESIGN COMPUTATIONS OF ALL STRUCTURES & FOUNDATIONS ASSOCIATED WITH ANTENNAS, MASTS & TOWERS, TRANSMISSION LINES, & LINE SWITCHING SYSTEM.	"
	DETAILED PRELIMINARY DRAWINGS, DATA, DESIGN COMPUTATIONS, MEASUREMENTS & RECORDED RADIATION PATTERNS OF SCALED MODELS OF ANTENNA SYSTEMS TOGETHER WITH THE CALCULATED RADIATION PATTERNS OF FULL SCALE ANTENNA SYSTEMS WHICH ARE ESSENTIAL TO THE ASSESSMENT OF THE MERIT OF THE DESIGN.	"
	DETAILED PRELIMINARY DRAWINGS, CONSTRUCTION PLANS, MATERIAL SPECIFICATIONS, DATA & DESIGN COMPUTATIONS OF TRANSMISSION LINES & LINE SWITCHING SYSTEM.	"
	DETAILED PRELIMINARY CIRCUIT DRAWINGS, OPERATIONAL DESCRIPTIONS, PANEL, RACK & CONSOLE LAYOUTS, EQUIPMENT SPECIFICATIONS, CABLING & CONDUIT DETAILS OF LINE REMOTE SWITCHING FACILITIES.	"
	DETAILED PRELIMINARY DRAWINGS OF SITE PLAN LAYOUTS OF ALL STRUCTURES, FOUNDATIONS, ANTENNA SYSTEMS, EARTH MATS, TRANSMISSION LINES, LINE SWITCHING SYSTEM, CABLES & CONDUITS.	"
	DETAILED PRELIMINARY CIRCUIT DRAWINGS, OPERATIONAL DESCRIPTIONS, PANEL, RACK & CONSOLE LAYOUTS, FLOOR PLAN LAYOUTS, CONSTRUCTION PLANS, MATERIAL & EQUIPMENT SPECIFICATIONS, DESIGN COMPUTATIONS OF ALL INTERNAL EQUIPMENT, INCLUDING TRANSMITTERS, PROGRAMME INPUT EQUIPMENT, CONTROL & SUPERVISORY EQUIPMENT & MONITORING EQUIPMENT.	"
	DETAILED PRELIMINARY INFORMATION OF ALL FOUNDATIONS, CABLING, DUCT ENTRIES, CONDUITS & ANY MOUNTING OR INSTALLATION FEATURES INVOLVING BUILDING DESIGN.	"
	DETAILED LIST OF RECOMMENDED TEST EQUIPMENT FOR THE EFFICIENT OPERATION & MAINTENANCE OF THE STATION EQUIPMENT & PLANT.	"
	DETAILED LIST OF RECOMMENDED DEPOT & SPARE PARTS FOR THE EFFICIENT OPERATION & MAINTENANCE OF THE STATION EQUIPMENT & PLANT.	"
	PROPOSED SCHEDULE OF ACCEPTANCE TESTS.	"

Figure 7.2 Information exchange schedule for high frequency transmitting station

The information exchange process is also important in the tender preparation stage. The latest dates in advance of the tender shedule for receipt of information which will be used in producing schedule drawing etc. must be agreed in detail. In some cases these dates may be as much as four months prior to the programmed tender schedule issue dates. It is important that the period should be no longer than is absolutely necessary, so that the works as subsequently detailed, do not differ more than is unavoidable from those specified in the schedule.

(c) Manufacturing.

Whilst there is a strong bias in favour of producing manufacturing programmes in network form, many manufacturers for various reasons still favour the bar chart form. However, the bar chart should be presented in such a way as to indentify, as clearly as possible, the work content with available resources. For a 250 kW medium frequency broadcast transmitter, a typical bar chart would generally set out the manufacturing or supply details of the following:

Radio frequency equipment
Audio frequency equipment
Modulation equipment
Rectifiers
h.t. smoothing filter chains
l.t. distribution switchboard
Power supply equipment
Cooling plant, including ductwork and filters
Control and supervisory equipment
Cables and guarding screens
Internal feeder lines and assemblies
Operational tubes and vacuum capacitors
Installation materials
Optional accessory materials
Spare tubes and vacuum capacitors
Depot and unit spares
Test equipment

Table 7.1 shows a material component listing for the manufacturing programme of one transmitter while *Table 7.2* shows a listing for the internal equipment of a tropospheric scatter system using quadruple diversity and employing two unattended repeater stations.

The bar chart should develop in detail the manufacturing and supply activities in the contract network and act as a link between the information exchange schedule and the detailed installation/commissioning network being serviced by the former and servicing the latter. Computer output of the delivery intention progress report produced subsequent to updating the manufacturing programme is used to update the start events of the manufacturing programme. For the monitoring procedure to be successful it is necessary that the data transfer events in all the programmes be compatible and identifiable with one another. This data transfer procedure is shown diagrammatically in *Figure 7.3*.

(d) Installation and commissioning.

The installation and commissioning network should be identified with the installation portion of the main contract network and should be compatible

Table 7.1 MATERIAL COMPONENT LISTING FOR HIGH POWER TRANSMITTER MANUFACTURING PROGRAMME

Radio frequency equipment
- Transistorised crystal oscillators
- Oscillator selector panel
- Fuse panel
- Broadband r.f. amplifier
- Tuned r.f. preliminary amplifier
- R.f. intermediate amplifier stage
- Voltage divider
- R.f. driver stage
- R.f. final stage
- R.f. output circuit

Audio frequency equipment
- A.f. preliminary stages
- A.f. final stage

Modulation equipment
- Modulation transformer
- Modulation reactor
- Blocking capacitor
- Lightning arrestor
- Premodulation network

Cooling plant
- Heat exchanger, air-vapour with blower units
- Distilled water storage tank
- Water level indicating device
- Cabinet ventilation fans
- Blowers for tube head ventilation
- Air louvre control device
- Pipes, valves, fittings and misc. items
- Water purifier

Control and supervisory equipment
- Fault signalling panel
- Control panel for switching steps
- Control relays and breakers
- Transmitter instrumentation
- Modulation supervisory panel
- Programme input control equipment

Cables and guarding screens
- Complete set for transmitter installation

Internal feeder lines
- Complete set with corresponding building outlet for transmitter installation

Rectifiers
- Main high tension rectifier
- Control units for grid controlled rectifier
- Backfire counters
- Switchboard
- Auxiliary high tension rectifier
- Bias rectifier

h.t. smoothing filter chains
- Smoothing chokes
- Smoothing capacitors
- Crow-bar protection
- Ripple damping equipment
- Earthing switch

l.t. distribution switchboard
- Circuit breaker
- Distribution contactors and fuses

Power supply
- Induction voltage regulator
- Main circuit breaker
- Plate transformer
- Current transformer
- Auxiliaries power supply

Operational tubes
- Complete set of tubes and vacuum capacitors for all transmitter sockets

Installation materials
- Set of cabling and wiring materials for transmitter compartment
- Set of cabling and wiring for interconnecting the transmitter compartment, modulation equipment, h.t. rectifier, smoothing filters, power supply circuits and the transmitter cooling and ventilation plant
- Set of installation materials and bushbars for modulation equipment cells
- Set of cable trays

Optional accessory materials
- Dummy load complete with pumps and heat exchanger
- Water purifier
- Tube trolley

Depot and unit spares
- Complete set

Spare tubes and vacuum capacitors
- Complete set

Test equipment
- Complete set

Table 7.2 MATERIAL COMPONENT LISTING FOR TROPOSPHERIC SCATTER SYSTEM INTERNAL EQUIPMENT MANUFACTURING PROGRAMME

Equipment	*Terminal A*	*Repeater No. 1*	*Repeater No. 2*	*Terminal B*	*Total*
Transmitters and receivers					
1 kW power amplifier	2 bays	4 bays	4 bays	2 bays	12 bays
Modulator	1 bay	2 "	2 "	1 bay	6 "
Exciter	1 "	2 "	2 "	1 "	6 "
Low noise amplifier	2 bays	4 "	4 "	2 bays	12 "
Receiver	2 "	4 "	4 "	2 "	12 "
Baseband combiner	1 bay	2 "	2 "	1 bay	6 "
Order wire equipment	1 "	2 "	2 "	1 "	6 "
Filters and feeders					
Bandpass filter	2 units	4 units	4 units	2 units	12 units
Dual bandpass filter	2 "	4 "	4 "	2 "	12 "
Coaxial cable	4 lots	8 lots	8 lots	4 lots	24 lots
Dehydrator	1 unit	1 unit	1 unit	1 unit	4 units
Spare parts					
Consumable spares	1 lot	1 lot	1 lot	1 lot	4 lots
Depot spares	1 "			1 "	2 "
Spare klystron	1 tube			1 tube	2 tubes
Spare panel	1 lot			1 lot	2 lots
Test equipment					
Test equipment	1 set			1 set	2 sets
1 kW dummy load	1 unit			1 unit	2 units
Installation material					
Complete set	1 lot	1 lot	1 lot	1 lot	4 lots

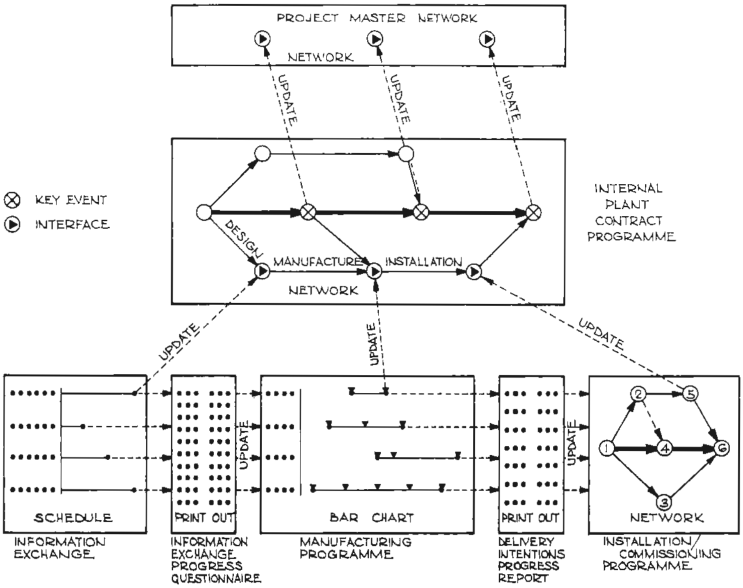


Figure 7.3 Data transfer procedure diagram

with the manufacturing programme which may be in bar chart form. The optimum installation and commissioning programme does not necessarily fit the optimum manufacturing programme and close co-ordination is required to produce the best overall solution. It is not possible to fix every activity in detail before installation commences and some flexibility must be allowed to take account of changes in the design and manufacturing stages.

For a turnkey contract, the commissioning of the system would be included as part of the work to be carried out under the contract. The contractor would have to prove to the satisfaction of the principal that the system fully meets the specification. This is of particular advantage when a complete system or station such as an earth satellite station is being supplied by the contractor. In other cases the contractor may only supply the equipment, with the principal installing and commissioning same. Where the contract stipulates that the acceptance testing is to be carried out after installation rather than in the factory or works, the contractor will often have a representative on site to observe the tests. For a new type of complex installation, such as a fully automated station complex, there may be advantage in having the contractor supervise or assist in the installation and commissioning tests, and also to train the station staff in the operation and maintenance of the equipment.

DUCTWORK, CONDUIT AND CABLING

Ideally the ducts, conduit, cableways and cabling associated with the radio equipment should be fully engineered before the building design has hardened up. In practice this is often not feasible and provision for transmission lines, transmitter air ducts, steam and water pipes, cable runways etc. are matters dependent upon experience, extrapolation of past schemes and consideration of the differences in the current schemes. Collection of the data necessary to compile duct and conduit sizes, support attachments, lead-through holes, cable schematics, routing diagram schedules, steelwork design etc. represents a continuing process of considerable magnitude. Works should be planned with sequential relationship in mind. The installation of inter-room and inter-building conduits should precede the installation of the pits and manholes, the installation of anchoring devices should precede the installation of cableways and transmission lines, the installation of screening or earthing grids in the floor should precede the placement of floor concrete topping, and so forth.

The actual installation of these facilities has to be squeezed into the period from when it becomes physically possible to start the work and complete it before commissioning is required to start. In the case of air duct systems, it is desirable to have all the main overhead work completed before the major equipment units like modulator and r.f. units are moved into place. For some interconnecting conduits required for cable and wire protection, the work cannot be commenced however until equipment has been located in its permanent position. The rate and sequence at which information becomes available for incorporation into design of runs, layout, schedules, block schematics etc., while not entirely fortuitous are often extremely difficult to control and sometimes, particularly in the case of cables, consists of a long series of approximations involving many modifications to diagrams etc. Methods of keeping this under control and ensuring, for instance, that a modification to one factor is reflected through the whole system, have not been entirely successful where they depend upon hand dressing of the programme and some form of mechanical checking and presentation of control data may sometimes be necessary.

Computer programs using punched cards have been introduced in some large installations in an attempt to save manpower and impose the requisite control. Refinements of a basic system are in use by at least one organisation and provide increased flexibility together with a facility for accommodating modifications. The prime requirement is for design information to be made available at as early a stage as possible and in a form which is less subject to subsequent modification. The effective programming of this information alleviates the many difficulties encountered in building ductwork, conduit and cable works.

AUXILIARY EQUIPMENT

Contracts for auxiliary equipment frequently become critical delaying factors in the later stages of a project completion, because the equipment is essential in the commissioning of the main equipment installation. Typical auxiliary equipment associated with a high power transmitter is shown in *Figure 7.4.*

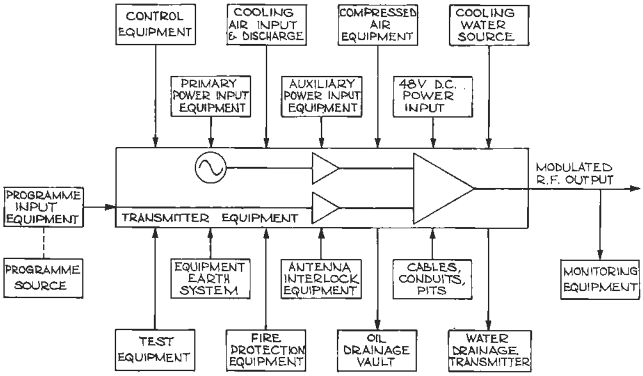


Figure 7.4 Auxiliary equipment for a high power transmitter

An examination of the restraints imposed on auxiliary equipment shows that there is no basic incompatability between a valid theoretical programme for the design, manufacture and installation of auxiliary equipment contracts and the requirements of the overall project programme of which these contracts form a part. However, experience has demonstrated that many auxiliary equipment contracts fail to achieve programme completion dates, even though the contract programme is soundly based. The trouble is largely due to non-achievement of the programme requirements in the design release stages of the contract.

From the aspect of programming auxiliary equipment work, the design of this auxiliary equipment is frequently dependent upon the detail and characteristics of the main equipment. The release of this information is the starting point for the engineering of much of the auxiliary equipment. The limiting factor is in many instances not the production or manufacture of the hardware but the finalisation of information and approval of details.

The information required for the completion of specifications for some auxiliary equipment items can be classified into two separate areas. There is on the one hand that part of the specification for the equipment which is entirely within the control of the engineer in charge of the contract and, on the other hand, there is an area in which the engineer is dependent to a very large extent upon information from other contracts including those associated with buildings, in carrying out his design work.

In many radio engineering installations where the same classes of equipment are involved, some degree of standardisation of auxiliary equipment can be made. This has consequent programme advantage and savings in time and engineering effort. If this is done it is often possible to specify firm information at the schedule stage and this will allow the contractor, immediately he is appointed, to proceed with the preparation of manufacturing drawings or to initiate supply arrangements.

The second area of design—that which is dependent upon information from others—produces difficulties which are not easily soluble by the standardisation approach. In some cases the problem can be solved by the physical elimination of the plant or work which it affects. An outstanding example of this has been the recent approach to vault equipment for high power transmitter equipment. Until recently a separate room was required for the installation of this vault equipment, the air scavenging plant, cables, conduits, busbars and safety fences. This arrangement which required close liaison with architects, electrical, civil and mechanical engineers and others, and which often resulted in considerable delays in design releases, has now been changed to an almost complete factory installation. The equipment is mounted in factory wired metal clad units with throat connected transformers. The equipment does not require building provision other than a concrete base. Safety fences have been eliminated because all exposed conductors are mounted within the safety interlocked metal clad enclosures.

A superficial reaction to this approach could well be that it amounts only to the transfer of the major information problem from one contract to another. However, by so doing the installation is freed from its chief design restraint. Furthermore, the equipment can be tailor made in the factory and an analysis of recent installations has shown considerable overall saving in contract time.

A major difficulty in the installation of auxiliary equipment is the availability of building access. The access period will in many cases cover the entire building project period. For instance in the case of a transmitter installation, the installation of the equipment earthing grid system may commence immediately the building is pegged out and continue well into the building construction stages. Fire protection equipment may be installed immediately the building is available and before equipment is moved into the area, programme input equipment may be installed in parallel with the transmitter, and antenna interlock equipment may be installed after the transmitter has been tested into the dummy load but before loading into the antenna system.

Compared with the major equipment, the time required for the installation of auxiliary equipment items is not very great. The limiting factor is not only access periods but also the time required to complete such works as cabling, conduit fixing, termination and acceptance testing. Access to areas and other equipment is required at the earliest opportunity, compatible with the safety of the equipment from accidental damage resulting from the main equipment installation activities.

Firm milestones in the main equipment installation programme are required, with adequate updating of progress throughout the installation, to give an accurate and realistic forecast of the access that is available to the auxiliary equipment contractors. From general considerations, the date at which the main equipment cubicles are laid on their plinth positions is the earliest starting point for some auxiliary equipment item installations such as conduits, cable trays, air duct systems, although work in some sections may commence earlier. It is necessary to programme in detail the access to the various equipment cubicles, areas and connection points that are available before the main equipment is set on the plinths. The installation of the main equipment itself would then follow the substantial completion of the various sections.

The main equipment contractor should indicate the priorities required for meeting the transmitter check-out date and phase the completion of the sections of the equipment to permit reasonable economy in manpower. Some auxiliary equipment contractors are entirely dependent on the access given at this stage of the work and require adequate time to properly complete their task. It is essential that the main contractor is fully aware of the auxiliary equipment requirements in the installation and commissioning programme, and after general starting dates have been agreed, the access position should be reviewed systematically and information released to auxiliary equipment contractors, at the earliest opportunity. When the main contractor has also the contract for the auxiliary equipment, co-ordination of the access work is simplified considerably.

ACTIVITY DURATIONS

The servicing of a contract based programme is not a simple matter. It requires careful thought and preparation and a clear understanding of the need to translate data from one environment (resource orientated) to another environment (contract orientated). Reference was made earlier to the manner in which the contract programme is developed from the key events of the project Master Programme and the way in which this is influenced by best and latest knowledge of the contractor's resource loading at the time of programme preparation.

It is necessary to recognise that the purpose for which the contract programme is produced excludes by implication its use as an executive control device. Programmes for executive control are necessarily much more explicit in detail and call for frequent review. In the preparation of the contract programme, therefore, the information scheduled should be capable of identification with whatever form of authoritative manufacturing control the contractor exercises. The manufacturing programme should be in sufficient detail to facilitate the regular production of realistic progress reports. Therefore in compiling the programme, careful consideration should be given to activity durations. Experience has shown that durations should not exceed about 12 weeks and wherever necessary arbitrary check points should be intruded to achieve this condition. Also, there is need to achieve a close relationship between the relevant sections of the contract suggested for physical control and those defined for financial control because of the principles inherent in the contract payment conditions.

Payment is often made on the basis of the equipment or plant manufactured and work executed, and so it may be necessary to intrude an arbitrary control event into a long manufacturing process for the purpose of ensuring that this condition is fulfilled.

FURTHER READING

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Chapter 8

Site Installation and Construction

The concept of site joint planning, which involves bringing all the individual contracts of a project together in planning on site, is a desirable organisational procedure for control of major projects such as broadcast, television, earth satellite, radar or tropospheric scatter stations or long haul broadband microwave radio relay systems. Essentially, the success depends upon the effectiveness with which separate plant and equipment is integrated, and work forecasts are implemented. What is required is a plan in a time-based network form with the minimum of detail but with events which are basic to the whole installation being shown. Each event must be such as to display all contract interfacing.

It is necessary that all contractors be made aware of the total scheme at the tender schedule stage, and to provide the necessary information it is usual to prepare a complete time based network. This network is prepared at the planning stage of the installation and commissioning phases of the project, and should be produced as soon as possible after the project becomes firm. The information supplied with the tender schedule documents would include this network but with the time base deleted and the particular activity associated with the schedule being emphasised by a double line. This gives the tenderer and contractor a full appreciation of the integration of his work into the total project without revealing, at that stage, any margins which might become available at a later stage. In order to define the contractor's interfacing with parallel works, critical dates would be given and thereafter he would be required to develop a detail network within these previously defined parameters. *Figure 8.1* shows a typical time-based installation network for a long haul microwave radio relay system. The network which would be included in the tender schedule would be similar to this drawing with the exception that the time base would be deleted, the critical path would not be shown and the activity covered in the schedule would be highlighted with a double line.

One of the functions of the installation network is to give a basis for overall monitoring of the site (or sites) progress to project group headquarters. Detailed networks would be used for site planning and monitoring. The preferred method of updating the site installation network is hand dressing on a day-to-day basis if necessary, using a computer only for long period total project up-dating at project headquarters for higher level management.

Experience with many radio engineering installation and construction projects has indicated that delays for several reasons affect about 25% of those items on the critical path of the network. That is, 75% of the delays are related to those items not on the critical path with the delay often being absorbed in the float time. One of the problems of project control is in keeping check on functions and items which may be involved in delays, and regular job check-ups may be necessary. In order to keep a network up to date, a considerable amount of

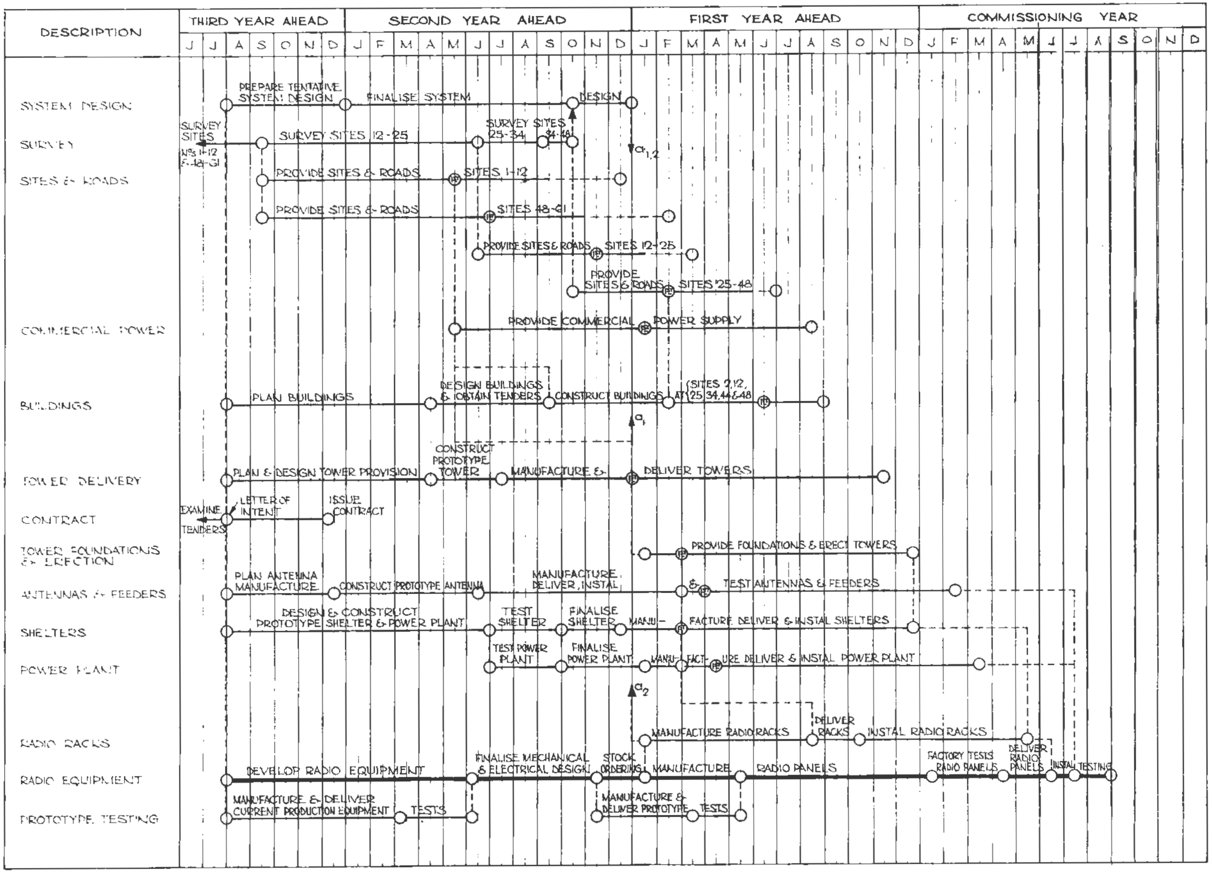

Figure 8.1 Time based installation network for long haul microwave radio relay system

background data has to be obtained and a properly organised process of communication has to be implemented to channel vital statistical information through the various levels of management and particularly to those directly responsible for the project control.

COMMISSIONING

Commissioning of the station or system to the on-air stage is regarded as part of the site installation and construction works, and is included in the plan. The commissioning phase of many projects covers a very wide area of the radio engineering field and thus necessitates a thorough understanding of many practical and theoretical considerations. The form which station or system commissioning programmes take is a study in itself, and it does not by any means suggest that network planning is the ideal. Again, this is work in which all aspects must be closely co-ordinated and the overall plan may well be best displayed in the network form supported by bar charts, schedules, etc. The outline of the commissioning programme should be developed as early as possible in order to better finalise the installation details.

Because of problems associated with the commissioning of many large scale and complex radio engineering projects some organisations provide a commissioning engineer with responsibility for putting the station or system on air. He is usually under the control of the project manager who has the dual responsibility for ensuring satisfactory installation and commissioning of the project.

For a large project and particularly where several contractors or sub-contractors are involved a sub-network or other suitable control diagram should be prepared to comply with main programme requirements to facilitate control of this end of the installation period. The main programme will have catered for the significant activities in the commissioning phase of the work and as various contractors requirements have been established at site the main programme will have been updated to accommodate new requirements. However it will frequently be found that the optimum conduct of the project at this time will be enhanced not only by progressive testing and commissioning but also by arranging such work in a dovetailing sequence between the various contractors. In some situations consideration may have to be given to even temporary supply of some services if the permanent services cannot be provided by the time required. On one project, completion of the station 210 m antenna was delayed because of wet weather and in order to allow the contractor to proceed with testing of the high power transmitter a temporary liquid type dummy load was set up.

In formulating the commissioning procedures and preparations of the station or system for handover the staff responsible for the subsequent operation should be given the opportunity to familiarise themselves with the equipment as early as practicable. In most situations it is appropriate for such staff to act initially in an installation capacity where it is installed by the principal. For a turnkey project, operational and maintenance training would usually form part of the contract requirements.

Proper documentation for operating and maintenance staff is essential at the handover stage. At the specification stage it should be practical to indicate the extent of maintenance information required on each item of plant, the manner in which it is to be presented and the detail drawings, parts lists and other relevant matters which are required for each item. Similar requirements for the station or equipment operation should also be indicated particularly for operating instructions covering a group of individual items and their interlocking. This applies particularly to such arrangements as transmitters/antenna switching system, mains/standby power plant, main/protection radio relay links and main/standby transmitter installations. The collection and preparation of preliminary operating and maintenance information should commence early enough to suit the handover.

INSTALLATION STAFF

The installation and commissioning of relatively small projects may be carried out by a single team of skilled specialists each familiar with the essential features of the project. However, for a large project, teams of specialists such as riggers, electricians, diesel mechanics, radio technicians, welders, ironworkers etc. may be involved in the installation and commissioning of various phases of the work. These specialist groups would each work to a schedule prepared to expedite the work but to minimise interference with the other groups. The ideal arrangement is for one group to move in to the work, followed in succession by the other groups. Experience has shown that on a large project the employment of the proper trades group for each class of work is the most satisfactory arrangement and in the end is more economical than the employment of radio technicians to carry out all of the work. However, in many situations, particularly in isolated areas, skilled tradesmen may be non-existent and in these cases the maximum possible amount of work should be prefabricated in the factory.

SITE INSPECTIONS

The site and its associated problems require perhaps the greatest personal effort in understanding and resolve between those charged with the various responsibilities of supervision and erection. The best planned programmes do not show when material and labour difficulties will occur, when accidents will happen, when disputes will arise or when bad weather will disrupt the work. The optimum conduct of the work at the site frequently requires as much planning, preparation and control again as has already gone into the project to date.

Periodic visits to the installation and construction site or sites are often made by headquarters staff in order to audit the programme. An on-the-spot review of progress of the project is made and the general status of the work is compared with the schedule and discussed with the key project supervisory staff. Headquarters assistance may be offered to the site engineer to push particular phases of the project that may be held up in such areas as material procurement, drafting, mechanical aid hire, extension of sub-contracts etc. Also, suggestions will most likely be made and discussed with the field organisation as to how the work progress can be improved.

On site discussions between field staff and headquarters staff are an important part of successful project engineering. Alternative solutions to particular problems may be reviewed, ideas exchanged and understanding reached by both the headquarters representatives and the field staff. This also equips both to handle a particular problem more effectively. The site inspection of the work progress is also an opportunity for a general interchange of ideas and techniques being used successfully or sometimes unsuccessfully on other current installation and construction works.

Another factor is that problems associated with interfacing of various types of equipment or components may first become evident on site. It is often found that satisfactory equipment or components do not necessarily produce a satisfactory total system. In a complex system it may be found that even though individual equipments and components satisfy all the specifications set down, the system as a whole will not work satisfactorily or meet the overall specifications. The satisfactory handling of these types of problems can best be carried out by detailed site studies by headquarters and site staff as a joint effort.

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Chapter 9

PERT/Cost Techniques

The PERT/Cost system is an extension of the PERT/Time technique. It is primarily the addition of cost analysis and control procedures to PERT but also includes recommended methods of carrying out analyses of manpower requirements for the work situation. Its objective is to develop a plan of action for cost expenditures by application of cost-estimating techniques and to act as a monitor in the control of the original estimate.

The PERT/Cost system is primarily concerned with the one-time-through programmes such as a station construction or a system installation, rather than the repetitive manufacturing situation, such as amplifier or television set production, where costs are closely allied with the number of items manufactured. The inbuilt selective reporting system enables each level of project management to compare the current cost progress with the future cost predictions, in so far as it relates to his responsibilities. The information is presented in a decision-making form and the manager does not have to review detailed data in order to evaluate the status of the programme under examination.

The main features of the system can be summarised as follows:

(a) The project work breakdown structure.
The important aspect of this is that it provides the framework for gathering data concerning costs and schedule status for the various levels of management-information that is required for the project control.

(b) Work package concept at the lowest level of detail and cost totals for each work package.
The work packages are obtained by breaking down the network into single activities such as panels, feeders, tower etc. or in some work, into groups of activities. The work packages are the basic units by which actual costs are collected and compared with estimates for project control purposes. *Figure 9.1* shows how the work packages are derived from the end items subdivisions which in turn are derived from the project end item. Each task is selected to be small enough to be considered as a complete entity for estimating purposes but at the same time is large enough to represent a measurable part of the whole project. In this particular example, the project end item is a television station. The extent to which the end items are subdivided depends on the amount of detail required for control purposes. In some cases they may be determined on a cost basis, or on a period basis such as 3 months or more.

(c) A manhour analysis of the project requirements.
It allows a check to be made on whether the best use is being made of the resources as planned and available for the work.

(d) Integration of the expenditure and actual progress of the project work.

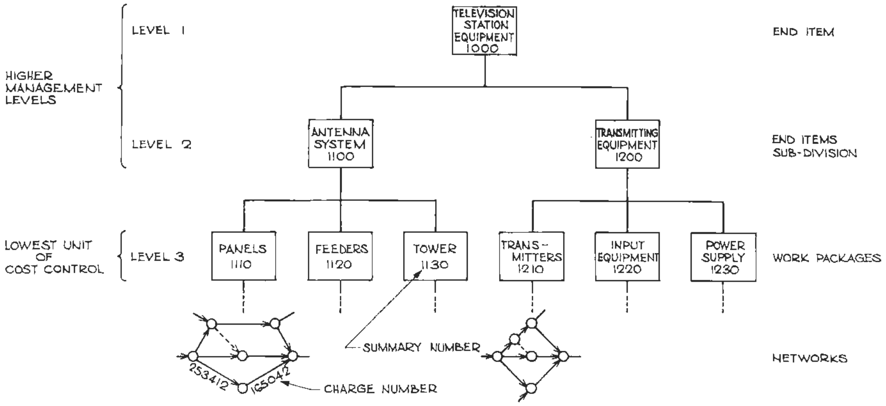


Figure 9.1 Project breakdown structure for television station equipment and plant

(e) Reporting on the forecast completion costs of the project.
It allows an assessment to be made on whether the outstanding part of the work to complete the project can be carried out in accordance with the estimate and the extent of any variation from the estimate.

The PERT/Cost technique provides management with vital project information which they would not otherwise be able to readily obtain. It has the flexibility to provide the vital measures to any depth and degree the schedule can accommodate. What is very important is that through its coupled cost and schedule mechanisms, it gives the type of information which is both most significant to the project work and most relevant for management action. However, it does not serve as a substitute for knowledgeable project managers. It does not solve the problem it reveals. Reliability of inputs depends on the knowledge and integrity of engineers, planners and estimators. It is obvious that techniques alone cannot make decisions and take action but it does clearly indicate where control is needed, and in time, to permit effective action. However, an important factor is that the usefulness of the technique for management action depends on top management understanding and supporting the system.

MANAGEMENT REPORTS

The various reports associated with the PERT/Cost system must be co-ordinated in order to provide a unified procedure for the presentation of decision information. The main reports used in the management of major radio engineering projects are:

(a) The management summary report.
This report sets out the overall schedule and cost position of the project as a whole for various levels of management, and also the major items or sections of the project. In this way the problem areas requiring attention are highlighted by showing the relative contribution of each of the major items or sections. A typical level 2/3 management summary report is shown in *Figure*

MANAGEMENT SUMMARY REPORT		
PROJECT :- BROADCASTING STATION COMPLEX	REPORTING ORGANISATION :- ABZ BROADCASTING CORPORATION	REPORTING PERIOD :- TOTAL PROGRAMME
LEVEL/SUMMARY ITEM :- 2 / INTERNAL EQUIPMENT 12200	CONTRACT NUMBER :- 423456	DATE OF THIS REPORT :- 31-1-75

MAJOR ITEM OR SECTION	COST OF WORK £ x 1000						SCHEDULE														COMMENTS
	ORIGINAL ESTIMATE	ACTUAL COST TO DATE	COST OVER EXPEND. OR (UNDER EXPEND)	CONTRACT ESTIMATE	REVISED TOTAL COMPLETION ESTIMATE	PREDICTED COMPLETION OVER EXPEND. OR (UNDER EXPEND)	Δ = SCHEDULED COMPLETION DATE OF TOTAL ITEM E = EARLIEST FINISH DATE OF } MOST L = LATEST FINISH DATE OF } CRITICAL ELEMENT													MOST CRITICAL SLACK (WEEKS)	S = SCHEDULE SLIPPAGE O = COST OVER EXPENDITURE U = COST UNDER EXPENDITURE
							1975												DAY		
							J	F	M	A	M	J	J	A	S	O	N	D			
INTERNAL EQUIPMENT LEVEL 2 12200	1285	1385	100	2065	2175	110										L Δ		E	20 15	− 6·0	1. TRANSMITTERS (S.O) 2. AUXILIARY EQUIPMENT (O)
TRANSMITTERS LEVEL 3 12210	1100	1200	100	1500	1600	100					L	E			Δ				15 15	− 6·0	1. VAULT EQUIPMENT (S.O) 2. DUCT WORK (O)
PROGRAMME INPUT EQUIPMENT LEVEL 3 12220	35	40	5	65	70	5			E			L Δ							30 15	8·0	1. JACKFIELD & RELAY SETS (O)
AUXILIARY EQUIPMENT LEVEL 3 12230	70	78	8	100	115	15		E	L						Δ				15 02	2·0	1. AIR COMPRESSOR (O)
EMERGENCY POWER GENERATORS LEVEL 3 12240	40	40	0	110	110	0									L Δ	E			30 15	− 6·0	
TEST EQUIP. LEVEL 3 12250	10	12	2	70	75	5				E	L Δ								15 30	5·0	1 WAVE FORM ANALYSER (O)
SPARE PARTS LEVEL 3 12260	30	15	(15)	220	205	(15)	TIME NOW								E	L Δ			30 30	3·0	1. SCREEN TRANSFORMER (U)

Figure 9.2 PERT/Cost management summary report

9.2. This report presents a complete picture of the status at time of reporting of the internal equipment which comprised a multi transmitter installation.

In a typical situation, the top level report, level 1, may cover the complete broadcast station complex comprising external plant, internal plant, buildings, civil engineering site works such as roads, drainage, clearing etc. and also design work if this is part of the project activity. The level 2 report may deal with the main items of the complex, such as internal plant, etc., level 3 with the sub-items, such as transmitters, etc., and level 4 with the work packages, such as control desks, etc.

The level 3 report in this case shows that internal equipment will be six weeks behind schedule at the end of January. It has already been over expended to the extent of £100 000, and is expected to reach £110 000 by the end of the period. The transmitters and emergency generating plant are responsible for the delay and the transmitters are also the main cause for the excess cost, whereas the total spare parts to be provided, are running below the estimated cost. The programme input equipment is ahead of schedule so there may be a case for transferring effort from programme input activity to transmitters or emergency generating plant.

In summary, the management summary report provides each level of management with information in regard to the following:

(i) Cost analysis of the estimated cost of the work compared with the actual cost incurred at the time of preparation of the report.
(ii) Forecast of the final cost of the project work compared with the estimated cost.
(iii) The forecasted completion dates of the major items and sections of the work and of the probject as a whole.
(iv) Identification of factors causing delays, deviations or cost variations which may require management action.

Management summary reports are an important feature of radio engineering management, but this does not mean that detailed written reports are unnecessary. These together with the summary reports need to be prepared when contracts are in debt and management require detailed explanation.

(b) Manpower report.

The manpower report supplements the management summary report by revealing the manpower loading situations for the project. *Figure 9.3* shows a manpower loading diagram covering a twelve month period of a project for the installation of the external plant of a broadcast station at a tropical location where seasonal wet weather conditions limit field activities from about January to March each year. The wide variations in manpower required from month to month for the work is undesirable and it is quite likely that the peak manpower requirements may exceed the manpower availability, particularly in a remote area.

The manpower loading diagram will show the total requirements for manpower for work, while the manpower report will show the allocation of manpower to the various work packages or groups of activities. This report provides management with information to assist in smoothing out and balancing idle manpower so as to make more efficient use of the available manpower resources. There would however, in the particular example, be

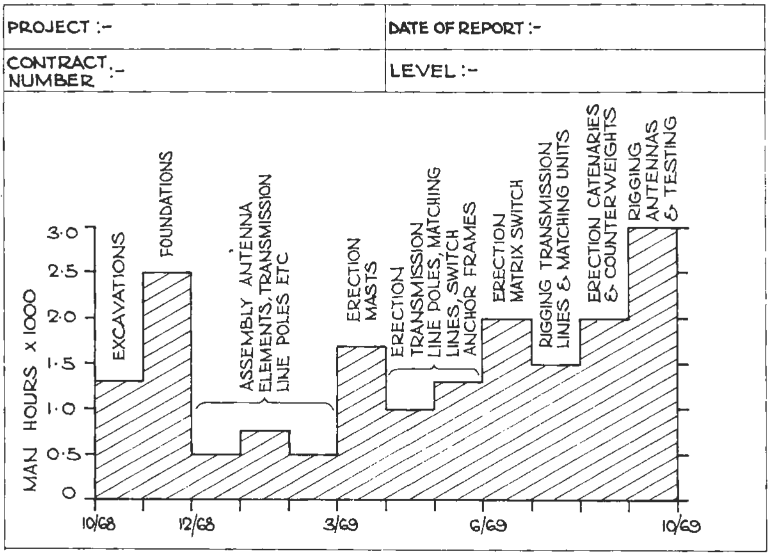


Figure 9.3 Manpower loading diagram

certain restrictions during the wet weather period but in the other periods more effective and efficient utilisation of the available manpower could be achieved. This is done by rescheduling of slack activities so that they are moved to another period of time in the work.

The manpower report contains the following information:

(i) The costed manhours at date given.
(ii) The contracted manhours for completion of the work.
(iii) The latest revised estimated manhours for completion.
(iv) Predicted over-run or under-run of total manhours.
(v) The most critical slack.

Schedule charts and graphs used for reporting of manpower often require close examination in order to assess the true situation of the work. Many reports simply show actual as compared to scheduled progress, and are often prepared in bar chart form with an overlay graph. As an example of the need for close examination, a chart may indicate that the work is well ahead of schedule and the manhour curve may show less manhours have been expended at that period in time than was scheduled, but this does not necessarily mean that the project commissioning date has been advanced.

Effective completion is tied to the key procurement and engineering items of the schedule by critical work items in their order of necessary precedence and only by carrying out a detailed analysis of the status of these key and critical items can it be determined whether or not this deviation from the schedule will actually affect the commissioning date.

(c) Cost-of-work report.

An example of a cost-of-work report is shown in *Figure 9.4*. It is seen to be a graphical presentation of the financial progress of the project. Many radio installation or construction projects progress at a slow rate at first, speed up in the middle and slow down near the end of the work. When the project

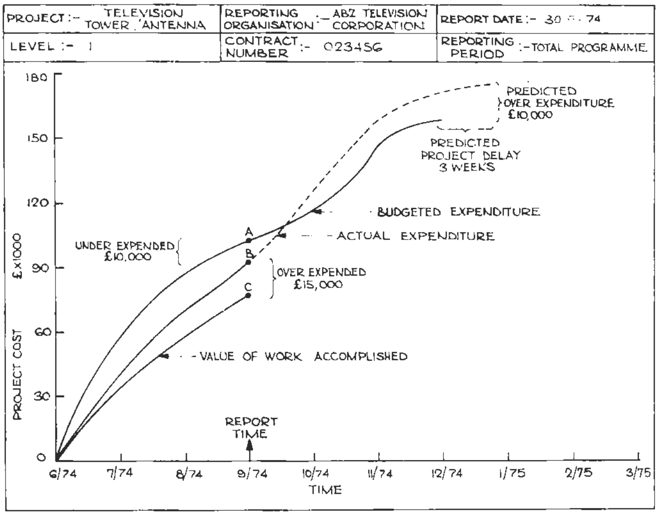


Figure 9.4 Cost-of-work report

is divided into separate installation items, and if each of those items is scheduled for uniform expenditure during its installation period, the combined expenditure will usually produce a cost-of-work curve of this type. The report is of considerable assistance to project management, as they can see both current status and future trends inherent in the planned work. However, it often involves much effort in the collation and presentation of the data as both direct and indirect charges associated with the work must be considered.

A feature of the report is that it highlights the value of the work accomplished or the valuation concept and time, and the deviations from the plan. In this regard it considers both a cumulative-to-date and predicted-at-completion deviation. In other words it provides a means of analysing the original estimate that was prepared for the project and a check on the actual costs expended at a certain report date with the costs which were estimated for that date. Briefly it depicts the following:

(i) The budgeted expenditure necessary to carry out the work.
Where the work is to be carried out under contract the budgeted costs will be related directly to the contract.
(ii) The actual expenditure or committed costs as at the date of reporting.
(iii) The predicted costs to complete the project.
These costs would be based on the actual costs which have been incurred at the date of reporting and the estimated costs to complete the outstanding work.
(iv) The value of the work accomplished at date of reporting.

The budget expenditure on the report is an estimated value only, and caution should be exercised when making a direct comparison with the actual expenditure curve, as the following questions arise:

(i) Are the budget and actual expenditure curves compatible?
(ii) Do segments of both curves represent the same work?
(iii) Is there acceleration or deceleration of performance?

The finance department may consider the distance between the two curves as an over or under-expenditure condition. However, based on the answers to the questions posed, the distance between the two curves could be any of the following three possibilities: over-expenditure, under-expenditure or on budget.

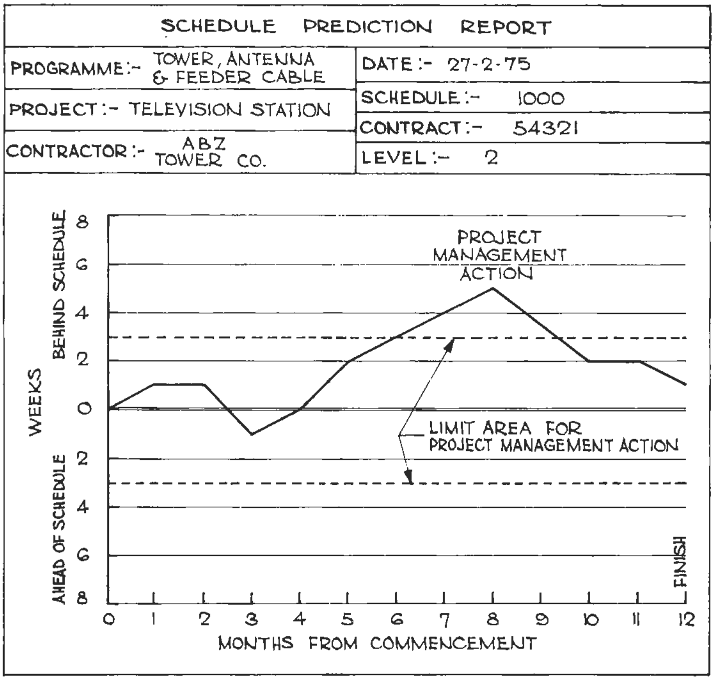
It is only possible to draw a conclusion as to whether or not the expenditure is out of estimated limits by comparing the actual expenditure with the value of work accomplished. Comparison of the actual expenditure with the budgeted expenditure only determines whether the project work is above or below the programmed financial progress. There is no relationship with the time schedule and plan nor indication on whether the work is costing more or less than the estimated value at a particular time. For example, if a contract calls for delivery of spare parts for a transmitter to be delivered say 3 months after delivery of the transmitter to the site for installation, and the contractor forwards the spares and transmitter as one invoiced consignment, the report might show a steep rise in expenditure above the budgeted value at the time. All this means is that money has been spent before its budgeted time, but there would be no affect on the final project cost.

In addition to being the most significant correlative property, physical accomplishment knowledge is one of the fundamentals necessary in the decision making process by management. Decisions such as additional or reduced manpower, increased or decreased overtime to finish the effort based on the current physical accomplishment are of vital importance to engineering management. In the example which is a cost-of-work report for a television tower/antenna project which was estimated to cost £160 000 it is seen that up until the end of September the actual expenditure on the work was less than the budgeted amount, and was £10 000 under-expended.

At the date of reporting, an accurate estimate of the cost of the outstanding work was made, together with an estimate of the time required to complete it and the analysis showed that from the information available, the total project would cost £170 000 or £10 000 more than the original estimated cost. Also, the completion date would be three weeks beyond the original scheduled date. The dotted curve is an extension of the actual expenditure up till the report time and is the result of the new estimated costs. It is also seen, that at the report date, the work carried out at that stage had cost £15 000 more than was estimated for it. However, the information available to management at the time indicated that for various reasons it was expected to be reduced before the project was due for completion.

(d) Prediction report.

There are generally two reports associated with a prediction report. One is a schedule prediction report which indicates the trend of the projected schedule for the completion of the project as it is seen on each monthly reporting date. The other is a cost prediction report which indicates the trend of the projected cost over-expenditure or under-expenditure for completion of the total project as seen on each monthly reporting date. By relating the trend of the projections to previous management decisions, management can observe the effects of those decisions on the cost and schedule for the project. They can determine on a month to month basis,



SCHEDULE PREDICTION REPORT

PROGRAMME :- TOWER, ANTENNA & FEEDER CABLE
DATE :- 27-2-75
PROJECT :- TELEVISION STATION
SCHEDULE :- 1000
CONTRACT :- 54321
CONTRACTOR :- ABZ TOWER CO.
LEVEL :- 2

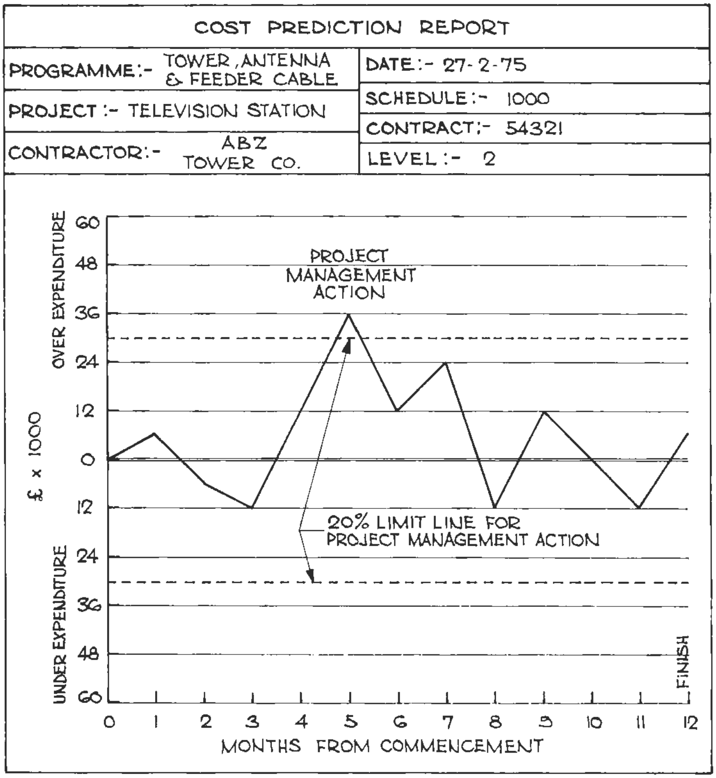
Figure 9.5 Schedule prediction report for a television tower and antenna system

whether or not the actions taken to control schedules and costs are producing the desired results.

Typical prediction reports are shown in *Figure 9.5* and *Figure 9.6* and from these particular reports the engineer can deduce that:

(i) At the end of the third month the project was one week ahead of schedule and the expenditure was £12 000 under-expended.
(ii) At the end of the fifth month the project had slipped 2 weeks behind schedule and the expenditure was £36 000 above the programmed level. This called for immediate management action.
(iii) After eight months, the financial position had changed to one of £12 000 under expenditure but the project had slipped and was then 5 weeks behind schedule.
(iv) At the completion of the project it was one week behind schedule and was over-expended by £6000 on a total budget allocation of £150 000 for the project, i.e. 4%.

The limit points where top management action is required will vary with the policy of the organisation, the cost of the work and the nature of the work. In one organisation handling many large projects this limit has been set at 10% for expenditure on particular sections of a project but 5% on the whole project, when the programmed cost is less than £250 000.



COST PREDICTION REPORT

PROGRAMME:- TOWER, ANTENNA & FEEDER CABLE	DATE:- 27-2-75
PROJECT:- TELEVISION STATION	SCHEDULE:- 1000 CONTRACT:- 54321
CONTRACTOR:- ABZ TOWER CO.	LEVEL:- 2

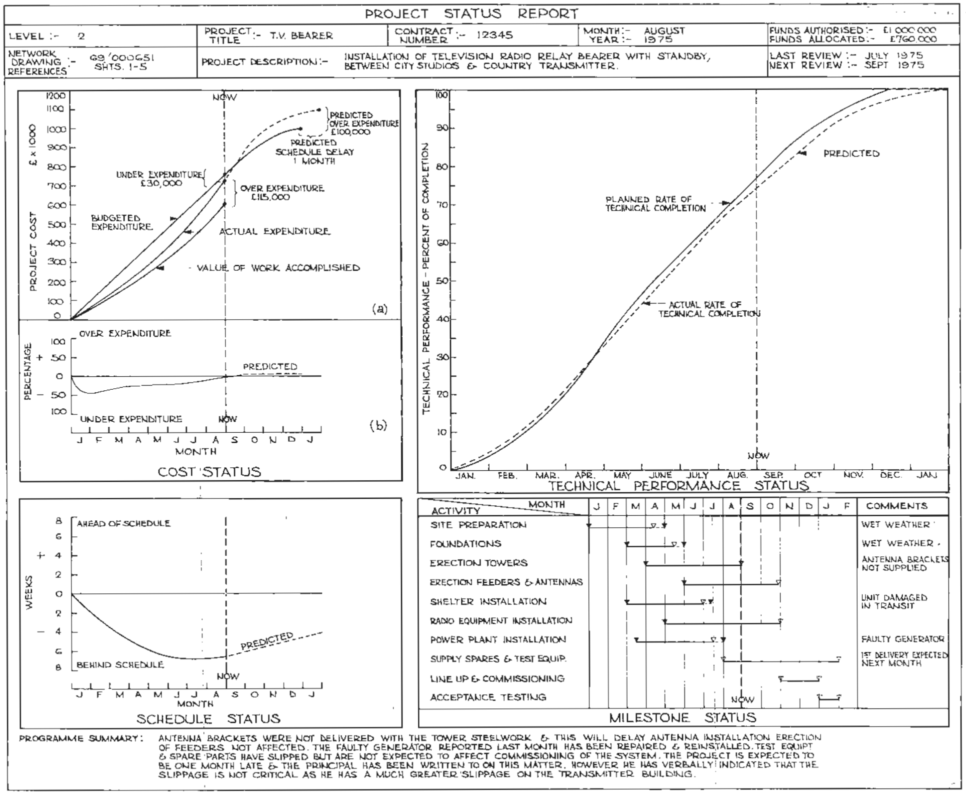
Figure 9.6 Cost prediction report for a television tower and antenna system

PROJECT STATUS REPORTING

Every project should have a programme before work is commenced. The programme should fully set down the objectives of the project, the approach to be taken and the commitments to be assumed. Planning is a continuing function, and updating may be necessary to meet changes in the scope of the work, development or manufacturing difficulties and changes in requirements. However, whether changes are required or not in the programme, status reporting of each project is required to allow management to review performance at regular intervals.

Management reports are most efficacious when prepared by experienced staff. However, since the results are sensitive to the quality of the input data, the staff should be particularly motivated and disciplined. They should be trained to make reports prompt, complete and factual in calling attention to delays and deficiencies. Report preparation should not be considered a chore to be performed by a subordinate when time permits, as is often the case.

There are many different ways of presenting project status to management but one typical project status report is shown in *Figure 9.7*. This particular



PROJECT STATUS REPORT

LEVEL :- 2

PROJECT TITLE :- T.V. BEARER

CONTRACT NUMBER :- 12345

MONTH :- AUGUST
YEAR :- 1975

FUNDS AUTHORISED :- £1 000 000
FUNDS ALLOCATED :- £760,000

NETWORK DRAWING REFERENCES :- G9/000651 SHTS. 1-5

PROJECT DESCRIPTION :- INSTALLATION OF TELEVISION RADIO RELAY BEARER WITH STANDBY, BETWEEN CITY STUDIOS & COUNTRY TRANSMITTER.

LAST REVIEW :- JULY 1975
NEXT REVIEW :- SEPT 1975

ACTIVITY	COMMENTS
SITE PREPARATION	WET WEATHER
FOUNDATIONS	WET WEATHER
ERECTION TOWERS	ANTENNA BRACKETS NOT SUPPLIED
ERECTION FEEDERS & ANTENNAS	
SHELTER INSTALLATION	UNIT DAMAGED IN TRANSIT
RADIO EQUIPMENT INSTALLATION	
POWER PLANT INSTALLATION	FAULTY GENERATOR
SUPPLY SPARES & TEST EQUIP.	1ST DELIVERY EXPECTED NEXT MONTH
LINE UP & COMMISSIONING	
ACCEPTANCE TESTING	

PROGRAMME SUMMARY: ANTENNA BRACKETS WERE NOT DELIVERED WITH THE TOWER STEELWORK & THIS WILL DELAY ANTENNA INSTALLATION ERECTION OF FEEDERS NOT AFFECTED. THE FAULTY GENERATOR REPORTED LAST MONTH HAS BEEN REPAIRED & REINSTALLED. TEST EQUIPT & SPARE PARTS HAVE SLIPPED BUT ARE NOT EXPECTED TO AFFECT COMMISSIONING OF THE SYSTEM. THE PROJECT IS EXPECTED TO BE ONE MONTH LATE & THE PRINCIPAL HAS BEEN WRITTEN TO ON THIS MATTER. HOWEVER HE HAS VERBALLY INDICATED THAT THE SLIPPAGE IS NOT CRITICAL AS HE HAS A MUCH GREATER SLIPPAGE ON THE TRANSMITTER BUILDING.

Figure 9.7 Project status report in graphical and bar chart form for a TV bearer project arrangement requires the preparation of a separate report for each project, but could be used to provide information for a project status board or drawing, where all projects have to be presented together. The information contained in the report is governed by the requirements of the particular organisation but would generally include the following:

(a) Cost status.
Diagram (a) of the cost status graph shows three curves, the budgeted expenditure curve which is determined directly from the contract time table before the work is commenced, the actual expenditure curve and the value of work accomplished curve at the date of preparation of the report. The function of the cost status report is to summarise material, labour and incidental charges for a given period of time.

Data for the actual expenditure curve is obtained from detailed costing records supplied by the project manager. These records which show the various elements of the expenditure break-up may be computer run-off obtained from an electronic data processing system. In some cases, a curve showing committed expenditure is also added, particularly if there are delays in obtaining current costing information or where costly items of equipment are involved. The analysis at the date of reporting indicates that the project is expected to be £100 000 overspent and to be one month behind schedule.

Diagram (b) indicates the percentage by which the total costs at a certain date of reporting fall short or exceed the expenditure which was budgeted for that particular date.

The curve is very useful in gleaning a picture of the status for previous months and also the future trend. In other words, it gives a profile of the over or under-expenditure of a project from commencement of the work until completion.

(b) Schedule status.
The schedule status curve shows the cost weighted measure of schedule performance of the project work. Like the cost status expenditure curve of (b) it provides a schedule status profile from the beginning of the project until completion. It indicates that at the time of reporting the project was about 6-7 weeks behind schedule but at completion this lag was estimated to be reduced to about 4 weeks.

(c) Technical performance status.
The definition of technical performance is not a simple matter when it has to be related to such factors as creativity, design concepts and the like, and also to setbacks in the progress of the work due to technical problems. For example, the technical performance status may be estimated to be, say 70% completed one month and yet be less than half this value at the next month of reporting due to a technical setback.

During the development of a new type of high power antenna system for one high frequency broadcast station, the technical performance status was estimated to be 80% when the antenna was erected on site. However, after a few days of testing, the antenna system failed due to serious corona problems and the project work was set back many months for major redesign and investigation work.

The control of technical activities is carried out in much the same way as cost and schedule control, i.e. by using bar charts and network diagrams for the technical task events and activites as outlined in the plan, measurements of the progress, evaluation of deviations and finally the implementation of ~~appropriate corrective action~~ where this is necessary. For some projects, it may be desirable to weight the technical performance status curve in order to take into account the fact that all work activities do not have the same weight. Some are more complex than others, some more costly than others and some are more important than others. Because subjective factors such as complexity and importance are difficult to measure and apply as a weighting factor the usual method is to use project cost. The technical performance status curve presented as part of the overall project status report would then take into consideration the relative costs of each work segment in relation to the entire project cost.

(d) Milestone status.

Milestones, which are points of significant accomplishment, refer to those selected points or events on which progress information is required in order to appraise performance in meeting programme objectives on time. They may indicate the start or completion of work, the attainment of approvals, the completion or start of reviews, the attainment of objectives etc.

The milestone bar chart shows the milestone responsibility inside and outside the organisation. For instance, site preparation work may be carried out by the principal on a separate contract but the timing is vital to the coordination of antenna and building foundation and other works. Appropriate comments on reasons for variations from the schedule are made on the chart. In some reports, it may be considered desirable to indicate the specific network numbering involved, to facilitate rapid network analysis where such may be required. Slack for the individual milestones and total programme slack in relation to the next equipment delivery may also be shown for the reporting period.

A programme summary is added and this sets out briefly, reasons for variations from planned figures and indicates follow-up taken with the principal, if this is necessary.

The rectangular bar chart used in the milestone status has one main disadvantage and that is it does not indicate the scheduled rate of progress or the actual rate of accomplishment for the particular milestone activity. To overcome this problem, some reports are prepared with a triangular bar chart in lieu of the rectangular bar. Obviously the hypotenuse of the triangle is a straight line only when the work is scheduled and executed at a uniform rate. A properly prepared triangular bar chart will indicate not only the duration of the work, but also the estimated and actual accomplishment.

It is evident that only the main items of a project should be shown on a graphical chart as too many small items tend to make the chart unwieldy, complex and too difficult to keep up to date. Any chart scheme will be found to be workable and useful only if three basic aspects are kept well to the fore. These are simplicity, clarity and a reasonable degree of accuracy. If a chart is too complicated to be readily understood or if too laborious to keep plotted, it will either fall into disuse or get so far behind current events that it loses its real value.

FORM OF PRESENTATION

Whilst a large part of information required for reports to management would normally be obtained from computer print-out of the network analysis, many managers prefer to have the information presented to them in graphical or chart form. Graphs and charts are considered to be more meaningful when a quick assessment of the status of the project is necessary.

A major problem confronting engineering management today, where many large projects are active, is the increasing availability of information and insufficient time to read and analyse it. It has become necessary therefore to tailor this information to enable it to be readily absorbed in the time available. To have management read and act upon the reports, they have to be presented in a form in which management will use them and it is generally agreed that the most acceptable form is graphs and charts.

Every control chart presented in graphical form should show comparative results. An annual trend representing a difference is in itself a comparison, since the rising or falling trend is with its single line, a continual comparison of the twelve monthly result recorded against the result at the end of the last financial year. Ratios should be compared against a normal line and there are occasions when a current or cumulative set of figures may with advantage be plotted against the current or cumulative figures for the previous year. Whatever the chart may be, however, it should not be presented to management without there being some method by which comparison of the recorded result with some standard of performance, either actual or desired, is made.

FURTHER READING

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MODER, J. J. and PHILIPS, C. R., *Project Management with CPM and PERT*, Reinhold, New York, 1964

PERT Co-ordinating Group, *PERT Guide for Management Use*, US Government Printing Office, Washington, 1963

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Chapter 10

Trend Analysis

Trend analysis is defined as the provision of information sufficiently far in advance of a threatened crisis to enable management to take effective action to forestall and mitigate the effects of that crisis. Most control systems data tend to be processed on a historical basis, that is after the event has occurred. The ideal is real time control where each event, as it occurs, is fed immediately into the system and combined with all the other information existing in the system and its effects determined so that the cumulative effects and trends may be worked out.

Some organisations with large broadcast and television networks administer the network via a computerised analysis programme. Data in the form of equipment trouble reports and transmission results are fed into a centralised computer. On demand, a Central Control Office retrieves real time analysis for areas of falling performance and trend identification. Performance indicators are produced and graded for various levels of management. Broadband radiocommunication links are also administered along the same lines. By this means the status and trend of the network is continuously monitored. Minicomputers and cathode ray tube (CRT) displays are used to collect, interpret and display status and trend data at selected regional and Central Control Office points.

Trend analysis in its objective has much in common with retrospective analysis, the former being a prediction and the latter an inquest. It has been said by some project engineers that retrospective analysis could never establish real causes. Although this might be true as a generalisation, retrospective analysis has merit in enabling courses taken and results accomplished to be reviewed. Very rarely can a full programme of works, however well planned, be fully accomplished without a perfect organisation. Good organisations can accomplish a high proportion of their programmes and moderate organisations a moderate proportion. It is frequently better to analyse the unaccomplished proportions in retrospect than under the pressures prevailing at the critical time, and to change future methods and reshape future programmes in the light of the reasons thereby ascertained for the failure.

THE MOVING ANNUAL TREND

Probably the best known and simplest evaluation of trend is the moving annual trend and it finds important application in the control of operations and maintenance expenditures of radio establishments. The moving annual trend is made up by taking the results of expenditure at the close of the last financial year and at the end of the following month, adding the results for the new month, and subtracting the results for the corresponding month of the old year. In this way a full twelve months total is again obtained, ending with the first month of the new year. As the year proceeds, each new month's result is added to the previous total and the corresponding month of the old year subtracted. Hence, when the new financial year comes to an end all the old months will have been subtracted, and all the new months added in, and so the moving annual total becomes itself the final point for the current financial period. In each month the controlling engineer is able to compare the position at the moment directly, and without any calculations, with the position at the end of the last financial year.

This moving trend method of control has a further aspect in that it eliminates what may be called seasonal fluctuations. Many large radio systems are installed in areas where there is a marked change in operation and maintenance charges with seasonal variations. In tropical areas, the monsoon season invariably results in added maintenance charges due to the high humidity conditions and in dry inland areas the very high prolonged summer temperatures may also result in increased maintenance expenditure. The moving trend method disposes of these aspects by the simple and effective means of always providing a twelve monthly figure for comparative purposes and it is obvious that this twelve monthly figure must contain a full range of a year's fluctuation.

The effect that the trend curve has in eliminating fluctuations can be seen by application to *Figure 10.1* which shows the total operating and maintenance expenditure associated with a large communications complex situated in an area subjected to both summer and winter rains. The expenditure was at its lowest during March, April, May, June and worst during summer rain months of December to March with a peak again during June to August winter rains.

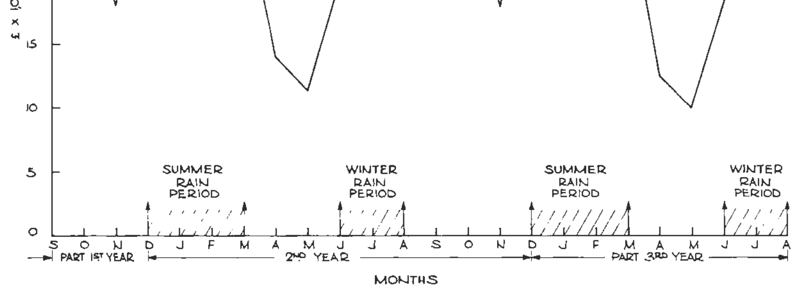


Figure 10.1 Operation and maintenance expenditure for a large communications complex

From a casual glance at the graph it is difficult to see whether the maintenance expenditure for the complex is showing much alteration. If however, a curve is made of the moving annual trend as in *Figure 10.2*, it can be clearly seen that the total expenditure for operation and maintenance over the last five months showed a gradual decrease. The trend curve is clearly defined but a careful

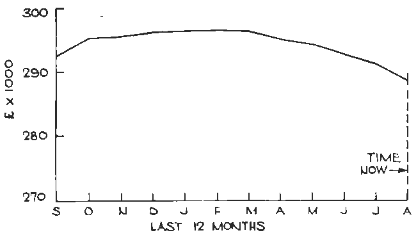


Figure 10.2 Moving annual trend curve of expenditure

examination of the current figures for the corresponding months of each year will show that the last five months were always slightly less than the same months of the previous year. The difference however is so slight that it could easily be passed over as of no significance and it is only when the difference between the two sets of monthly results is set out by the trend method that the continued decrease in maintenance and operation expenditure for five months in succession becomes clear.

The reason for the falling expenditure in this case was due to a reduction in staffing, the installation of standby transmitting equipment, replacement of several old transmitters with more efficient models and a rescheduling of transmitting times for traffic handling purposes. The moving annual trend curve indicated to management that the planned reduction in total costs was in fact being realised.

THE MOVING AVERAGE

A moving average is simply the average over the last n readings where n is the period over a complete set of values. A typical graph of moving average of a project associated with the operation of a high frequency point-to-point radiocommunication station is shown in *Figure 10.3.* The month by month actual

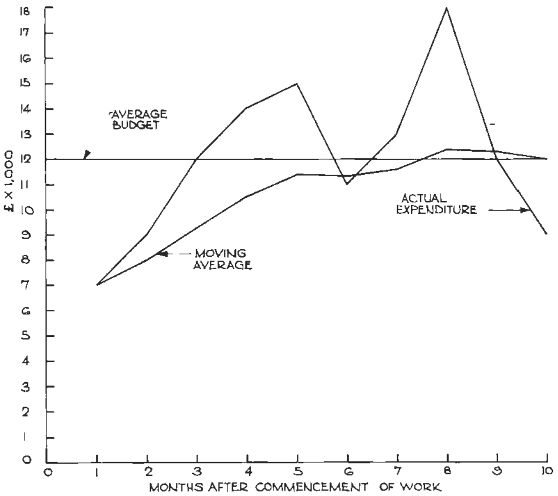


Figure 10.3 Moving average and actual expenditure graphs

expenditure is also shown for comparison purposes. The moving average is the average calculated by dividing the accumulated expenditure on the project—both direct and indirect costs—at the end of each month by the number of months in the whole reported period. The average budget sets the reference level and a comparison between this average budget reference and the moving average indicates the trend of the project expenditure.

The method of moving averages is essentially a descriptive technique and does not yield a mathematical trend equation. Moving averages tend to follow the original observations up into large peaks and down into large valleys, and they may introduce what appear to be cycles in some studies rather than smoothing the cycles, because moving averages are serially correlated. It may change the timing of peaks and valleys because it shifts the specific timing of the data. Large irregular peaks will be spread out over the period of the moving average. The effect is to produce moving averages, all of which are much less than the original single large value, but several of which are slightly larger than the original values adjacent to the large irregular value. The simplicity of the moving average method makes it a useful procedure where more elaborate techniques may not be justified.

RATE OF EXPENDITURE

In this form of monitoring, the expenditure is plotted cumulatively against time. It has a zero origin as it can reasonably be expected that no progress is being made without expenditure. The actual cumulative expenditure is compared

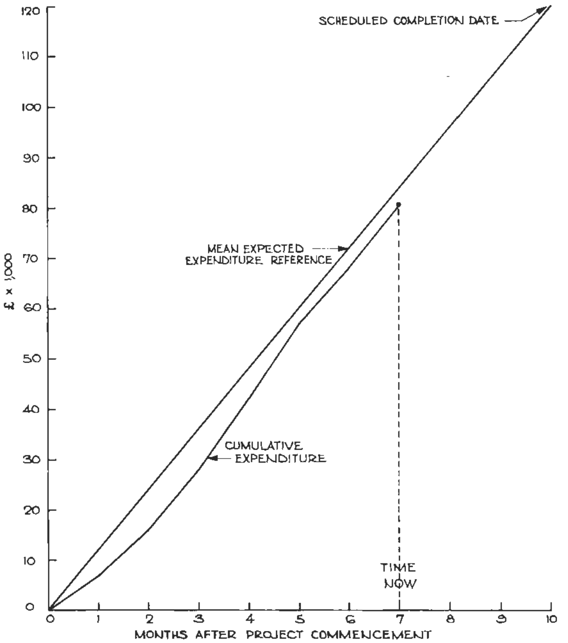


Figure 10.4 Cumulative actual expenditure compared with a planned rate of expenditure

against the mean expected expenditure reference line. A typical curve developed during the installation of a television transmitter is shown in *Figure 10.4.* Caution must however be exercised in using this method because there is no indication of the corresponding project accomplishment. What is generally not sufficiently understood is the futility of trying to judge accomplishment from only a cost performance report. For example, in a particular period, there could be one or more sections of the work which have been over-expended by say, a total of £10 000 and there could also be one or more material items under-expended by about the same total amount perhaps because of non-delivery of material. In this situation, the monthly expenditure at the time, would show that the expenditure was being incurred at the predicted rate and there could be a danger in management assuming that the state of the project was healthy.

Only through a management information system that directly relates:

(a) Work accomplished to schedule performance,
(b) Work accomplished to cost performance,

can management obtain meaningful answers to:

(a) The extent of possible over- or under-expenditure of the project.
(b) The extent to which the project may be behind or ahead of schedule in time,
(c) The sections of the project work responsible for the expenditure or schedule variations.

ACCOMPLISHMENT ANALYSIS

As seen from the previous method, a knowledge of the budget allocation and actual expenditure of a project is in itself of little use to the project manager unless the corresponding progress of the work can be gauged. It is necessary to monitor not only the actual costs incurred but also the work progress in relation to those costs.

Finance for a project would normally be allocated at the beginning of the work or at the beginning of the financial year, depending upon the particular arrangements within the organisation. The establishment of the budget expenditure throughout the period of the project is a straightforward procedure. Also, the determination of the actual expenditure at a particular date would normally not present any problem as most organisations have adequate costing facilities. However, the delay between actual expenditure and costing dates does often cause concern and this can be very important where large costly items of material and labour are involved.

Accomplishment analysis is however a difficult problem, as it does not normally form part of the management facilities of many organisations. In determining labour accomplishment expenditure it is necessary to consider how many different categories of costs are to be taken into account. They are as a general rule easily determined as they will often resolve themselves into identifiable major sections of work. *Figure 10.5* shows how this step is carried out on a typical project associated with a radio relay system for industrial pipe line control purposes. The time duration of each bar would generally be obtained from the network. From the estimated manhours, the actual number expended on the work, and the number of manhours accomplished, the final manhour total can be determined.

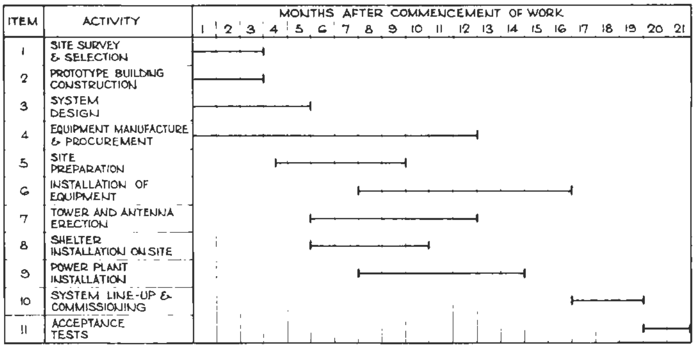


Figure 10.5 Major sections of work associated with radio relay system for industrial control

Figure 10.6 shows a monthly manhour accomplishment analysis for part of work associated with the design and manufacture of a radar station. The total estimate is seen to be 10 670 manhours for the work and the analysis reveals that 7000 manhours have been accomplished. Against this, the costed worked manhours at the same date is 7030 or 30 manhours higher. In accomplishing 66% of the work the group has used about 65.9% of its manhour budget. The information available from the analysis can be used to predict the final manhour usage of the group working on this sub-system, if it is assumed that no corrective action is implemented to improve subsequent performance.

The final manhour total of this sub-system can be calculated from:

$$\text{Total manhours} = \frac{AE}{P}$$

where A = actual number of manhours expended on the work, E = estimated number of manhours for the work, P = number of manhours accomplished

$$= \frac{7030 \times 10\,670}{7000}$$

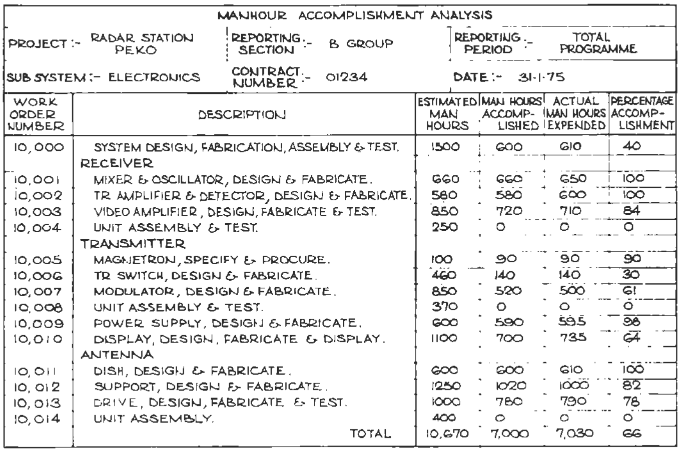
$$= 10715 \text{ manhours.}$$

This represents a group over-expenditure of 45 manhours and for this particular example it represents less than 0.4% which indicates that the status is reasonably healthy.

Accomplishment analysis will give forewarning of possible manhour excesses and allows action to be taken, if appropriate, to retrieve the situation.

In the early stages of project labour activity there will be a tendency for the analysis results to be fairly unreliable for prediction purposes due mainly to the fact that very few work items have been brought to completion. However, a pattern will emerge, generally after about 8 to 10 weeks for a large task, and the trend will be seen to better advantage. The results at this stage will carry sufficient weight to determine the necessity for corrective action.

Figure 10.7 illustrates the pattern of results from an analysis of the labour performance of the installation of a directional antenna system for a medium frequency station with several masts, earth mats and transmission lines. At



MANHOUR ACCOMPLISHMENT ANALYSIS

PROJECT :- RADAR STATION PEKO	REPORTING SECTION :- B GROUP	REPORTING PERIOD :- TOTAL PROGRAMME
SUB SYSTEM :- ELECTRONICS	CONTRACT NUMBER :- 01234	DATE :- 31-1-75

WORK ORDER NUMBER	DESCRIPTION	ESTIMATED MAN HOURS	MAN HOURS ACCOMP-LISHED	ACTUAL MAN HOURS EXPENDED	PERCENTAGE ACCOMP-LISHMENT
10,000	SYSTEM DESIGN, FABRICATION, ASSEMBLY & TEST.	1500	600	610	40
	RECEIVER				
10,001	MIXER & OSCILLATOR, DESIGN & FABRICATE.	660	660	650	100
10,002	TR AMPLIFIER & DETECTOR, DESIGN & FABRICATE.	580	580	600	100
10,003	VIDEO AMPLIFIER, DESIGN, FABRICATE & TEST.	850	720	710	84
10,004	UNIT ASSEMBLY & TEST.	250	0	0	0
	TRANSMITTER				
10,005	MAGNETRON, SPECIFY & PROCURE.	100	90	90	90
10,006	TR SWITCH, DESIGN & FABRICATE.	460	140	140	30
10,007	MODULATOR, DESIGN & FABRICATE.	850	520	500	61
10,008	UNIT ASSEMBLY & TEST.	370	0	0	0
10,009	POWER SUPPLY, DESIGN & FABRICATE.	600	590	595	98
10,010	DISPLAY, DESIGN, FABRICATE & DISPLAY.	1100	700	735	64
	ANTENNA				
10,011	DISH, DESIGN & FABRICATE.	600	600	610	100
10,012	SUPPORT, DESIGN & FABRICATE.	1250	1020	1000	82
10,013	DRIVE, DESIGN, FABRICATE & TEST.	1000	780	790	78
10,014	UNIT ASSEMBLY.	400	0	0	0
	TOTAL	10,670	7,000	7,030	66

Figure 10.6 Monthly accomplishment analysis

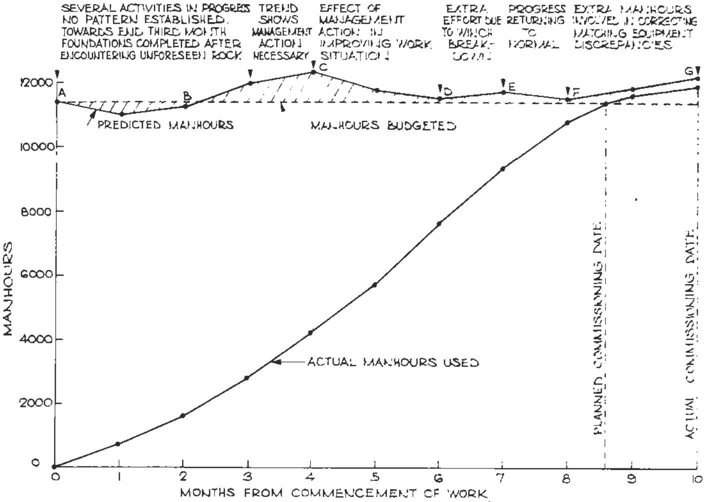


Figure 10.7 Labour accomplishment prediction for a multi-element m.f. directional antenna system project

the third month when some sections of the work were nearing completion, a rise in the expended manhours above the estimated figure was evident. This was due to unforeseen rock being encountered in the foundation excavation work. The rise continued up until the fourth month due to wet weather causing flooding of three of the excavations and subsequent damage to the walls. The trend then showed a gradual fall after the project engineer reallocated his resources to overcome the difficulties. After the sixth month, one of the winches used for hauling the mast steelwork became temporarily unservicable and some effort was lost in the actual construction programme because of its unavailability. At the beginning of the eighth month when phasing and matching equipment was being adjusted, it was found that an error had been made in mast base impedance assumptions and that four coils and capacitors required replacement. This resulted in the usage of more manhours, and slippage of commissioning date of the antenna system.

It is seen that much more information can be gleaned from the predicted manhour curve than from the curve showing the actual manhours used. The only time that warning of possible over-utilisation of labour is given by an actual manhour curve is very late in the project when it may be too late to apply effective measures to correct the unsatisfactory situation.

OPTIMISATION

When determining time estimates for the performance of an activity a certain quantity of resource is assumed. However, it is often possible to reduce the period of the activity by increasing the resources but it could mean an increase in cost of the work. For example, the manhours could be increased per week by having the men work overtime but as overtime hourly rates are greater than ordinary time rates the average manhour rate and consequently the final project cost would be greater than an original estimate based solely on ordinary time rates. Mechanical aid equipment could be used to shorten the activity time but this also may add considerably to the final cost. For each activity there is a particular combination of labour and equipment which will give the minimum cost for completing the activity. It will invariably be found however that the minimum cost will seldom coincide with the minimum time that is necessary to complete the activity or work.

In order to reduce the project duration, the timings of critical activities must be reduced. Any reduction of the planned critical path could result in previously near critical activities forming a new or an additional critical path through the project. Also, as activities represent independent phases of work, relative costs will vary according to the nature and quantity of resources employed. Therefore, there is a need to consider which activities will involve the least cost for each reduction of unit time. Careful scheduling and time allocation of resources may make the difference between completing satisfactory work at the correct time and maintaining an economic schedule, and completing unsatisfactory work at the wrong time at an uneconomic level.

CRASH COST

The cost/time relationship of an activity in a network may be represented in the form of *Figure 10.8* but the exact nature of the curve will vary from case to case. Estimates of the time and resources necessary to complete an activity are generally made on the basis of the most economical means available. This would be the normal situation of allotment, and the cost of each activity can be considered as the normal cost. The normal point is the combination of the normal time and normal cost and indicates the time required to complete the activity at minimum cost. If the time for an activity is to be reduced, there will be a limit past which no additional allocation of resources will achieve any further reduction in activity duration. This limit is termed the crash point and the cost of achieving it is called the crash cost. If it is necessary to introduce a crash programme,

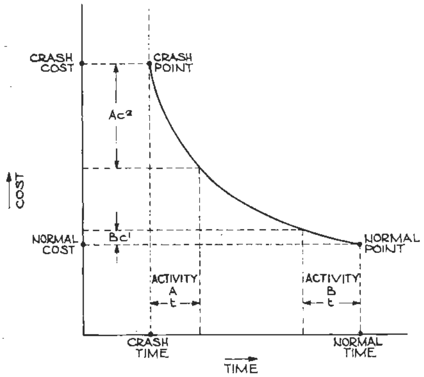


Figure 10.8 Time/cost function for a typical activity

it is inevitable that the cost of the work may be considerably increased due to decreased efficiency in the use of resources. Unnecessary additional cost may be introduced by placing the work on an all-crash basis instead of concentrating on the critical path. Many operations are non-critical and have little bearing on the project completion time. Consequently time will be wasted and unnecessary expenditure incurred for an all-crash action. The cost of the work may also be increased if it is allowed to taper out beyond the normal time. An increase in time beyond the normal time, which corresponds to minimum cost, implies increasingly inefficient use of facilities and equipment, and increasing liability to engineering change which cannot be compensated for, by increasing efficiency in the use of manpower. Because of the decrease in efficiency, costs in many cases may rise rapidly. This extension of time beyond the normal time is sometimes referred to as the 'drag out' time.

THE COST SLOPE

The derivation of the true minimum cost curve for each activity when comparing alternative projects is a rather tedious operation as it involves the calculation of costs from permutations of all the possible alternative methods of carrying out the activity. Fortunately, it is as a general rule sufficiently accurate for purposes of comparison if the relationship of time to cost is considered as a linear slope between the crash point and the normal point, although the actual relationship will depend on a number of factors not necessarily applicable to all activities.

The rate of change from the normal cost to crash cost or the cost slope can be determined from:

$$\text{Cost slope} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

Hence the cost slope of an activity is the cost of shortening the activity by one unit of time. As an example, if an activity has a cost slope of £1000 and it is on the critical path and all other activities have positive float, the duration of the particular project could be reduced by one day for an additional expenditure of £1000, by shortening the critical activity. By re-evaluating the network and using crash costs only for activities on the critical path and leaving normal costs untouched for activities with slack, a saving can be realised.

RE-ALLOCATION OF RESOURCES

It is interesting to note in the crash cost example the effect on cost of two serial activities of equal duration but located at different points on the time base and to the left of the normal time. Although the duration of each activity is the same, the cost of carrying out activity A is very much greater than for activity B. In this case the cost of the serial path itself can be minimised by reallocating resources in such a way that the time/cost functions all have equal slopes along the curve and such that the total time of all activities on the path must be completed in the allocated time. An allocation of time from activity B towards activity A will reduce the total cost of the two activities without changing the programmed time. This is because the cost saving from increasing activity A time is greater than the cost increase for decreasing activity B time by reason of its steeper slope. It is seen that the transfer of resources is in the opposite direction from the transfer of time.

TOTAL PROJECT COSTS

The total cost of a project is made up of two kinds of expenditure, direct costs and indirect costs. Direct costs include the cost of labour and materials to carry out the activity. They also include costs associated with the engagement of a sub-contractor, if work is to be carried out by this means. As the activity duration is reduced, direct costs will rise in proportion to the amount of the additional resources employed. Indirect costs consist of those costs which are incurred in direct proportion to the length of time that the project takes, and which cannot

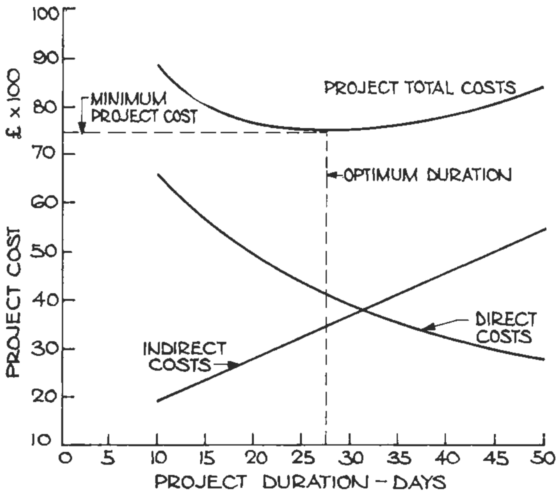


Figure 10.9 Project total cost curve derived from direct and indirect costs

be attributed to any individual activity. Such costs include expenditure on administration, accommodation, site rental, power and lighting and interest on the capital borrowed for the work. Because these indirect charges are proportional to the project duration, their total cost increases as the project duration increases. This trend is opposite to the direct costs which rise as the project duration decreases.

The total cost of a project is the sum of the direct and indirect cost incurred in its operation. As direct and indirect costs vary inversely to one another, the project total cost for different times can be combined graphically, as in *Figure 10.9* to obtain the total cost. Many organisations have a general formula for calculating the indirect costs. Some strike a charge based on the number of manhours involved, whilst others take a percentage of the total cost of the project. In any case, the costs are assumed to be represented by a straight line although variations to this approach do exist.

It is seen that the project total cost curve gives a least cost at a particular project duration. Schedule durations on either side of the optimum duration result in an increase in the total cost and the minimum project cost does not necessarily coincide with the normal point or minimum project direct cost.

One indirect cost which may have a considerable influence on the project total cost is penalty payment for failure to meet a schedule date. Penalty payments can be very high in some contracts, particularly in the case of high revenue earning systems such as a main line high capacity radio relay system used for telephony purposes. A system scheduled for completion just prior to heavy Christmas traffic would be under high pressure to ensure that no slippage occurred, as its revenue earning capacity would probably be at a peak at that time of the year. If a contractor was under a penalty of say £10 000 per day for every day slippage beyond the scheduled date, the indirect charges would rise substantially and the optimum point could shift significantly.

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Chapter 11

Productivity and Efficiency

The continuous pressure by management for greater productivity in order to meet high rates of demand with limited fund allocations has called for greater skill and ability on the part of the engineering workforce. It has been estimated that if the same output rates needed 20 years ago were still applying today, to the increased volume of work, a 25% increase in the workforce would be necessary.

The improvement in productivity in radio engineering has been achieved by:

(a) Improvements in the design of equipment, plant and materials to give greater reliability and to require less installation and maintenance manpower.

(b) Improvements in the methods and techniques of installation.

(c) Improvements in maintenance practices and systems by the application of controlled maintenance indicators so that unnecessary preventative maintenance is eliminated, by computer controlled service indicators which give accurate information on service performance and by installing a system for computer surveillance of network alarms.

(d) Improvements in safety practices to reduce loss time resulting from accidents.

(e) The use of cost analysis and performance studies as a means of indicating areas where improvements could profitably be made.

(f) The substitution of high production, low cost components, for low production, high cost components.

(g) Retirement of old high maintenance tube equipment. The maintenance of some old equipment often represents a significant proportion of the total maintenance load.

(h) Increased concentration of equipment such as when expanding existing broadband radio relay routes.

When new bearers are added to an existing system the only additional maintenance cost is that associated with clearing faults on the new radio equipment which usually is very low with modern equipment.

(i) Substitution or elimination of parts, finishes or unnecessary operations.

(j) Better organisational practices for carrying out work, aimed at reducing ineffective time to a minimum.

Facilities well located, materially increase the efficiency of a job. Sometimes portable buildings and caravans can be used to advantage on external plant work to meet shifting location requirements as the work progresses.

(k) Continuous study of practices in other countries and adaptation where justified to meet local requirements.

(l) Development of training programmes to increase manipulative, supervisory and administration efficiency, improvement in staff morale by improving information flow to the work face, by staff development, by providing satisfactory remuneration for work and by improving conditions.

(m) Encouraging workmen to look for better and more efficient ways of carrying out work for which they are responsible.

(n) Having sufficient competent supervisors available and at an early stage of the project to plan the work and to resolve difficulties as they occur in the field.

(o) Better co-ordination with building and site contractors in connection with early building and site access for installation and construction activities.

The finish of the equipment rooms at time of commencement of installation work has considerable influence on efficiency. Due to tight schedules in many installations it is not always practicable to await building completion before installation activities commence. Also, there are many situations where technical work has to be phased in with the building works. These include the earthing grid system, wall cutouts for transmitter air ducts, chases, conduits, manholes, bonding and screening and transmission line anchorages.

The erection of external plant such as masts and towers, earth mats, transmission lines and trench work can be affected by the condition of the site access roads, particularly during wet weather. Of course, if the roads are inadequate during the first few weeks of the work then only those manhours incurred in this period will be affected. However, mechanical aids which become bogged due to the poor site access roads not only cause loss of manhours on the programme but may result in damage to the plant with resultant further delays in the work.

(p) Organising the engineering department in such a way that its methods and operations are under continual review.

As an example of this, one organisation was in the practice of purchasing all testing instruments for its new installations through a collective purchasing system which had also been used for obtaining its operation and maintenance requirements. After an analysis of overhead costs involved in obtaining equipment for several projects, it was found that it was more economical to purchase the testing instruments through the contractor supplying the system equipment. Although the contractor added his surcharge to the manufacturer's price, the surcharge was less than the overhead costs being incurred by the organisation. The reason being that many items of test equipment have long delivery times and the cost of manhours involved in regular follow-up by engineers and administrative staff to ensure delivery on time to meet tight project scheduled dates exceeded the surcharge costs for contractor supply. Several instances also occurred where material was faulty on delivery and additional follow-up expense was incurred.

After consideration of the ultimate costs, responsibility for project progress and organisational efficiency, a decision was made to purchase all project new works testing instruments concurrently with equipment contracts. No change was made, however, in the purchase of instruments for maintenance requirements, as the need was generally foreseen some considerable period ahead and follow-up action was in line with the normal stores purchasing procedure.

UTILISATION OF RESOURCES

Greater production or output does not necessarily mean higher productivity. Production can be increased simply by using more resources, provided that of course more resources are available. Productivity on the other hand must take into account not only the volume of goods, achievement and services produced, but also the resources required to produce it. Productivity in simplest terms is the result of efficient use of all the resources available and, in the main, these resources are men, machines, and money.

The allocation of resources is a most critical factor in productivity improvement. If future works programmes fail to set the optimum relationship between men and materials or suddenly change the work emphasis from one range of materials to another, then productivity is likely to suffer. Resource availability can seldom be stated without qualification, for although a fixed labour force may exist at a particular period in time, it is usually possible to vary it, providing adequate notice is given.

An important factor in programming and scheduling activities is the capacity of the available manpower resources to carry out the work. The capacity would include not only the permanent workforce of the group but also that which could be obtained on transfer from other areas or recruited locally. It should also take into account loss of effort due to recreation leave, holidays etc. and additional effort which could be obtained from overtime. The manhours available from the total resources should be known reasonably accurately in order to programme and schedule the work properly. There is little point in preparing a programme of work if the staff available are unable to maintain the schedule.

On any project it is undesirable that there should be peaks of labour employment at a number of different points in the work programme. Hiring and firing workmen to meet peaks in the work can be inefficient, and does not lead to high productivity. New workmen take time to get accustomed to new surroundings, to learn to use new plant, to familiarise themselves with material supply arrangements etc. It is desirable, therefore, that there should be a levelling in the demand for manpower over the whole of the project with a smooth build-up during the commencement stage, and tail-off towards the completion. Also, the start of each new activity on a site requires extra attention by engineers and supervisory staff, and the schedule should not have too many new activities commencing simultaneously. The work will be handled more efficiently and with less false starts and confusion if commencement dates for new activities are distributed over a reasonable period of time.

The rate of build-up of work activity in the programme is important as it can have considerable influence on productivity. If the rate is too rapid, problems could occur in work co-ordination between groups, the smooth supply of materials, the more efficient utilisation of mechanical aids, inadequate supervision and work space congestion etc. Another point is that all installation and construction activities are made up of discrete steps of work many of which are dependent on the completion of some prior activity. Shift work can sometimes overcome some of the problems, but in many activities work cannot be carried out as efficiently under artificial lighting conditions as during day-time. In fact, some operations such as mast and tower work would be extremely hazardous. Continuity of the work may also be difficult with shift work on activities such as rack and transmitter wiring, where staff on successive shifts must pick up the partially completed work of others.

HUMAN FACTORS

Of all the resources on which productivity depends, people are probably the most important. It is obviously a very practical consideration for management to be concerned with the maintenance of an efficient and stable workforce, with proper selection and the proper placement of workmen in tasks, with the strengthening of supervisory skills, with effective communications and with the numerous other facets which are directly related to the capacity of the organisation to develop and sustain the effort required for greater efficiency and productivity.

It is particularly important that senior staff of the project group be appointed to the job well before commencement of the actual field work in order that they may become familiar with the requirements of the work, and to allow proper planning of the operations. The calibre and numbers of the senior staff, including the field supervisors, should be adequate from the beginning if productivity is to be at a high level throughout the life of the project. Staff should be carefully selected as it is often very difficult to retrieve wasted manhours and upgrade work practices which may occur as a result of incompetent supervisors.

FACTORS DETERMINING HIGH PRODUCTIVITY

Labour productivity is unfortunately a function of many variables, any one of which can have a considerable influence on the output. Many of the job situations are intangibles and not amenable to measurement. Some of the factors which determine high productivity on radio engineering projects are as follows:

(a) The proper equipment or plant must be available to allow the work to be performed with the minimum of direct labour effort. Inadequate mechanical aids, test equipment and tools can substantially increase the manpower effort necessary to perform a given amount of work.

(b) The workforce must be adequately qualified and skilled, and be properly organised to allow an efficient output.

(c) Materials, tools and test equipment must be in good order and readily available when required.

    Central location, and efficient service at the store and toolroom are also important. Time spent away from the job in obtaining materials and tools has a deleterious effect on productivity.

(d) Sufficient information of the work to be carried out must be available at the correct time.

    If drawings or data arrive just as they are required, it may not give the workman sufficient time to study the details in order to determine the most efficient means of doing the work or whether the details are adequate. If the information is supplied later than is required, men may not be fully occupied or they may have to be directed to other work temporarily. These aspects result in overall job inefficiency and do not allow efficient utilisation of manpower.

(e) Management must be competent and skilled, and there must exist a high co-operative effort between management and the workforce.

(f) All workers, at whatever level in the project organisation, should share a sense of community and involvement in it.

(g) There must be a high degree of confidence on the part of all concerned that higher productivity will not impose penalities through the incidence of unemployment or reduced wages.

(h) The processes of liberating, channelling and enhancing motivation are crucial to achieving the maximum use of the workforce.

A study of the project work conditions and their relationship to productivity provides information of value in managing the work. It allows optimisation of productivity by manipulating the conditions under which the work is performed. For instance, where new machinery or measuring instruments are capable of saving human labour and yielding economies in installation or maintenance, management cannot afford to ignore the question of premature obsolescence. It is the responsibility of management to keep abreast of technical developments even though additional capital outlay may be involved.

Economies can often be obtained by shifting resources so as to shorten the time required to complete the project. In some cases, earlier and greater revenues can result by getting the work completed and into operation at an early date. However a price has often to be paid, as reallocation of resources and changes sometimes involve increased costs. Thus the usual economic study problem of balancing costs against revenue arises, and frequently alternative choices exist. Clearly, the objective is to obtain the maximum benefits at minimum cost if a change is to be made.

COMPUTERS AND RESOURCES

Several resource allocation computer programs are available which can produce schedules which have taken into account limited availability of resources. Typical situations covered by some of the programs include the following:

(a) Two or more projects each with its own completion dates, and all of which have to be completed with the same basic set of resources.
(b) The resources required to finalise each job can be described in terms of manpower, materials, machines or money. These descriptions include resource type, combination of resource types, the amount required of each particular resource per unit of time, the total amount of each resource required to finalise the work, and the cost of interrupting the work once it has commenced.

Even with present day computer techniques, there is inevitably room for further development and the many methods currently in use are undergoing a process of continual development as more and more is learned about the nature of decision processes in this complex area.

However, notwithstanding the availability of many computer programs, many engineers consider there is advantage in manual assignment and analysis of manpower. Although manual loading of manpower resources takes more of the engineer's time, it does in many cases result in a more accurate and realistic summary in that he can allocate varying amounts of manpower over the time periods of the work function as he anticipates they will be needed, without reverting to an average manpower loading. Because average manpower loadings are used in many computer programs, the resulting manpower peaks as summarised by the computer will often be higher and the resulting troughs lower than might be realistically anticipated.

MANPOWER SOURCES

There are two sources from which manpower for a project work may be obtained: the staff of the organisation, and contractor staff.

Almost any project can be performed by contract staff but the ability of an organisation to perform its own work would be influenced by many factors. Some radio engineering organisations carry out their complete programme of works, even to the extent of manufacturing and producing a large amount of the material. Others may have a large professional staff to undertake feasibility studies, design and planning work, operations and maintenance, but contract all major installation and re-arrangement projects. In some situations, projects have been completed by a combination of organisation and contractor efforts.

The decision as to what manpower will be used will depend upon the policy of the organisation, the capability of the organisation, the availability of suitable contractors, the extent of labour requirements, the availability of outside resources, and the characteristics of the project. There are advantages and disadvantages in both schemes.

The advantages associated with the utilisation of organisation staff are:

(a) Maximum utilisation of local labour resources.
(b) Allows build-up of expertise of technical knowledge and experience within the organisation. This aspect may be of considerable benefit where the organisation will also be responsible for the operation and maintenance of the station or system.
(c) Eliminates profit on the work which would normally be payable to a contractor.
(d) Permits maximum flexibility and allows ease of modification to plans, should these be found necessary or desirable, during the course of the work.
(e) Makes maximum utilisation of staff whose long range well being is coincident with that of the organisation with whom they are employed.
(f) Eliminates scamping and poor workmanship by a high profit seeking contractor.
(g) Eliminates problems, effort and time involved in preparation of detailed specifications and tender schedules.
(h) Reduces overhead cost associated with contract administration and inspectorial charges.

The disadvantages of using organization staff are:

(a) Tendency to maintain a full installation and construction organisation when not fully justified.
(b) Real savings are usually not great. Administrative charges associated with drawing office, workshops, transport, costing, material expediting, mechanical aids may in fact be much higher than a contractor's costs.
(c) Difficulty often occurs in fixing responsibility when work deviates from programme in time or expenditure.
(d) Inspectors sometimes tend not to perform their tasks with the same zeal as when oversighting the work of a contractor.

In the case of a contractor's staff being used for the work, the advantages are:

(a) Availability of groups of specialists, experienced and accustomed to working together as a team, for example, transmitter specialists, mast erection riggers, power plant tradesmen etc.
(b) Availability or ready access to specialists who may not normally be employed by the organisation, for example, structural engineers for consultation on a mast problem, transmitter designers, micro-electronic experts etc.
(c) Expertise in project installation and commissioning works developed from long experience with many projects—large and small—under a wide range of situations.
(d) Availability of specialist installation tools, equipment devices and test equipment necessary to carry out the work efficiently, speedily and for proper evaluation during commissioning. Many specialist items of equipment and plant may be required to proof test or performance test a system during the commissioning operations but could not be justified as part of an operations or maintenance requirement.
(e) A high level of efficiency generally exists in the operations of a large contractor organisation because of acute competition in the field.
(f) A contractor can provide efficient follow-up service should the system require attention or modification at a later date.
(g) Availability of skilled manual writers to provide comprehensive information on the total system installation. This aspect tends to be left undone when an organisation purchases various pieces of equipment and installs the units to form a system.

The disadvantages of the use of contractor's staff are:

(a) The contractor's aim is to make a profit, and when unforeseen or unbudgeted work becomes necessary there may be a tendency to reduce the quality of workmanship in other areas to recoup these extra costs.
(b) On some projects, an impasse developed on certain contract issues and had considerable influence on the work schedule.
(c) Contractors are invariably late in providing data essential for the operation and maintenance of the system.

Design work may sometimes be undertaken by the organisation's own staff, but because of the many specialist areas involved in radio engineering, much work can often be carried out more efficiently by firms which specialise in a particular field. A good example of this is firms which specialise in the design and erection of masts, towers and earth station antennas. These firms have at their disposal a great amount of detail and experience concerning their specialist fields. They are usually in a position to offer alternative designs of equipment or plant which have been installed elsewhere. Also, their execution of the design utilises standardised, well proven and economic procedures which invariably result in an item involving minimum cost and ensuring satisfactory service.

ENGINEERING EFFICIENCY

Closely allied with productivity is efficiency. It denotes a comparative grade of operational or structural excellence ascertained by measurement and calculation. For any engineering device or process, it is broadly defined as the ratio of output to input when these quantities are appropriately specified and measured. A transmitter has its highest efficiency when the losses have a minimum value at the predetermined output. The same transmitter has the greatest commercial efficiency when the total operating costs including energy losses and capital repayment charges are a minimum.

Some forms of radio engineering plant, such as masts and towers, involve no cost for energy or energy losses from a mechanical view point. These structures which require considerable capital expenditure are chargeable only with the expense of maintaining them in good order and covering the interest and depreciation on the capital cost. When the amount of these charges is a minimum, consistent with safety, the structure has its highest efficiency. On this basis, a structure which requires regular painting because of aircraft warning requirements has a lower efficiency than one not requiring painting. The financial return of the structure may be considered to be dependent upon the hours of transmission while the outlay is the total sum of the expenses numerated. The question of actual cash receipts for the use of the structure does not immediately arise; it is one of the factors in the trading profit of the organisation but the more efficient the structure the higher would be the net revenue on the hours of transmission at fixed schedule rates. The revenue may vary depending on the use to which the structure is put. For example, a mast or tower used for a medium frequency broadcast station would have a revenue related to the number of hours for which commercial sponsorship would be available. Where the structure is used to support high capacity radiocommunication systems, the revenue would be related to the number of channels occupied and the duration of occupancy.

The efficiency of power driven equipment, such as a transmitter or diesel generating plant depends on many more variables than those associated with a mast or tower. Whereas maximum efficiency for a structure may be obtained by proper consideration of dimensions, shape, materials and finishes etc., in relation to stresses and environmental conditions, additional considerations in the form of power input, average depth of modulation, temperature, power supply variations and many others, may be necessary for a transmitter. For a diesel generating plant, size, speed, magnitude and characteristics of the load and other factors would have to be taken into account. Thus the development of high efficiency equipment and machines presents a more difficult problem than the economic design of a structure.

Economic efficiency within an organisation involves problems of selecting the combinations of resources to use and the techniques to use in carrying out the project work. The choice of techniques to use will depend upon relative resource cost and the quantity of work to be performed or product to be produced. The aim is to produce as efficiently, that is as cheaply, as possible. Thus if labour is expensive and capital is relatively cheap it may be desirable to use techniques making use of much capital and little labour. For example it may be more economical to use mechanical aids to construct antenna and transmission lines foundations of a large broadcast station complex than to employ labour at a high hourly rate. On the other hand, in a country where the capital cost of providing the mechanical aids is very high but labour is very cheap the most efficient arrangement would probably be the employment of local labour. However, cheap, unskilled labour may be of little use in a situation where a high degree of technical skill is required.

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Chapter 12

Engineering Budgets and Costing

In the final analysis, budgeting is simply a means of planning so that the best possible use may be made of all available resources in achieving certain defined objectives. It is an integral part of forward engineering planning and provides the means for measuring the efficiency with which these plans are put into operation. The budget establishes, in monetary terms, an objective of performance, and having been established with sufficient detail, it serves as a guide, as time elapses, against which to check actual performance and in turn to keep the performance on programme.

As a general rule, budgets for the provision or maintenance of the engineering facilities pass through three stages of developement:

(a) Preparation of needs or initial overall requirements.
The preparation of needs budgets is a decentralised operation. The needs or overall requirements are developed by those in day-to-day contact with the provision of the radio engineering services. They represent, therefore, a series of budgets, not necessarily co-ordinated, which are a guide to what ought to be done.

(b) Preparation of the co-ordinated realistic requirements.
The realistic budget involves decisions on competing claims to the use of probable resources. At this stage, budgets are integrated into an overall programme. The development of a programme structure requires that management subjectively analyse its goals, and relate them to overall objectives. In many organisations the co-ordinated programme covers a period of three years, prepared on a firm basis for the first year, with the second and third years more flexible. Because of the shortcomings of a three year period with present day large project expenditures, there is a tendency in many of the larger organisations to prepare the co-ordinated program for a five year period. This permits variations in the light of experience and other factors affecting priorities.

(c) Preparation of the annual budget.
The annual budget is developed from the co-ordinated realistic budget and represents what will be done during the ensuing financial year.

RESTRICTIONS OF ANNUAL BUDGETS

An organisation which has an annual budget system only is severely restricted in its growth. An annual budget has limited usefulness as a basis for comprehensive long term planning. It is normally broken down into function categories, such as operations and new works, rather than into categories which are related to organisational objectives. With budgets prepared on a year-to-year basis, it is a very difficult task to bring together all the costs which eventually result from a management decision to undertake a large project which may be spread over several years. This applies particularly to operating costs which do not become effective until the project work has been completed. Without adequate forward planning the situation could arise whereby overall operating costs rise steeply from one year to the next without management being properly prepared to meet the situation in this area. For example, a large new high power international broadcast complex with a large staff could involve an overall operating cost of £800 a day or more.

PLANNING AND IMPLEMENTATION

Two main factors associated with budgeting are planning and implementation. The essential features of planning are:

(a) The determination of priorities between the various competing installation and operation projects.
(b) Attention to long term as well as short term aspects of proposals and commitments.
(c) Consideration of expenditure over the various years for large projects which extend beyond a single financial year.
(d) Analysis of the short and long term economics of the projects programmed. This is an area where engineering economic studies are involved.
(e) Assessment of economic trends and their effect on demand for facilities and services supplied by the organisation.
(f) The assumptions, needs, and criteria which support the recommended programme.
(g) Identification of the main uncertainties in the assumptions and in estimated programme accomplishment or costs, and the sensitivity of recommendations to these uncertainties.

The essential features of implementation may be classified as follows:

(a) Determination of the extent to which it will be necessary to forward order materials, equipment, plant and services, and the dates that such orders should be placed to ensure delivery or provision on time to allow the target date for completion of the project to be met.
(b) Availability of staff and examination of staff recruitment and training programmes to see whether skilled labour will be available for the installation and subsequent operation and maintenance for all the projects planned.
(c) Final decision on projects involving provision of sites, buildings, site access road works and services in sufficient time to ensure accommodation and access being available when required.
(d) Development of associated and ancillary projects, such as supply of vehicles, mechanical aids, caravans for office or on-site accommodation etc.
(e) Firm estimates of costs of labour, materials, incidentals and administration charges for each project.

THE CO-ORDINATION PROCEDURE

In a very large organisation, such as one charged with the responsibility for providing national radio communication, television and broadcasting facilities and services, the engineering budget may proceed along the following lines:

(a) Preparation of area, zone or State programmes for each branch of activity (radiocommunication, broadcasting, television etc.), based on surveys of needs and built up in accordance with general policy. These would be framed on a three or five year basis.
(b) Determination of priorities within branch programmes in accordance with relative urgency, but adjusted in relation to such factors as probable availability of accommodation, equipment, services and trained staff.
(c) Integration of branch programmes into a co-ordinated area, zone or State programme arranged in order of priority.
(d) Co-ordination of the area, zone or State programmes on a national basis.

The final result is a single programme of works capable of achievement with the resources likely to be available.

MATERIALS PURCHASING BUDGET

The advance ordering of radio engineering materials is essential to the economic and orderly development of capital works, operations and maintenance programmes. Unco-ordinated delivery of materials invariably leads to uneconomic utilisation of the workforce and slippage in the schedule.

Each year the engineering department seeks authority to place orders for material for delivery in subsequent years. When authorisation is received, a series of budgets covering each group of materials to be ordered is approved. These are related as closely as possible to the planned programme for the years concerned. Before an order is placed, it is usual in many organisations for a certificate to be given to the accounts department that the proposed order forms part of a specific budget and that its placing will not cause the total authorisation to be exceeded.

The balancing orders which would be placed on a short term basis are budgeted for on an approximate basis at the time of preparing the advance ordering programme. These are assessed in greater detail at a later stage and the same general procedure is followed as in the case of advance orders.

Considerable importance is invariably placed on the budget method of control on the materials side. For instance, all advance engineering purchases are covered by budgets related to the prospective programme for the ensuing year, and even further for certain materials and plant such as masts and towers, large transmitters, diesel generating plant etc., where production schedules are lengthy. These budgets are not prepared in isolation but considered in relation to the short term purchases which will be necessary. These are purchases which can be initiated during the year of the programme itself.

Because of its nature, many items of radio engineering equipment and plant must be ordered well ahead of the date required for installation or maintenance purposes. Delivery times of 12 to 24 months and sometimes 36 months apply to some types of radio materials. Other items can be obtained off-the-shelf or within a few months. Under these long lead time conditions, careful planning of purchases is necessary. However, too heavy forward ordering can result in insufficient funds being available at a later stage to purchase associated material available on short term orders. In addition, material ordering must be balanced with respect to the works programme, that is having decided the nature of the programme material should be purchased fairly accurately to provision this programme.

Prior to approving the budgets for purchase in any year, including forward ordering, a careful analysis is made of the:

(a) probable usage of materials,
(b) probable deliveries of materials,
(c) possible cost rises e.g. from wage agreements,
(d) labour and overhead costs in stores and workshops.

When the total funds for collective purchase are determined, a detailed budget is prepared in which amounts are allocated to the various classes of material taking into account the many factors affecting the level of purchases for each class. The budget at this stage shows as accurately as possible the value of materials to be ordered in advance of the financial year and prediction of the value of material to be ordered on a short term basis, after the beginning of the financial year.

As the budget in the first place is prepared on a fairly broad basis in regard to the split-up between classes of material, some flexibility is desirable, and variations are made as found necessary when detailed consideration is given to each purchase. However, the overall ordering is controlled within the total amount of the budget.

FLEXIBILITY IN BUDGETING

The actual operating conditions often differ considerably from those assumed when the budget is being prepared. Material delivery from contractors may have fallen behind schedule, unforeseen wage rises may have been granted, wet weather may have seriously hampered progress on external plant works and many other changes may have occurred which make it unreasonable to expect the operating results to conform to those set down in the budget. In order to properly handle these situations, a degree of flexibility is required in the budget. It has been found that the presence of rigid restrictions leads to a less than optimal adaptation to change whilst under particular constraints. Several means of securing such flexibility are available and include alternative budgets, flexible budgets and regular revisions. However, regular budget revision is the most widely used method in radio engineering project practice. The others are more suited to organisations that make a single product or perform some basic operation for which volume of activity can be readily defined.

The general practice is to revise budgets regularly at the end of each quarter. However, in some organisations where large expenditures are involved, monthly revision is carried out. Often the budget will be computed for a year ahead, then at the end of each quarter the budget for the quarter immediately following will be revised on the then current conditions and if desired a new budget for the twelve months ahead can be added. In this way it always provides a general picture twelve months ahead to govern the basic plans of the organisation and a specific estimate of the immediate future to serve as the foundation of day-to-day operations. This practice is widely used for maintenance aspects of large networks of radiocommunication or broadcasting systems.

There is a tendency on the part of many people to regard budgets as a control or a form of management itself. A budget is nothing but a tool and as such should be looked upon as an aid to intelligent management and nothing else. It is based primarily on estimates that depend for their accuracy upon experience, good judgment and accurate information. Hence should unpredictable circumstances occur and which completely cancel a budget's worth, previous estimates should be discarded and new ones made to fit the conditions better. A budget should never be allowed to stand in the way of progress but be changed to assist in that direction.

BUDGETARY CONTROL

The introduction of budgetary control in engineering management has arisen from the realisation of the importance of planning operations with an ever-watchful eye on the future. However, budgetary control is not merely a forecasting system. It involves a concerted plan of action based on a careful consideration of all relevant tendencies and factors, and it is in itself a complete system of controlling costs and preventing waste.

The essential features of budget control are that it enables an objective to be established from the consideration of the probable course of events in the future, it enables policies to be formulated to ensure that all activities are co-ordinated to enable this objective to be met, and it provides a means whereby achieved results can be measured in the light of the preconceived plan to provide a check on progress towards the desired target.

With delegation of authority principles applied in modern organisations, there is an implicit necessity for some means of ensuring that the major plans are put into operation. The realisation of this fact has been one of the main tendencies leading towards the adoption of the budget control system. This delegation of authority has led to the necessity for some method of co-ordinating the activities of the various branches and sections, and also for some measure of the efficiency of project management.

It must not be thought that a budget is designed to turn project management into a mechanical operation or that it is intended in any way to act as a bar against the exercise of personal initiative. Its object is to guide rather than to control. The idea of preparing a budget is not, essentially, to lay down rigid programmes, but to indicate what will happen if certain plans are followed. Its aim is to enable the most practical and profitable policy to be established for the future and to provide a milestone or indicator against which actual progress towards this end can be measured. It also aims at providing an indication of impending weakness and dangers sufficiently far in advance to enable precautionary measures to be taken in good time by the project manager.

To ensure success, before any system of budget control is put into operation, there should be a clear understanding on the part of the management of both how the system is to operate and what objects are in view. The nature of budget control is such that all the various estimates involved are strictly interdependent.

It is consequently very necessary for arrangements to be made to ensure that they are prepared in a logical sequence, and it is unwise to commence the operation of a budget system before those arrangements have been made and before a comprehensive procedure has been established to govern the preparation and use of the various estimates.

The need for correlation of accounting and organisation is important for budget control. Also, it is necessary that the budget system should be constructed on the same plan so that actual results can be compared accurately with budget forecasts and responsibility fixed on the appropriate project manager for any failure to meet the estimate. The necessary preparation for the introduction of budget control, therefore, involves careful consideration of aims and objects, the establishment of a properly aligned organisation to establish the delegation of authority, and an interlocked system of budgets, accounts, costs, reporting, monitoring and organisation.

COSTING

Costing involves finding the cost of undertaking separate classes of work such as erection and maintenance of masts, installation and maintenance of radio equipment, power plant etc. or finding out the cost of undertaking separate types of work, such as the cost of establishment and operation of a broadcast station, television station, radio relay station, radar station, earth satellite station etc. Cost control has to do with the organisation, administration and control of the cost procedures necessary for the work, and its primary functions are to document historicial costs and to compare those costs with the original estimates. Methods of collecting and allocating costs are a fundamental part of the plan for managing the engineering department, since intelligent planning is extremely difficult without accurate knowledge of costs.

Whereas accounting is a record of financial transactions, costing besides recording operations allows greater scope for planning and analysing results with the definite object of enabling management to control better the factors of installation, operation, maintenance and production. Costing seeks to measure the results in terms of unit installation, erection, operation, maintenance or production, and the basis of measurement is not confined to only money values as in the case of general accounting. Besides accounting for the money expended in the process of the work, costing seeks to test the efficiency of the factors of installation, maintenance etc. and to indicate areas of waste and inefficiency. To do so, all expenditure whether for labour, materials, administration charges or incidental expenditure is classified and analysed in relation to the cost per operation or cost per unit of outlay. Consequent on the maintenance of an efficient costing system, management investigation may reveal instances of defects in the organisation, procedures and methods covering such matters as inefficient or unsuitable plant, idle machine time, excessive use of transport vehicles, incorrect material lists on drawings, spoilt materials, excessive spares holdings, etc.

No costing system can of itself either reduce costs or increase output. It can but record facts. The question is, does it record the right facts and present them in such form as to reveal operating inefficiencies? If it does so then the task of exercising directive control over the inefficient factors of installation, operation, maintenance or production, devolves upon engineering management, whose efforts if successful should be apparent in future cost statements.

It is very seldom that costing for radio engineering projects is carried out on site as is the practice for some large civil engineering works. More often, the costing is carried out on a centralized basis at the head office of the organisation and copies sent to the resident engineer when complete. From the costing information the engineer and supervisory staff can see if the site works are being achieved within the planned or estimated cost and schedule, and whether incidental and overhead expenses are within the allocation.

Costing data from many previous projects may often be used to a reasonably high degree of accuracy for future estimates. As the estimator will usually be aware of various productivity conditions affecting projects with which he has been associated, costing data can usually be interpreted to future situations. It is good practice for copies of all pertinent costing data to be collected and categorised for future reference. In order to predict costs the estimator must have information concerning either historical costs or the relationship between cost and technology.

Computer systems are now widely used in the preparation of costing information. One broadcast organisation with a technical staff of some 6000 and an annual capital works programme in excess of £11 million uses a database system. The system deals with a large amount of data relating to capital projects and the operation of transmitter, studio and programme networks. The database system is designed around only three physical files designated WELL, INDEX and LINKS. It is known as EMIAS which was derived from the words Engineering Management Information and Accounting System. Financial data relating to 700 engineering cost centres involving more than 3500 capital projects are stored in the system.

BENEFITS OF COSTING FACILITIES

Many benefits accrue from the establishment of a proper system of costing records. Some of the services and facilities provided include:

(a) The ascertainment of actual costs of installation, erection, assembly, operation, maintenance or production, thus furnishing guidance in estimating and in deciding what plant and designs are more economical or profitable to install, operate, maintain or produce.
(b) The preparation of periodic comparisons, generally on a monthly basis, of actual versus programmed total cost for each project.
(c) The preparation of periodic comparisons, generally on a fortnightly basis, of actual versus programmed manhours.
(d) The presentation of concrete facts with which to judge the efficiency of branches, sections, work groups, stations or systems.
(e) Indication of a warning of any operation or work which may be running at a loss or inefficiently and is therefore in need of special management attention.
(f) Indication of leakages, waste or theft of materials and plant.
(g) The provision of factual data arising from a particular project contract for the assessment of variations and extras which require the calculation of new prices.

(h) The establishment of standards for overhead expenses and the localising of increases of unproductive labour, material and indirect expenditure, with the object of controlling and reducing.
(i) The provision of information which can be stored for reference for future tendering purposes.
(j) The establishment of a basis of normal operating capacity or output. This is important in relation to overhead apportionments and also in regard to determining and promising delivery or commissioning dates.
(k) The auditing of project works.
(l) The up-dating of cost-to-complete project reports and funding schedules.
(m) The sponsoring of cost-improvement programmes.
(n) The supply of costing statistics for management reports, etc.

While in the financial books of account, the various classes of expenditure are kept in separate accounts such as wages, salaries, materials, light and power, depreciation, general expenses, etc., for costing purposes the whole of the expenditure is divided into four main groups of labour, materials, incidentals and administration charges. The system of costing merely consists of the current recording of the expenses in these groups in such a manner as will facilitate the ascertainment of the proportion of each group which is equitable to charge each work performed.

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Chapter 13

Engineering Organisation

The best form of organisation is that which furnishes the most effective and direct means for the operation of management. No matter how high the efficiency of management, experience has shown that it cannot operate effectively through a bad organisation. However brilliant the personnel, however progressive the policy of management, its full effects cannot be obtained through a form of organisation in which

(a) Work is unscientifically divided between branches, sections, sub-sections or individuals.
(b) Duties are not properly and clearly defined and which overlap.
(c) Responsibility is divided between groups or individuals.
(d) There is no provision for understudying.
(e) Some individuals have too much to do while others have too little.
(f) No management exists for full co-ordination of effort.

To achieve the best, both good management and good organisation are vital. Just as radio equipment is chosen to carry out a specific function, so the form of organisation must be designed and adapted to suit the type of management which is to be installed.

ORGANISATION REQUIREMENTS

The general results which may be expected from a sound organisation include the following:

(a) Stability and endurance.
The form of organisation should have the capacity to endure and develop. Changes in staff and methods are inevitable, but the establishment should not be thrown out of balance simply because of changes in personnel, no matter how indispensible these individuals may appear to be. The organisation should be sufficiently flexible so that it can be adjusted to changing staff and technology. This applies just as much to a single station employing only a small workforce as to a major communications organisation employing thousands of people.

(b) Cohesion and co-ordination.
The more necessary it becomes for work to be divided between branches, sections and individuals, the more it is required that there be some machinery to ensure corporate working and the direction of all the parts towards a common objective. The form of organisation should therefore provide for co-ordination so that the work of each group is scientifically related to that

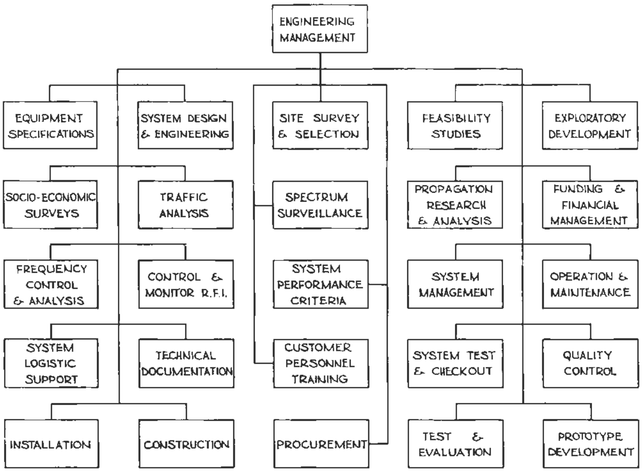

Figure 13.1 Capabilities of a large organisation engaged in total communications systems

of others, that both overlapping and unallotted areas are avoided and the whole is employing its energies for a single purpose. The crux of high performance of any project lies in the effective inter-relationship between organisational structure and individuals. The necessity for this is well illustrated by *Figure 13.1* which shows the wide range of activities undertaken by one large engineering organisation specialising in 'total' communications systems.

(c) Facility in working arrangements.
The machinery set up for carrying out the activities of the enterprise should primarily be designed to facilitate the most economical and effective working arrangements. An organisation which impedes the proper practice of management is wholly opposed to what a good organisation should be. There must be clear lines of authority running from the top to the bottom of the organisation.

(d) Clearcut duties and responsibilities.
Each individual should be provided with a clear set of duties and an unqualified responsibility for their execution. No form of organisation can be considered to be satisfactory which either leaves an individual in doubt as to what his duties are or which divides the responsibility for their execution. Responsibility should be matched with corresponding authority.

The responsibility and authority of each supervisor whether he be in charge of an installation cell or station should be clearly defined and communicated to him.

(e) Normal capacity of the individual.
The form of organisation should provide for the allocation of duties according to the normal capacity of the individual. Some people may be capable of executing a particular set of duties much more effectively and efficiently than others but the position duties themselves should not be altered to suit men who are either above or below normal capacity. Also, the work of every person should be confined, as far as practicable, to the performance of a single leading function.

(f) Single and direct leadership.
The organisation should ensure a single and direct leadership of the station or project workforce. Only a single competent leader can correct the tendencies which functionalism and division of labour create. Only the leader can keep the group committed to that unity of aim which alone produces the optimum results.

The structure should be such that no one is required to report to more than one line supervisor. Every member should know to whom he reports and who reports to him. At many large stations an assistant manager may be provided to assist the station manager and the relationship of the assistant manager with staff should be clearly defined.

ORGANISATION DESIGN

The building of an organisation is something quite distinct from the use of an organisation for purposes of management. Just as the design of a transmitter is different from the control of the transmitter in operation, so is the designing of a form of organisation different from the managing through an organisation.

Having defined the broad requirements above, it is possible to outline the particular features which must be introduced into the form of organisation designed to achieve these requirements. The main features conducive to these ends may be summarised as follows:

(a) Functionalisation of the higher management.
Functionalisation is the grouping of the necessary activities of the engineering department according to scientifically determined lines of demarcation, irrespective of works, products or processes of manufacture etc. In the functional form of organisation the department is divided, not according to the products, but according to a scientific grouping of work. Instead of each branch or section being responsible for its own costing, planning, recruitment and discharge of permanent staff, union negotiations and training of apprentices and cadets, the functional principle requires the setting up of a costing section, planning section or branch, staff and industrial section and so on, each one of which is responsible for its own functional activities on behalf of all branches or sections.

(b) The scientific planning and central control of the organisation.
It is often not easy to determine what the functional divisions should be, nor having determined them, to ensure that all work together for the common end. It is necessary, therefore, to analyse what activities are essential in the conduct of the business of the engineering department, what their relationships are to each other and what is the relationship of the higher parts of each to its subordinate parts. For example, if it is decided that one function is planning, it is necessary to determine precisely what planning is, what the relationship of planning should be in connection with new installation works and what the relationship of the planning of the work of each branch or section should be to the planning of the work for each project.

It is evident that the greater the degree of functionalisation, the greater the need for co-ordination. If one branch or section is costing the project, another planning the project, another carrying out new projects and another carrying out the operation and maintenance of those projects, obviously there must be some machinery to weld all these project activities together. It is therefore essential that at some point, all functions must concentrate and come under a common direction from above.

(c) The establishment of co-ordinating officials at various points in the organisation.
There must be co-ordinating officials at various points in the organisation. In an engineering department concerned with, say the manufacture of products such as radio equipment, these officers could be the manufacturing managers. However much the theory of functionalisation may be elaborated, the basic fact remains that the backbone of this particular organisation is the making of the equipment. All the activities of costing, staff employment etc. are subsidiary to this main business of manufacture. Their purpose is to serve the manufacturing process. It is logical therefore that the control of manufacture should be the point at which all the functional activities are co-ordinated. However, it also has to be kept in mind that there is a practical limit to the number of positions that can be co-ordinated by a single individual.

(d) The proper and regulated use of committees.
The proper and regulated use of committees is a feature of the form of organisation which will yield the results outlined above.

Committees are normally necessary for two main purposes: to act in an advisory capacity to management and to co-ordinate its activities. For instance the project construction manager may feel the need for an advisory committee to assist him in carrying out a policy relating to safety.

(e) A planned system of understudying.
If an enterprise is to persist and develop, it is essential that the continuity of policy should be preserved. This can only be achieved by provided for understudies for all important positions in the organisation. The absence or departure of any responsible official should not occasion a break in policy or execution. There should always be someone available to take over the work. This does not imply that a position of understudy should be created in the establishment, but rather that the work which has to be done in any area should be so allocated that there is always one junior who, by the very nature of his work, is qualifying to occupy the position above him. It is therefore largely a problem of grading and proper distribution of duties. It is, however, an important factor from the point of view of stability.

(f) Individual foremanship.
Just as the head of the engineering department forms the point at which all the activities of the functional branches, in so far as they effect his department, are co-ordinated, so the foreman or station supervisor in charge of a station or network forms the point at which all functional activities in so far as they effect his section or group are co-ordinated. He thus becomes the representative to his workers of the whole body of the management. Above him may exist a vast organisation covering the whole enterprise from design of the product or equipment to its eventual sale or installation.

The plan of the organisation therefore must be so designed as to ensure that the workers are directed in their work, not by a multitude of officials with different interest but by one official—the foreman, station supervisor, resident engineer or project manager—who stands in their eyes as the representative of all those interests.

(g) General knowledge of the organisation structure.
The whole form of the organisation should be known to all concerned with the management of the engineering department. The positions and duties of each member of the organisation should be appropriately publicised. This means that the organisation charts of the department should be published and distributed so that there can be no lack of definition either as to duties, status, authority, or responsibility. However, an organisational structure which is only a chart showing the relationship between various groups, is of little real value in itself although it is an important step. The working relationship must be factually established.

In practice, some of the foregoing principles are frequency neglected and resultant problems encountered include

(a) Organisation not designed to accomplish specific goals because of failure of management to think through the objectives of the function or department.
(b) Relationship with other functions necessary to accomplish goals not being clearly defined.
(c) Staff functions not clearly separated from line functions. Difficulty is often experienced in properly defining the role of staff with relation to line, and the optimum size of staff in the total organisation.

ORGANISATIONAL PLANNING

Organsiational planning is the management process of grouping tasks, portraying authority and responsibility and establishing working relationships that will enable both the engineering department and the individual to realise their mutual objectives. Factors which have to be taken into account include the structure of the enterprise, manpower needs and availability, environment, potential and expansion programmes.

A sound organisation is fundamental to the success of any engineering department but it has to be realised that organisation must be brought about in terms of people. It matters very little how perfect the organisation structure may appear on the chart or in a manual. It is lifeless without persons to occupy the various positions shown on the chart. Also, a considerable amount of matching is often required to obtain the right persons for the various positions, but it is very seldom that the proposed ideal organisation matches perfectly the actual organisation. Another aspect is that objectives and philosophies sometimes change and the structure and policies must be amended to meet the new requirements. With reworking of organisation plans, rematching of many positions and personnel may be involved.

A soundly based organisation plan enables changes to be made as the need arises. It must be sufficiently flexible to cater for changes, particularly those changes associated with expansion. Where no plan exists, changes generally have to be made on the basis of expediency and often the changes fail to realise the fundamental requirements, and may introduce organisational errors.

The functions of an engineering department organisational plan may be briefly classified as follows:

(a) To set down the objectives and philosophy of the engineering department.
(b) To set down the responsibilities of the various branches, sections and sub-sections.
(c) To show the organisational structure and the inter-relationships of various groups, with the aid of functional diagrams, organisational charts, matrix charts, position descriptions and other such models as may be necessary for a full and proper description.
(d) To set down policies with regard to delegations of responsibility and authority, line/staff responsibilities, and other important functions.

The most effective type of organisation is influenced by many factors which include

(a) The magnitude and pressure of tasks.
(b) The nature of the engineering activity.
(c) The number of major tasks being handled.
(d) The importance of uniqueness of the tasks.
(e) The extent of common activity in the various major tasks.
(f) The degree of involvement and numbers of specialists.

The most common types of organisations used in a radio engineering environment, include project, section and matrix types. There are many variations, with the nature of the engineering activity affecting the type of organisation used.

PROJECT TYPE ORGANISATION

The project type of organisation can be described as the separation of a group engaged in the engineering of a specific project. It is typified by the fact that the task is under the technical and administrative direction of a project engineer and the project is almost autonomous and self-contained. Because it is self-contained and handles practically all the essential activities needed to accomplish the task, it is almost possible to divorce a project from the rest of the organisation, and in this way create a separate and self-sufficient organisation.

The project type of organisation finds its greatest application under the following situations:

(a) Tasks which are unique.
(b) Tasks which require a high degree of technical and financial control.
(c) Tasks which involve the solution of many important technical problems.
(d) Tasks of high priority and importance.
(e) Tasks involving tight schedules and restricted budgets.

Where many large tasks are undertaken, there may be several project engineers, each with a staff and supporting technical personnel. These project engineers would generally be under the control of a chief project engineer. *Figure 13.2* shows a simplified organisation structure for a large radio engineering authority involved in the design, installation and construction of broadcast, television and radiocommunication networks. There are three projects, each with necessary

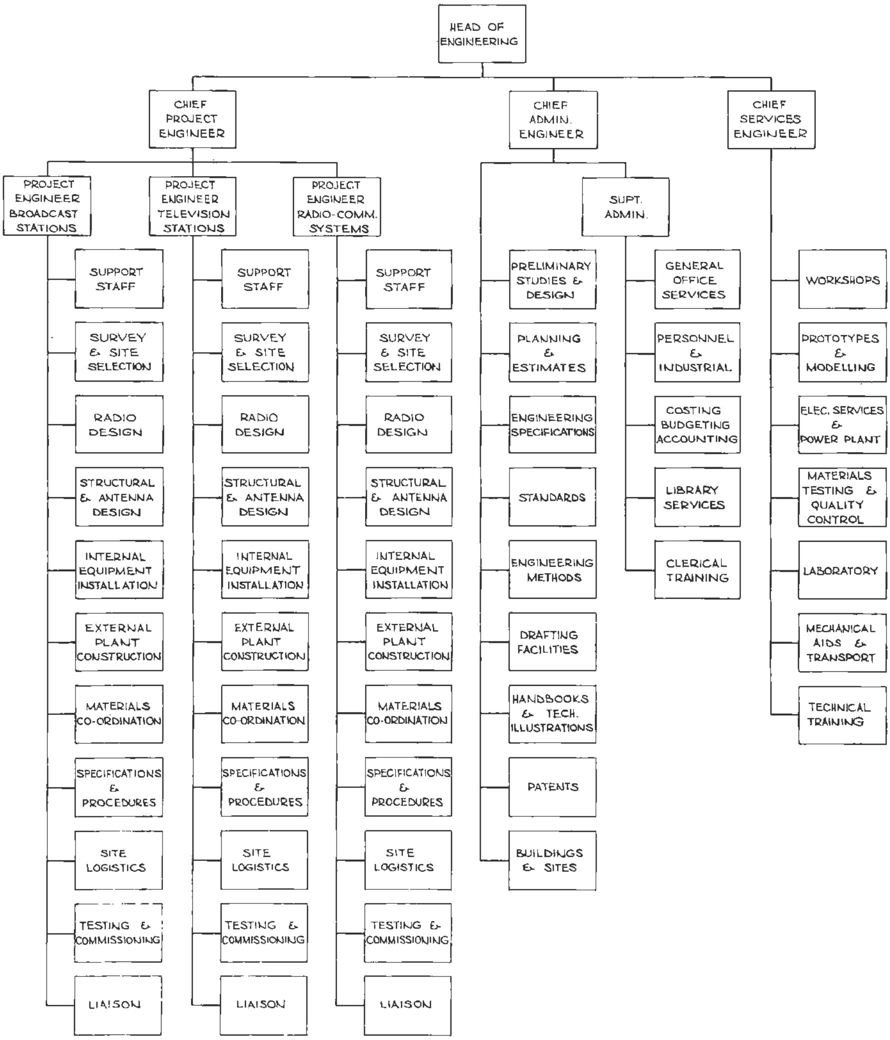

Figure 13.2 Typical project system organisation

support to carry out its task and under the control of a project engineer. It is evident from the diagram that most technical and administrative services are common to all three projects. The services and administrative sections provide all additional support necessary to complete the tasks. Part of the function of the chief administrative engineer is to handle the preliminary studies and design aspects of a task to such a stage where the details are sufficiently advanced that they warrant project status. Often the chief administrative engineer handles the tasks through the proposal stage, and the chief project engineer takes over at the contract or approval-to-proceed stage.

The project type of organisation is a continually changing organisation. It is either accelerating or decelerating, and a project by its very nature must finally be wound up. Because the project is finite in duration the organisation structure tends to be adaptive to the environmental conditions. Nearly every large project will pass through conceptual, establishment, implementation and termination stages during its life cycle and as the task progresses through these stages, there will be continual changes in the project size and structure.

Many engineers consider that the advantages of the project type of organisation lie mainly with the project engineer, because of his independence and autonomy.

The principal advantages may be summarised as follows:

(a) Given adequate resources and facilities, the team will function at high efficiency.
(b) Staff obtain experience in a wide range of radio engineering activities.
(c) There is one information source.
(d) Good co-ordination of effort, because of centralised location and control of the workforce.
(e) Each team can specialise in a particular type of project and so acquire a high degree of skill and efficiency.
(f) Each project is given full time and individual attention, and pressure can be applied at the appropriate points in order to overcome inertia which is inherent in many large tasks.
(g) Instructions are expedited because they do not have to be channelled through other sections. They are issued direct to the working level.
(h) There is considerable inbuilt flexibility, provided that the project is not too large, and the number of personnel assigned to the task can be increased or decreased rapidly in order to meet the demand situation.
(i) Original thinking is stimulated among the designers because they are not restricted by specialist groups, and also because of continual regrouping of personnel of varying talents and experience.
(j) Only one learning period is required, since only one group of people is involved.
(k) High morale is a characteristic of a project team because of the close association and identification of the individual members with the goal.

Because of the independence and autonomy, some managers consider work of varying quality results, and for the same reason, inconsistent operating policies also occur within the organisation. These and other disadvantages may be summarised as follows:

(a) For a large project, an excessive work load is placed on one individual.
(b) Inefficiency may result where work assignments are given to individuals who may not be fully qualified to handle the particular task.
(c) There is often less uniformity of output because there is no co-ordinating body to ensure uniformity among the teams.
(d) Inefficient use of manpower may result in the event of shortage of materials.
(e) It permits inconsistent operating policies within the teams.
(f) It permits duplication of facilities and personnel.
(g) The apparent lack of stability, for promotional purposes, discourages staff from joining project teams.
(h) A project engineer, who is determined to impress management by breaking schedules and undercutting costs, may sidetrack standard procedures.
(i) After completion of the task it is often difficult to check back with designers or installers, as they may be assigned to other works elsewhere.

(j) With increasing expansion of a large project, co-ordination problems may occur, resulting in the evolution of other types of organisation within the project.
(k) Permits multiple representation to outside bodies as each project may handle its activities, such as material purchases, independently.
(l) Since there may be no reservoir of specialists in functional elements, staff may be held on a project longer than they are really needed.

SECTION TYPE ORGANISATION

The section type of organisation consists essentially of a number of teams of homogeneous specialists with each team headed by a section engineer. For tasks where project engineers are involved in this type organisation, the tasks are under the administrative direction of the project engineer but the section engineer is the person responsible for the technical direction.

The chart of *Figure 13.3* shows an organisation carrying out the same type of work as that in the previous case, but using the section type of organisation. The three section engineers still retain their support staff, but a chief design and installation engineer has been included at a level equal to the chief project engineer. The chief design and installation engineer has under his control chief section engineers in charge of radio design, external plant installation and internal plant installation and internal plant installation activities. The chief administrative engineer and the chief services engineer carry out the same function as in the project type organisation.

The advantages of this type of organisation may be briefly classified as follows:

(a) Provides flexibility in the utilisation of skilled staff.
(b) Tasks of a specialist nature can be carried out efficiently.
(c) A high degree of stability and promotional opportunity exists within the specialist team.
(d) Expansion is easily handled by breaking off segments of work and forming additional groups.
(e) Specialists can be grouped into a team so that the experience gained on one task may be used on another.
(f) Permits uniformity of output because effort is consistent and related to past tasks.
(g) Provides a consistent approach and subsequent solution to design and installation problems.
(h) Reduced duplication of design work and also repetitional errors in basic design.

The principal disadvantages of this type of organisation are:

(a) Co-ordination between specialists is not always easy to obtain.
(b) Technical specialists are often required to spend a large portion of their time on administrative functions.
(c) Pressure from project engineers to meet schedules often creates friction with technical specialists who may consider solution of a technical problem of more importance.

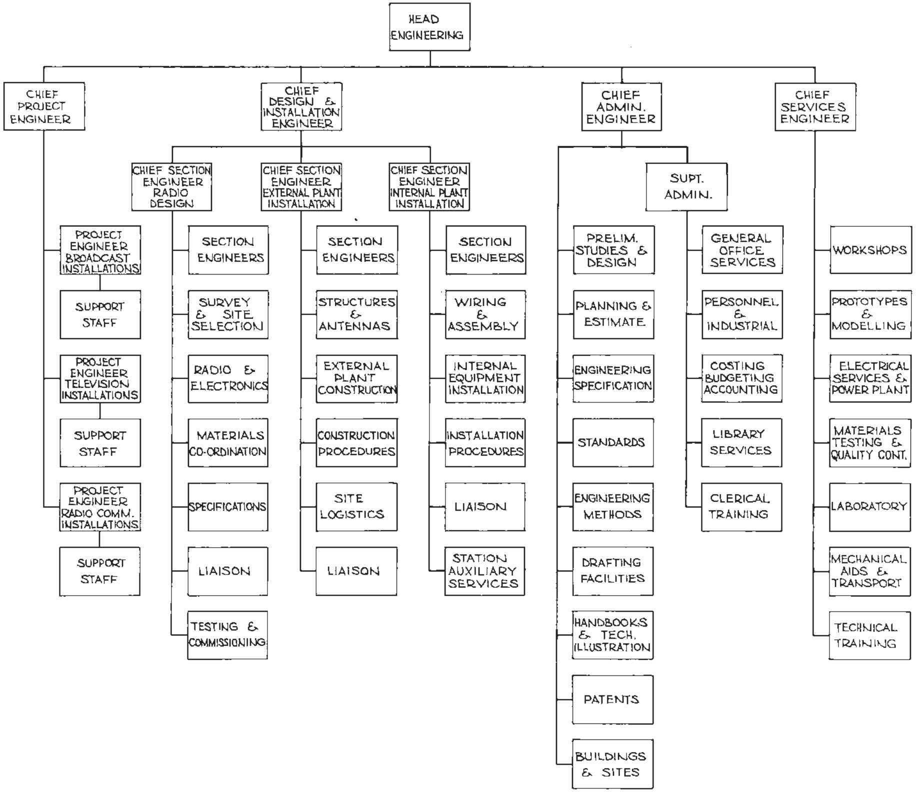

Figure 13.3 Typical section system organisation

(d) Because there is a leader for each specialist section, multiple supervision sometimes occurs.
(e) Where a high degree of specialisation is necessary, there is little flexibility in the movement of staff from one section to another.
(f) It is often difficult to expedite work flow through several specialist sections.
(g) The establishment of priorities is not easy to achieve.

MATRIX TYPE ORGANISATION

The matrix type of organisation is a combination of the project and section type structures and is used to establish a flexible system of resources and procedures in carrying out large complex projects with tight schedules, high technical standards and within fine financial limits. Changing conditions in modern radio and electronic technology have caused management to create new relationships of organisational principles in order to make more efficient use of resources, including skilled technical staff. The degree to which the project type or the section type of organisation is used is determined by the particular requirements and nature of the tasks.

The matrix organisation finds its greatest application in handling large separate project tasks rather than in standardised tasks of large volume. Each project is under the control of a manager who has the authority, responsibility and also accountability for ensuring satisfactory completion of the project in accordance with the specifications, schedule and budget allocation. The project manager's staff numbers will depend upon the degree of centralisation and magnitude of the task and may vary from one–the manager only–to a hundred or more.

Figure 13.4 shows a simplified organisation developed along these lines for handling three major radio communication projects. Additional projects can be easily added to the organisation and when a project is completed it is simply deleted. It is a very flexible organisation. The line organisation develops from the project and the functional sections provide support for the project line organisation.

When approval has been received to proceed with a project, a manager is appointed to control and implement the task and is allocated specialist personnel within each functional section, in sufficient numbers to allow the work to be properly carried out. The manager is in full control of the sub-section assigned to him for the duration of the project. He is fully responsible and accountable for successful completion of the task and consequently has full control over the allocated functional sub-section staff, for the work they do and their assignment. Upon completion of the task the members return to their nominally appointed functional positions for re-assignment to other tasks.

In the chart, the line functions are shown horizontally, and the support assistance involvements by the functional sections are shown vertically.

The concept of this type of organisation envisages a grid relationship of task performance rather than pure line and staff relationship. This is a radical departure from the line–staff organisation principle used for many years in engineering organisations. The extent of the resource allocation for each particular project depends upon the project's magnitude, extent of research and development necessary and the priority.

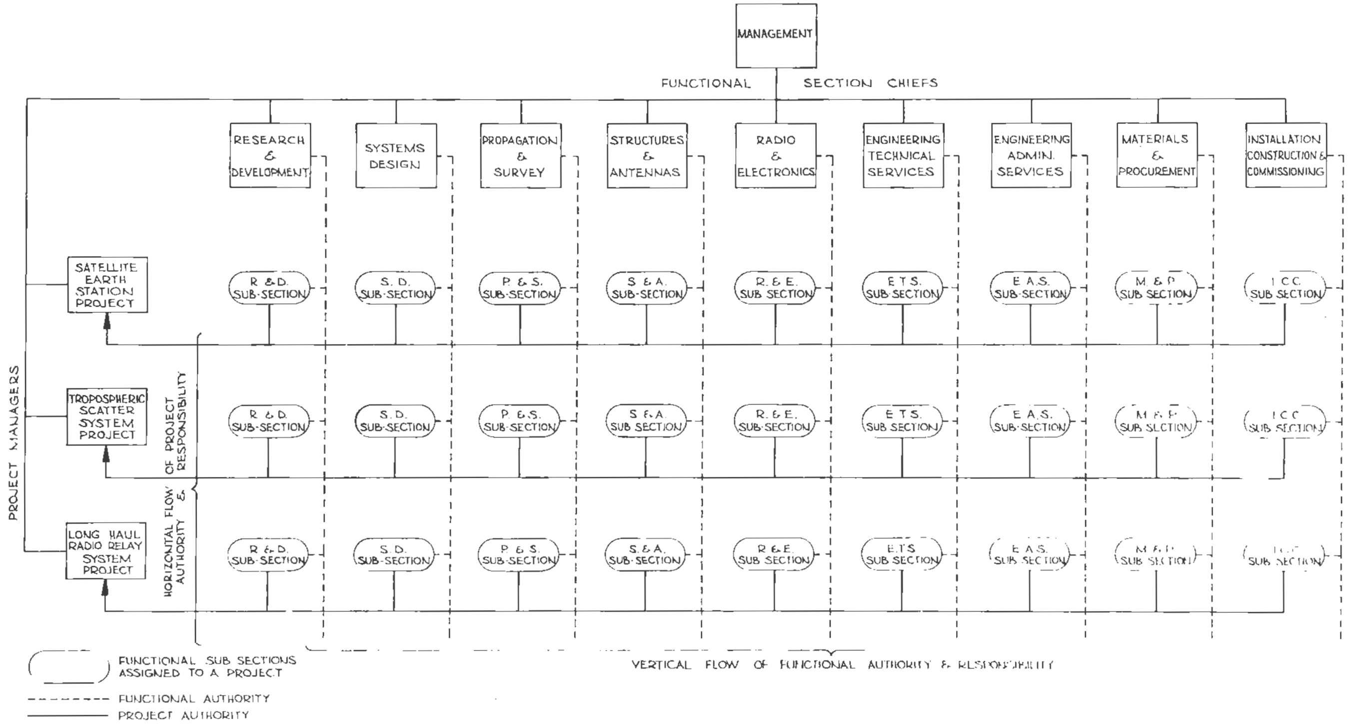

Figure 13.4 Typical matrix type organisation

The main responsibilities of the functional sections are:

(a) To ensure the proper quantity and quality of output.
(b) To assign groups of personnel of appropriate numbers and qualifications to accomplish the allocated task.
(c) To organise the necessary facilities from within their resources to ensure that the allocated task can be properly carried out.
(d) To form and train a stable workforce skilled and capable of supporting the particular discipline of the section.

The project manager, who can be considered as heading an array of diverse groups working on a particular task, has the following main responsibilities:

(a) Integration of inter-functional and inter-organisational interests pertaining to the broad task.
(b) Arranging for line groups to carry out the sub-tasks.
(c) Establishment and maintenance of proper communications and direction, to ensure attainment of the objective.

Advantages of the matrix type organisation are:

(a) One person is responsible and accountable for ensuring satisfactory completion of the task. It identifies one individual who is responsible for the project.
(b) Greater responsiveness to task needs, because decision points are centralised and lines of communication are established.
(c) Permits a high degree of specialisation, with maximum efficiency.
(d) Experience and knowledge gained on one task can be transferred to another.
(e) Consistent output and standards can be maintained.
(f) Promotional opportunities for staff within their function section is retained.
(g) Checks and balances between the project and functional organisation results in better balance between cost, time and output.
(h) Specialised services are available to all projects on an equal basis.
(i) Staff return to their appointed functional position after completion of each task and so facilitate rapid wind-up of the project.
(j) Project managers know whom they are to contact to get greater effort in order to speed up particular phases of the task.
(k) Provides a single point for customer contact and service.

Disadvantages of the matrix type organization are:

(a) Priorities are not easily established when several major projects are involved.
(b) Balance of power between the project manager and functional sections must be controlled, in order that one does not usurp the power of the other.
(c) If one project is very much larger than the others there is a tendency to concentrate the resources on the larger effort at the expense of the smaller tasks.
(d) The activities of each section must be closely monitored to ensure that proper balance of time, cost and performance is maintained.

There are many combinations of the above types of organisations in existence and each type has particular advantages but none can be considered best for all radio engineering applications. Every organisation structure must be formulated to meet the specific requirements of the enterprise. Also with the rapid changes taking place in management systems, technological developments and work practices, the organisation plan must be flexible. An organisation structure this year may be inappropriate next year.

The organisation often has to be changed as the environment changes, but this creates problems, sometimes with decreased general efficiency for a time. Working in an environment characterised by change as new projects are started and others wound up is not as conducive to comfort, security and high morale as carrying out a continuing task in a standardised work flow situation which is more stable. However, regardless of the problems, some change will always be necessary.

INTEGRATIVE AND CO-ORDINATIVE RELATIONSHIPS

Within this organisation, the executive maintains a consciousness of its individuality as an institution, yet he sees also the individuals within the organisation linked to each other and to the enterprise, and to other external institutions by a complex network of groupings and relationships. If he is to properly influence the organisation he must have a thorough understanding of how the organisation functions and a key to this understanding is a model which shows the integrative and co-ordinative relationship of every controller within the organisation. The model should depict the type and degree of authority exercised by each controller in performing a task where the co-operation and work of others is involved.

INTER-RELATIONSHIPS

The informal relationships are almost as important as the formal relationships to the effective working of an organisation, but they are not shown on the traditional organisation charts. Traditional pyramidal organisation charts do not adequately show the true inter-relationships of the staff in their day-to-day work role. Additional information is necessary in order to understand organisation interfacing processes.

To appreciate how an organisation functions as a system in many of today's complex activities, two organisation charts are necessary. The pyramidal chart together with a compendium of all the position descriptions is not sufficient for this purpose. It has little use as an analytical instrument. What is required is a chart which sets down in line diagram form, how the organisation is functionally structured to meet the needs of communication up and down the line, and a second chart or model which sets down in suitable form just how it operates in the work process. The form of presentation must go further than the traditional display of only functional sections and lines of formal responsibility and authority; it must also show the integrative and co-ordinative inter-relationships that assist in moulding the functional activities into the whole system.

THE MATRIX CHART

One model which fulfills these requirements is a matrix chart. It shows how the organisation is interconnected as a working system and the relationship of senior managers and their functions. It takes into account the fact that the individuals of an organisation are not confined precisely to a thin line of specialisation as may be suggested by a line diagram. Extensive horizontal contacts as well as the vertical contacts, and sometimes also diagonal contacts, are often required to

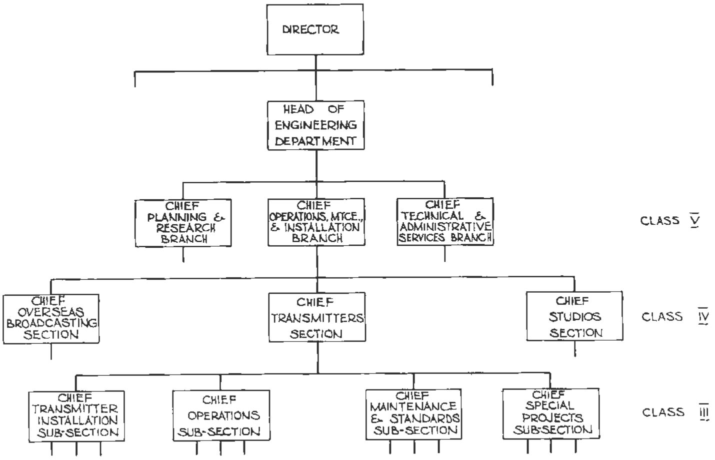

Figure 13.5 Pyramidal organisation diagram

A PERSON RESPONSIBLE FOR THE TASK.
B PERSON RESPONSIBLE FOR OVERALL SUPERVISION.
C PERSONS WHO MUST BE CONSULTED
D PERSONS WHO MAY BE CONSULTED.
E PERSONS WHO MUST BE ADVISED.

		DIRECTOR	HEAD OF ENGINEERING DEPARTMENT	ENGINEER CLASS V CHIEF OF BRANCH	ENGINEER CLASS IV CHIEF OF SECTION	ENGINEER CLASS III CHIEF OF SUBSECTION
I	CONTROL & DIRECT THE OPERATIONS OF THE ENGINEERING DEPARTMENT	B	A	D	D	D
II	CO-ORDINATE ENGINEERING RESEARCH, PLANNING, OPERATIONS, MAINTENANCE, INSTALLATIONS & SERVICES.		A	D	D	D
III	CO-ORDINATE ENGINEERING BUDGETS.	B	A	C	D	D
IV	FORMULATE POLICY COVERING THE SATISFACTORY IMPLEMENTATION OF AN APPROVED ENGINEERING WORKS PROGRAMME.	C	B	A	E	E
V	ANALYSE, COMPARE & EVALUATE THE PERFORMANCE OF ENGINEERING SYSTEMS.		B	A	D	D
VI	ORGANISE, CO-ORDINATE & CONTROL THE PLANNING & EXECUTION OF WORK ACCORDING TO APPROVED PROGRAMMES.		C	B	A	E
VII	RECOMMEND MAJOR CHANGES TO ACHIEVE GENERAL OBJECTIVES.	E	B	C	A	E
VIII	REVIEW IMPORTANT TECHNICAL VARIATIONS & STANDARDS.		B	C	A	E
IX	PLAN & ALLOCATE WORK WITHIN AN APPROVED PROGRAMME RELATING TO GROUPS OF ACTIVITIES & MANAGE & CONTROL THE SUBORDINATE STAFF.		D	B	C	A
X	REVIEW REPORTS, ORDERS & INSTRUCTIONS.	D	E	B	C	A
XI	EXAMINE TENDERS FOR CONTRACT WORK & MAKE RECOMMENDATIONS THEREON.	B	C	C	C	A
XII	INVESTIGATE & RECOMMEND ALTERATIONS TO DESIGN, CONSTRUCTION & MANUFACTURE TO IMPROVE EFFECTIVENESS & EFFICIENCY OF EQUIPMENT.		E	D	B	A
XIII	ASSUME RESPONSIBILITY AS PROJECT ENGINEER FOR MAJOR ENGINEERING PROJECTS.				B	A
XIV	DEVELOP NEW & IMPROVED TECHNIQUES, PROCEDURES & STANDARDS, ACCEPTING RESPONSIBILITY FOR DETAILS.		D	D	B	A
XV	ASSIST IN DEVELOPING SPECIALISED ENGINEERING SYSTEMS, FACILITIES & FUNCTIONS.		D	D	B	A

Figure 13.6 Matrix chart showing authority inter-relationships

carry out day to day activities. The matrix chart shows these vertical and horizontal inter-couplings between individuals of the organisation.

Figure 13.5 shows a typical type of pyramidal diagram and indicates how the organisation is functionally structured. *Figure 13.6* is a matrix chart of the same organisation showing how it operates with regard to certain activities. It shows the authority inter-relationships of positions from the director down to the level of chief of a sub-section in a large radio engineering organisation concerned with broadcast and television services. The matrix displays the same information which may be contained in many pyramid type drawings, position descriptions, policy directions, instructions etc. It not only serves as a quick reference to determine the responsibilities of individuals for certain activities but also to show how a given position is related to the others in those activities. In this way the responsibilities of related executives may be easily compared in the performance of a particular activity. It is easy to make a quick summary of the salient responsibilities of any position in the organisation, by simply reading down the chart for the appropriate position.

LINE AND STAFF

Much confusion often exists as to what line and staff are. Some engineering managers have said that there is probably no other single area of management which causes more difficulties, more loss of effectiveness and more friction. The roles of line and staff are not always simply described or defined in the same way in all organisations. One of the most widely used definitions is that line functions are "those which have direct responsibility for accomplishing the objectives of the organisation" and staff refers to "those elements of the organisation that help the line to work most effectively in accomplishing those objectives". Some have also defined line managers as the 'doers' and the staff managers as the 'thinkers'.

Engineering is one of the few professions that require large staff support—mainly because engineering as such is so heavily involved in spending, rather than earning. Many professionals such as dentists, doctors, and lawyers need comparatively little support, but the engineer often needs a very large support group involving draftsmen, testing laboratories, costing and accounting, workshops, staff and industrial, records, library, patents staff, etc. The structure of an engineering organisation therefore resolves itself into a technical group—the line organisation—charged with the responsibility for engineering design, research, development, planning, construction, installation, maintenance etc. and an administrative group—the staff organisation—charged with the responsibility for providing proper support to the engineer to enable him to carry out his work.

LINE AND STAFF RELATIONSHIPS

The position of the line officer is generally very well established. He knows who reports to him and knows to whom he himself must report. He has a comparatively limited sphere of responsibility. The staff officer on the other hand generally does not find his position so well defined and, although he normally knows who his superior is, it is often very difficult for him to determine just who reports to him.

In many cases this situation has been brought about by the fact that the staff officer has been implanted upon an existing line organisation because of growth in activities and is regarded as an addendum rather than an integrated member of the engineering department team. Staff functions have appeared on the scene in only comparatively recent years in the radio engineering management field as a result of the complexity and size of the modern radio and communication engineering projects and services. Because of their recent introduction, many staff officers have found not only opposition to their entry into the organisation structure by line management, but even the erection of barriers, often effective, by line management to protect their long standing position.

DUTIES OF STAFF

Staff functions originate in the line. They are specialised to perform the particularised functions and assist the superior functions. The duties of staff may include the following:

(a) Collation, assembly, summarising and interpretation of data and facts.
(b) Carrying out investigations and recommending particular courses of action.
(c) Interpretation and explanation of regulations, rules, instructions, orders and the like.
(d) Advice to personnel with regard to the performance of duties that have been delegated to them.
(e) Preparation of instructions or orders necessary to put an approved plan into operation.
(f) Monitoring of operations, in order to determine whether instructions are achieving the desired result.
(g) Co-ordinating the views or comments of executive and section heads with regard to proposed plans.

The primary purpose of these staff activities is to supplement the work and accomplishments of others and also to remove administrative detail, such as collection of facts and figures, from others. In the usual situation the line superior must issue the orders which are necessary to carry forward the advice or information furnished by staff.

STAFF ASSISTANCE

An assistant can recommend a particular action to the head, but as a staff recommendation, it carries no weight until the head acts on it and gives orders regarding it. The assistant to the head has no right to command by virtue of his position. Although he is incapable of holding a person responsible for failure to properly perform his duties, he can hold that person accountable. The assistant can report back to his superior on the actions and his superior can then hold the person responsible. This relationship is based on the concept of accountability for an action, and for the consequences of that action.

The benefit of staff assistance is most commonly acknowledged when the assistant has special knowledge and skill not possessed by the head or his subordinates. For a top management position this could for example be a legal counsel. A staff assistant may also serve in an overall capacity, handling those problems on which the head needs assistance most, at a particular time.

It is often considered by many people that staff assistance is applicable only to top level management. Staff assistance can be employed at any level in the chain of command. The manager of a large broadcast station complex for example may well have an administrative officer working on the station administrative problems and another providing overall assistance on technical matters. This relationship is shown in *Figure 13.7* which is an organisation chart for a large broadcast relay station complex involving two transmitting station centres and a receiving station. In this particular example, an assistant is also necessary for each of the transmitting station supervisors, because of the work load. In an organisation of this nature which would employ about 125 people on the

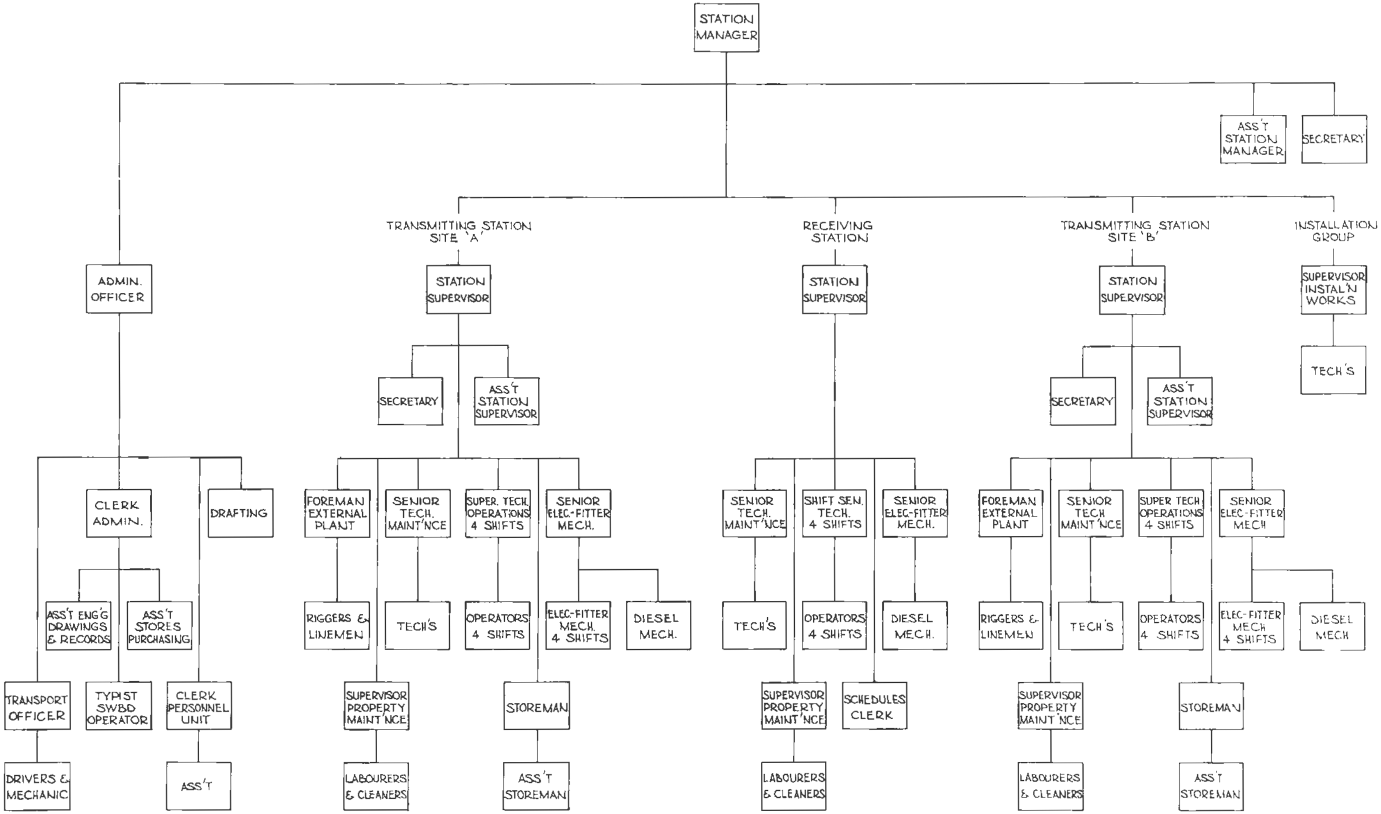

Figure 13.7 Organisation chart broadcast relay station complex

complex, it is usual to combine some operating and staff duties. For example, the administrative officer acts as a staff assistant to the station manager and is also in charge of the unit performing the general administrative functions. Although there are some disadvantages to this grouping, such an arrangement is usually dictated by economic considerations. It is less expensive to use the specialised ability of the administrative officer in both staff and operating capacities.

DELEGATION AND RESPONSIBILITY

Delegation causes an organisation to become operational. The process of delegation is to assign to another person the duty of performing some part of the total task which is the responsibility of the assigner. Responsibility however is not delegated. No diminution occurs as a result of assigning authority to another, because the assigner does not escape his accountability for the manner in which the delegated task is carried out.

The advantages claimed for delegation include:

(a) It allows managers to devote more time to the study of important problems by freeing them of routine duties which can be performed by subordinates.
(b) It encourages personal development in subordinates and fits them for promotion to higher positions.
(c) It streamlines communication channels.
(d) The organisation responds much more rapidly to changes in the work situation or environment because decisions are made at a level closer to the workface.
(e) It provides a higher level of morale and satisfaction for subordinate staff.

Some of the disadvantages are:

(a) Bad decisions resulting from inadequate appreciation of the problem can be costly.
(b) Duplication of effort.
(c) Inconsistency in decision making.
(d) Less flexibility in resource allocation to meet changing needs.
(e) Reduction in control for ensuring the objectives of the organisation are being met.

In nearly every radio engineering organisation, some delegation of authority is essential. Organisation depends upon sectionalisation and in some cases specialisation also, and consequently delegation is required by those who are responsible for managerial activities. As a general rule, delegation is vested in the incumbent of a specified position in the organisation and all powers attached to a position are vested in the officer who is performing the functions of the position specified. It is normal for a controlling officer to be empowered to exercise the powers approved for subordinate officers working under their direction.

Because of the relationship of delegation and the incumbent of a specified position it is essential that the position be:

(a) Clearly defined as to authority.
(b) Clearly defined as to duties.
(c) Clearly defined as to function.

(d) Staffed by a person qualified to do the task and aware of his proper position in the organisation structure.
(e) Staffed by a person who is adequately supervised in the performance of his work.

LIMITS OF AUTHORITY

Almost every delegation is surrounded by limitations, either expressed or implied, and often these limitations are not always recognised. An officer may give authority to a subordinate without first considering the implications or he may fail to make himself clearly understood by the subordinate. If a subordinate is expected to observe particular general rules of organisation policy etc., it is the duty of his senior to make sure that he fully understands those limitations.

As well as restrictions of a general nature, there are often restrictions placed on the incumbent of a position with regard to specific types of transactions in connection with his work. In a well-organised establishment, these specific limitations will be clearly set down for each position in the organisation structure. The authority granted to the engineer in charge of one large broadcast organisation with a network of several television, frequency modulation and medium frequency stations is shown in *Table 13.1.*

It is interesting to note that in this case the engineer-in-charge has very little authority in relation to staff employment and dismissal, but he has considerable authority in financial aspects of the engineering activities. In nearly all cases, authority over personnel is not delegated in the same way as equipment, materials,

Table 13.1 EXAMPLE OF AUTHORITY GRANTED TO A STATION CHIEF ENGINEER

(a) *Operating expenditure*
Full authority to authorise and approve all normal expenditures, standing fully accountable for the overall total cost of operation of the engineering services.

(b) *Plant and equipment maintenance*
Full authority to maintain station engineering equipment and plant in a safe and efficient operable condition.

(c) *Technical standards*
Full authority to maintain station engineering equipment and plant to the technical standards required by the licensing and other regulatory authorities.

(d) *Capital expenditure*
Full authority for major and minor works listed in the approved annual works programme up to the specified amount for each work.

(e) *Line hire*
Full authority to lease programme and control line circuits from common carrier organisations on requisition from Director of Programmes.

(f) *Wages and salaries*
Full authority to approve overtime and travelling expenses of engineering subordinates. Changes in established wage and salary schedules require approval of the Manager.

(g) *Organisation changes*
Changes in the basic plan of the engineering organisation require the approval of the Manager.

(h) *Staff*
Make recommendations in regard to the employment, promotion and dismissal of staff. Approval of these matters is vested in the Chief-of-Staff.

moneys etc. Most organisations use the authority to discharge, only in extreme cases, and as a last resort, and consequently are particular when recruitment of new staff is being undertaken.

PRINCIPLES OF DELEGATION

For delegation to exist certain elements must be present. The most important of which are:

(a) There must be a working administrative organisation.
(b) The structure of the organisation must be such that one person is responsible to another.
(c) A person must give a subordinate work to do and the subordinate must have a measure of discretion.

Although these elements on delegation appear simple and straightforward, there are some basic principles which must not be neglected. The main ones may be summarised as follows:

(a) When authority is delegated the assigner does not delegate responsibility. Responsibility cannot be delegated as is sometimes believed. It is a relation which cannot be broken up and parts passed on to somebody else. Responsibility is not a fixed quantum like a collection of resistors–the more that is given away the less that is left. What in fact happens when a person delegates is that he calls in someone to work with him in a particular task. He retains his responsibility to his superiors for the final result, but the delegate acquires a responsibility to the assigner for his part of the task.

As an example, if the manager of a broadcast station assigns all the technical functions for the station operation to the engineer, there is a contract expressed in the reciprocity of the relation responsibility. Provided that the engineer has all the necessary staff and facilities, such as test equipment, spare parts etc., he cannot delegate the contract and pass it on to someone else, for the sense of obligation is personal to two contracting parties–the manager and the engineer. If the engineer relinquishes his obligation he is no longer in relation of responsibility with the station manager; he breaks his contract and therefore cannot retain the facilities, staff, equipment and authority inherent in the contract. The station manager is responsible for providing the staff and facilities. If, however, the staff and facilities are not proper, or inadequate, the engineer cannot be punished for failure to fulfil his function because the manager has failed in the contract, by not providing the necessary staff and facilities. He cannot hold the engineer responsible for what he is unable to do.

(b) There should be only one line supervisor.
An important principle of organisation is that a man should normally report to only one line supervisor. Dual subordination invariably leads to frustration and poor morale.

The practice of bypassing is a frequent example of dual subordination. If a station manager deals directly with a technician without working through the station engineer, the technician finds himself with two bosses. When placed in such a situation the technician will most likely give preference to the instructions of the manager and consequently places the engineer in a most difficult position. It leads to confused responsibility and undermining of the authority of the engineer who has been bypassed.

Contact between manager and technician does not however always lead to dual subordination. Exchanging information, for example, is a different matter from giving directions for a particular task. In fact many senior executives consider contact with staff several levels below, to obtain a particular type of information, is good for morale.

(c) Authority and responsibility should be matched.
The idea that authority and responsibility should be suitably matched is another important principle of organisation. The principle recognises that if a person, for example a station engineer, is to be held accountable for the technical activities, he must be permitted to guide according to his own judgment. It also recognises that if the engineer is given wide latitude of action, he should be held accountable for the wise·use of this permission given to him by management. To give too little authority is to make frustration inevitable, and to give too much is unnecessary and dangerous, in many situations.

(d) There must be some supervision of the process and its results.
As outlined previously, a senior can delegate authority to do a task to a subordinate but he cannot divest himself of the responsibility for ensuring that the task is satisfactorily completed. Consequently, he must have means of monitoring what progress is being made in the task. Delegation cannot exist effectively without control. Some of these controls may be centred around project schedules, operational costs, material deliveries, productivity, staff levels etc.

For the person carrying the authority, carefully prepared plans provide definite goals for specific periods of time. But, most important, they provide for management, as well, clearly stated control. Each regularly knows when any unit is behind, ahead, or meeting of the programme target.

POSITION DESCRIPTIONS

Position descriptions are important for the proper instruction of an officer in his duties and responsibilities, and from the management aspect, in the proper planning both of work flow and of the organisation itself. Every person in the organisation should be acquainted with:

(a) The duties and responsibilities which have been assigned to him as incumbent of the position.
(b) The authority and delegations given him to allow him to properly carry out the assigned tasks.
(c) The results expected of him, and the quality of the output.
(d) The standards against which his performance in the position will be measured, and the method of monitoring to be used.
(e) The extent of assistance and guidance he may expect from management in his current position, and for his development for future promotion.

IMPORTANCE OF POSITION DESCRIPTIONS

Bad organisation and staffing have been traced in many instances to failure to make that necessary examination of work and procedures which must precede preparation of a proper position description. Descriptions are also of considerable importance in relation to salary classifications, and should therefore reflect the nature of the important duties performed. It is practice in many engineering establishments to request section heads to examine all position statements of staff under their control, on an annual basis.

The position description:

(a) Is important in selection and placement of staff because, by showing the full extent of duties to be performed by its incumbent, it indicates the demands it will make on him and thus assists a selecting officer, panel or committee to choose the person best suited, experienced and qualified to fill the position.
(b) Contains the basic data from which information is drawn to enable evaluation of the position—that is, the determination of its grading, the incumbent's place in the organisation, and the salary he will receive.
(c) Provides the most vital items of information required for the design of training courses.
(d) Simplifies salary fixing procedures by facilitating the grouping of positions which require similar qualifications and involve similar duties and for which similar rates of pay are therefore justified.
(e) By defining the duties of officers, shows their precise relationship to one another.
(f) Provides a datum point for the personnel inspectors conducting an organisation and methods survey.
(g) Is essential for successful planning of an organisation and the flow of work.

To satisfy all these purposes the description must be accurate, concise and informative as possible.

SENIOR ENGINEERING MANAGERS

The description of the work of a senior engineering manager would generally be given in broader terms than for lower level subordinate positions. In such cases a satisfactory description can generally be prepared by considering replies to such questions as:

(a) What functions are directed, supervised and controlled?
(b) What part is played in formulating and developing operating and new works plans, programmes, methods and policies?
(c) Upon what type of problem is a decision given, that does not require higher approval, and that generally is unrevised?
(d) Upon what matters is a recommending authority only exercised?
(e) Over what territory is administration jurisdiction exercised?
(f) What is the size of the establishment, the number of assistants and subordinates, or amount of annual expenditure?
(g) With what other senior administrators, public and private and government is contact made in carrying out the work, and for what purposes?

The basic tasks carried out by senior engineering managers may be summarised as follows:

(a) Co-ordinates the activities of various units and people.
(b) Advises more senior administrators on possible ways of incorporating broad policy aims into workable plans of operation.
(c) Expertises in personally discharging specialised tasks, such as briefing senior managers on technical aspects of proposals.
(d) Inspects engineering installations, facilities, services and construction projects.
(e) Formulates plans which shape organisation technical and associated financial aims and objectives.
(f) Interprets and clarifies rules and directives. Also gives decisions on rulings in cases where proposed plans or activities depart—for apparent good reasons—from the approved policy on instructions.
(g) Consults professionally in giving advice or aid in engineering problems.
(h) Schedules in laying out sequence of operations involving engineering participation.
(i) Selects and promotes staff, maintains morale, discipline and deals with disputes and complaints.
(j) Evaluates the soundness of practices and policies of particular engineering activities.
(k) Examines and passes judgments on plans, designs and proposals and economic studies drawn up by subordinates.
(l) Keeps subordinate senior engineers and administrators informed of matters affecting the progress and well being of the engineering organisation.

The more senior the engineering manager's position in the business, the wider the scope of his responsibilities, the wider the ramifications of the matters he must consider and the activities he must co-ordinate. It must be remembered that as a general rule no description could completely define what a senior engineering executive does in detail or the full scope of his authority.

DESIGNATIONS

In engineering organisations the use of designations varies considerably from one organisation to another. Within the organisation it is important, however, that designations take on distinctive meanings. These designations should follow a consistent pattern in order to identify comparable levels or status. Titles which are well established and meaningful should be retained when any re-organisation is proposed, but opportunity should be taken to change those designations which may have lost their significance with changing technology. *Table 13.2* lists some typical designations in radio engineering organisations. In many applications the designations consist of two or sometimes three parts such as Assistant Director (Engineering), Supervising Engineer (Transmitters), Technical Manager (Engineering), Supervising Technician, Technical Operator, Skilled Craftsman and many other combinations to suit particular situations.

By custom and practice over many years, particularly in broadcasting and television work, technical staff in some organisations have been accorded the title of Engineer with the officer-in-charge being designated Chief Engineer. In many instances staff qualification are at the level of Technical College Certificate

Table 13.2 TYPICAL RADIO ENGINEERING DESIGNATIONS

BASIC DESIGNATIONS

Director
President
Chief
Superintendent
Manager
Executive
Consultant
Specialist
Chairman
Technologist
Engineer
Controller
Operator
Technician
Foreman
Mechanic
Electrician
Party Leader
Linesman
Rigger
Technical Officer
Inspector
Artisan
Assistant
Shift leader
Craftsman

QUALIFYING TERM DISTINGUISHING RANK

Assistant
Deputy
Superintending
Supervising
Divisional
Project
Group
Staff
Foreman
Executive
Vice
Chief
Principal
Administrative
Systems
Senior
Junior
Technical

DESCRIPTIVE QUALIFYING TERMS

Work content

AM, FM and TV broadcast stations and networks
Tropospheric scatter communications
Space communication systems
Research and development
Mobile radiocommunications
Fixed radiocommunications
Navigational radio aids
Telemetry and timing systems
Systems planning, integration and management
Systems performance analysis
Maintenance and operation
Provisioning, installation and construction
Technical documentation
Training

Function

Installation
Construction
Maintenance
Operation
Production
Estimating
Testing
Development
Procurement
Analysis
Evaluation

Unit

Department
Division
Branch
Section
Sub-section
Station
Studio
Group
Unit
Project
Cell

Region

Network
Area
District
Town
City
State
National
Foreign

(or equivalent) and confusion often exists with regard to the role of Professional Engineers with academic qualifications. The situation is further confused by the use of the title Technical (Engineering) Manager mainly in the operational sections of the engineering department. Operational expertise, managerial qualities and technical knowledge all play their part in appointing staff to this latter position.

There are semantic difficulties in describing the work of Professional Engineers and Sub-professional or Technical Officer staff because the description of the work of the Technical Officer reads similarly in parts to that which might be used to describe the work of Professional Engineers. However it is necessary to ensure that where both grades are employed that the duties of the Technical Officer are correctly placed within the framework set by his level of qualification and experience.

Whatever system of designation is used, it should:

(a) Facilitate a clear understanding of the structure of the organisation and the functions of the positions in the structure.
(b) Ensure orderly and logical relationships among the various designations.
(c) Be sufficiently flexible to allow for organisation changes which may occur in the future.
(d) Satisfy the dignity of the incumbent of the position, by providing proper recognition of his work.

POSITION STATEMENT

The purpose of the position statement is to show the principal functions for which the incumbent of the position is responsible. Other names by which the statement may be sometimes locally known include duty statement, position description, position guide, position outline etc. The statements take many formats and in some cases are quite brief, indicating the important duties and the channel of line authority as for example in *Table 13.3*, which shows the position statement for a senior technician or technical officer engaged in the

Table 13.3 POSITION STATEMENT FOR TYPICAL BROADCAST STATION SENIOR TECHNICIAN

POSITION TITLE: Senior Technician	SECTION: Engineering

IMMEDIATE SUPERIOR:
Supervising Technician

BROAD FUNCTION:

Under the direction of the Supervising Technician, take charge of the maintenance and operation of the transmitter and studio equipment.

PRINCIPAL ACTIVITIES:

(a) Supervises the operation and maintenance of transmitting station, studio, outside broadcast and emergency power supply equipment and plant.
(b) Liaises with programme and production staff and arranges for technical facilities as required.
(c) Controls the technical store.
(d) Supervises the training of technical trainees.

operation of a typical broadcast station where such position is justified on a work load basis. In some broadcast organisations his immediate superior may be designated Chief Engineer, while in others Supervising Technician may be a typical title. For positions associated with senior engineering management, much more detailed description may be required in the statement in the form of managerial and functional objectives. *Table 13.4* shows a statement for a Supervising Engineer in charge of international broadcast operations of an organisation with a large network of high power local and relay stations.

Table 13.4 POSITION STATEMENT FOR A TYPICAL ENGINEERING MANAGEMENT SITUATION

POSITION TITLE: Supervising Engineer International Broadcast Operations	SECTION: Transmitting Stations
IMMEDIATE SUPERIOR: Assistant Director (Transmitters)	DEPARTMENT: Engineering

BROAD FUNCTION

The Supervising Engineer has managerial and functional responsibilities for the operation and maintenance of all transmitting stations, home and abroad, associated with the activites of the international broadcast service.

PRINCIPAL ACTIVITIES

(a) Sees to the effective and efficient day-to-day operation and maintenance of transmitters and station support facilities.
(b) Organises, initiates and measures the activities associated with the operation of equipment and plant assigned to the section.
(c) Recommends to Assistant Director (Transmitters), programmes and budgets for operation and maintenance, within the policies and objectives of the organisation.
(d) Ensures that Section, Sub-section and station control positions are staffed with competent personnel.
(e) Sees to the preparation and review of Section budgets and financial forecasts and sees that Sub-sections are properly advised and assisted in the preparation and presentation of their budgets and forecasts.
(f) Promotes the growth, enthusiasm and effort of all personnel assigned to the Section by means of technical and general guidance.
(g) Furnishes surveillance over the operations and maintenance of the assigned equipment and plant to ensure compliance with the technical specifications and standards.
(h) Sees to the timely preparation and submission of reports necessary to meet the requirements of management.
(i) Ensures that all activities for which he is functionally responsible are reviewed periodically and that they conform to authorised policies and procedures.
(j) Makes recommendations to the Assistant Director (Transmitters) with respect to the establishment of policies, procedures, work programmes and practices necessary for the execution of his function.

GENERAL FEATURES OF DUTIES

The functions set out in *Table 13.5* gives an indication of the types of duties which would be expected of various classification of professional engineers, while *Table 13.6* indicates the types of duties normally applicable to technical officers or technicians engaged on the operation and maintenance of a broadcast relay station complex involving high power transmitters, microwave relay systems

Table 13.5 GENERAL FEATURES OF DUTIES OF PROFESSIONAL ENGINEERS

ENGINEER CLASS I

In this class are positions, the duties of which may include

(a) Draft less complex orders, instructions, plans, specifications and reports.
(b) Detailed design and investigation work requiring professional treatment, including the application of higher mathematics.
(c) Inspect field and other facilities and activities to assess and report on standards.
(d) General liaison to obtain basic data and information.
(e) Assemble and present basic data in a co-ordinated and useful form.
(f) Supervise and/or inspect projects and prepare reports for higher authority.
(g) Issue professional advice.
(h) Set out and measure work including checking thereof.
(i) Supervise engineering contracts.
(j) Plan and allocate tasks according to an approved programme of work and supervise subordinate staff.
(k) Ensure that work is performed according to prescribed standards and specifications.

ENGINEER CLASS II

In this class are positions, the duties of which may include

(a) Plan and allocate activities according to an approved programme and direct the subordinate staff.
(b) Make some original contribution and/or apply new approaches and techniques to design and development of equipment or specific aspects of facilities.
(c) Contribute to planning within defined limits such as planning the provision of a specific engineering facility.
(d) Investigate, examine and recommend for approval, methods and procedures, designs, drawings, specifications and any requests for concession.
(e) Draft technical instructions, specifications, standards, manuals, reports, submissions, directions and works estimates.
(f) Undertake investigations, preliminary and revision surveys of facilities and equipment.
(g) Supervise more important engineering contracts.

ENGINEER CLASS III

In this class are positions, the duties of which may include

(a) Plan and allocate work within an approved programme relating to groups of activities and manage and control the subordinate staff.
(b) Review reports, orders, instructions, accept responsibility for modifications.
(c) Accept responsibility for modifications of standards and specifications in aspects of details to suit local conditions, examine tenders for contract work and make recommendations thereon.
(d) Investigate and recommend alterations to design, construction and manufacture to improve effectiveness and efficiency of equipment.
(e) Assume responsibility as project officer for major engineering projects.
(f) Control specific geographical or functional groups.
(g) Develop new and improved techniques, procedures and standards, accepting responsibility for details.
(h) Assume final technical responsibility for details for design.
(i) Assist in developing specialised engineering systems, facilities and functions.

ENGINEER CLASS IV

In this class are positions, the duties of which may include

(a) Organise, co-ordinate and control the planning and execution of work according to approved programmes.
(b) Recommend major changes to achieve general objectives.
(c) Review important technical variations and standards.
(d) Recommend appropriate research, design and development.
(e) Recommend applicability to local conditions of important engineering developments.
(f) Assist in investigating, planning, developing and designing a project of national importance.

Table 13.5 *(continued)*

ENGINEER CLASS V

In this class are positions, the duties of which may include

(a) Control and direct an engineering function.
(b) Formulate policy covering the satisfactory implementation of an approved programme.
(c) Undertake major design and development work accepting full technical responsibility.
(d) Analyse, compare and evaluate the performance of engineering systems.
(e) Formulate design principles and overall technical standards.
(f) Provide highly advanced technical information to higher management.

Table 13.6 DUTIES OF TECHNICIAN EMPLOYED ON H.F. BROADCAST RELAY STATION COMPLEX

DUTIES

The incumbent of this position will be expected to

(a) Operate and perform corrective and preventative maintenance on high power high frequency radio broadcast transmitters and related mechnical, electrical and electronic devices such as pumps, blowers, meters, indicators, recorders, counters and transmitter switch gear.
(b) Maintain and operate microwave link and high frequency receiving equipment, switching, monitoring and recording equipment. Duties include retuning and adjusting transmitters to new frequencies and switching antennas according to schedule, recording and evaluating meter recordings, continuous observation and evaluation of equipment performance, cleaning, checking components, repairing and replacing defective components, installation of new equipment and making performance measurements on electronic and related equipment.
(c) Perform other related duties as assigned.

and a receiving station. With some organisations, technical officer is a higher status than technician but with others the duties are identical.

Professional engineering work involves the application of professional knowledge and experience to designing, providing, controlling and maintaining radio engineering facilities, systems, equipment and associated services. These include the fields of applied research, planning, design, installation, development, construction, maintenance and associated management and control responsibility.

A technical officer or technician carries out a variety of skilled tasks connected with the installation, maintenance, operation, testing or laboratory investigation of radio equipment. A main characteristic of the technical officer is the ability to undertake a range of tasks on a number of different types of radio and electronic equipment and associated plant. He carries out full maintenance duties on a variety of equipment and plant, and in addition he may carry out first-in maintenance on that equipment on which he does not have sufficient experience or training to carry out complete maintenance duties.

Requirements for employment as a radio technical officer or technician vary considerably, but generally four to five years training is required together with demonstrated ability to perform the basic duties of the position. Typical experience requirements of one organisation for technical officers or technicians at high power high frequency transmitting stations are shown in *Table 13.7.* In this case the technician must have had the amounts and types of progressively responsible experience listed for each salary level classification. Excess amounts of 'A' category experience may be substituted for 'B' or 'C' category experience. Pertinent residence study in technical broadcast or television equipment successfully completed in a technical college or institution which included one or more

Table 13.7 EXPERIENCE REQUIREMENTS FOR TECHNICIANS EMPLOYED ON HIGH POWER HIGH FREQUENCY BROADCAST STATIONS

	EXPERIENCE REQUIREMENTS Years of experience required			
Salary classification	Category A	Category B	Category C	Total years required
1	0	0	5	5
2	0	2	3	5
3	0	4	1	5
4	3	2	0	5
5	5	0	0	5

Category A

Experience in carrying out the duties and responsibilities listed immediately below, requiring the operation and maintenance of high frequency broadcast equipment having at least one transmitter of 50 kW or more of output power or point-to-point equipment having at least one transmitter of 40 kW of output. The experience must have included all the activities listed below, (a) to (g) inclusive.

(a) Starting; tuning to specified frequencies including selection of crystal or other frequency source and activating and adjusting same; adjusting or replacing coils; neutralising; performing adjustments during operation and carrying out all procedures for shutdown of transmitters.
(b) Recognising, analysing and repairing faults.
(c) Using specialised electronic instruments for measuring and detecting phenomena such as the standing wave ratio of transmission lines; field strength intensities; noise, distortion and frequency response of transmitter equipment.
(d) Measuring frequency response, distortion and noise characteristics of audio equipment; isolating and protecting audio equipment from induced radio frequency fields and maintaining professional recording and playback equipment.
(e) Operating and maintaining frequency monitoring or counter devices.
(f) Demonstrated knowledge in the care and handling of various types of vacuum tubes and capacitors.
(g) Demonstrated knowledge in the radiation characteristics and utilisation of several different types of radio transmitting antenna systems such as are used with professional high frequency point-to-point services.

Category B

Experience in any of the following activities:

(a) The operation and maintenance of transmitter equipment having at least one broadcast or point-to-point transmitter with a power of at least 5 kW.
Such experience must have included
  (i) Operating transmitters, including starting, stopping, logging of meter readings, continuous observation of equipment performance and making the necessary operational adjustments and repairs.
  (ii) Maintaining transmitters which included cleaning, checking of components, locating area of mechanical, electrical or electronic difficulty and repairing or replacing defective components.
  (iii) Operating transmitter control facilities.
  (iv) Installing and modifying electrical and electronic equipment.
  (v) Making performance measurements on transmitters and related equipment.
(b) Responsibility for the installation and testing of a radio broadcast station. Such responsibility shall have included installation, proof of performance measurements, and testing of transmitter equipment and antenna facilities.
(c) Operational development and responsibility for floor testing transmitters (5 kW and above) built as prototypes for a manufacturer's line or for specialised broadcast or point-to-point communication services.
(d) Responsibility for designing, construction, testing and obtaining operational authorisation for a directional antenna system used for a medium frequency broadcast station (this element will count as one year of Category B experience and will be limited for credit to a single occasion).

Table 13.7 *(continued)*

Category C

Experience in any of the following fields demonstrating knowledge of the theory and practice of radio transmitter operations on a subprofessional level.

(a) Experience in any three of the following elements of radio broadcasting or communications using professional transmitting equipment:
  (i) Design (iii) Installation (v) Maintenance
  (ii) Testing (iv) Operation
  A minimum of 9 months in any field shown above is required for credit.

(b) Experience as a technical representative dealing directly with customers for a commercial manufacturing or service organisation and having responsibility to
  (i) design overall communications systems requiring use of radio transmissions, or
  (ii) to oversee the installation of such systems, to conduct proof of performance tests and to train personnel for the operation and maintenance of the equipment.

courses in each of the following subjects: mathematics, physics, radio theory or related sciences, radio and audio frequency and radio operating practice may be substituted for a maximum of 6 months of category 'C' experience.

POSITION CLASSIFICATIONS

The classification of positions within a unit is largely determined by decisions on organisation, the allocation of responsibilities, definition of job content, and the structuring of work processes. If faulty decisions are made in these matters, not only will basic deficiencies of organisation emerge but also inappropriate classification of the work will result. Operational defects which may occur include:

(a) Job fragmentation and unnecessary spread in work values.
(b) Excessive supervisory structures.
(c) Overlapping of functions, unnecessary provisions for co-ordination, assistance or liaison.

Considerable care must be exercised to ensure that organisation is determined by sound logic of work flow, delegation of authority and provision for supervisors and managers based on requirements for control of the work performed by the group.

The principal objective in classification is to classify the position and not the occupant. An officer is entitled to a grade and rate of pay only by virtue of the position he occupies. This does not deny, however, that in some circumstances the occupant may have an important impact on the duties of the position, sometimes to the point where its classification may be affected.

In the case of supervisory positions a higher classification may not be justified simply because an officer checks the work of another in situations where both employ essentially the same skills and knowledge, and the assurance of accuracy depends on agreement of results. The classification of supervisors should be determined having regard not only to supervisory tasks but also any significant individual work performed. It is usually necessary to consider all of the following:

(a) The level of work performed by the group and the nature and extent of the incumbent's supervisory work.

Table 13.8 POSITION CLASSIFICATION PROCEDURE

DUTIES AND RESPONSIBILITIES

Consider
(a) Duties to be performed by the occupant.
(b) Responsibilities (delegations, decision making authority etc.).
(c) Relations with other positions, placement and significance in the overall organisation.
(d) The most significant and responsible duty or duties regularly performed.

JOB ANALYSIS

The task is to break down the job into its basic components and to analyse them.

Analyse
(a) Qualifications, basic training and experience necessary.
(b) Supervisory responsibilities (number, levels etc.)
(c) Judgments and discretions exercised.
(d) Complexity, scope, significance and difficulties of work performed.
(e) Instructions, manuals, guides etc. available to the occupant.
(f) Direction and guidance received from occupants of other positions.
(g) Any unusual features of the work which call for special aptitude, experience or skills.

JOB COMPARISON

Having analysed the position in terms of factors contributing to classification, the task then is to place the position in the classification structure.

Identify
(a) Appropriate designation for the position.
(b) Classification of the position taking into consideration
  (i) Characteristics and features of duties.
  (ii) Definitions or work level classification standards.
  (iii) Classification of similar existing and related positions in the organisation.
  (iv) Classification of subordinates and immediate supervisor.

SUMMARY

(a) Prepare organisation chart showing designation and classification of new position and relation to other positions.
(b) Confirm that there is no duplication of effort and overlap of work of other positions.
(c) Prepare duty statement.

(b) The delegations and authorities exercised by the incumbent.
(c) The complexity of individual work performed.

Table 13.8 indicates guide lines set down by one large organisation for position classification procedure for new positions or reviewing existing positions.

FURTHER READING

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Section 2

Engineering Economy

Introduction

The preparation of budgeting data for new installations, the maintenance of existing facilities and replacements is an important function in radio engineering management. It is the engineer's responsibility to explain to management why new plant should be installed or existing plant modified, retired or replaced, to show why action should be taken at a particular point in time and to list, by means of a cost/benefit study, benefits that would result from the proposal.

A cost/benefit analysis is required by management for most major radio engineering projects. It is a practical way of assessing the desirability of a project. It is a way of enumerating and evaluating factors which need to be taken into account in making economic choices. It assists management in determining whether or not a project is worthwhile, which is the best of the proposed alternatives and the optimum time at which to implement the proposal.

Many radio engineering establishments are characterised by high capital costs, high maintenance charges and the high cost of changing or extending the plant once it has been installed. Because some types of installations, for example a broadband microwave radiocommunication relay system, have to be extended at high cost at certain periods of their life to meet traffic growth demands, correct management decisions are of great importance because of high capital and maintenance expenditures.

Engineering economic studies deal primarily with one thing–money–money to be spent or received in various amounts at various points in time. In the case of a commercially oriented organisation the principal objective might be the maximisation of profitability while the objective of a government department might be maximisation of operating efficiency. However, the concepts of economic profitability and efficiency are closely related.

A sound knowledge of the economic aspects is essential for the radio engineer so that he can make an effective contribution in the economic decision making process of management.

Chapter 14

Economic Studies

Engineering economy is concerned primarily with economic choice, that is determining among all courses of action that which is the most attractive economically. It is an accepted principle that the greatest economy results from the provision of the right amount of equipment or plant in the right place at the right time. Of course, with many radio engineering problems, there are a number of other factors to be considered and which cannot be expressed in monetary terms and these factors will always have some influence on the final decision.

Since money has the power to earn more money, its use must be paid for in some way. The cost of money is defined as interest. The basis of economic studies is transferring values from one time to another for comparison purposes. Expenditures or savings cannot be considered to be independent of time. Standard formulas have been developed for converting present amounts into equivalent future amounts, uniform series of payments (annuity) into future amounts etc. Economic comparison tables most commonly used are set out in *Appendix A*.

It is very seldom that alternative radio engineering schemes can be compared on the basis of their initial costs only. It is nearly always necessary for costs associated with maintenance, power consumption, travelling expenses, building rental and operations to be taken into consideration. It may also be necessary to take into account any further capital investment which may be required at a future period of time for increased capacity etc. This also applies to the assessment of tenders submitted for radio engineering projects. For all these factors to be properly covered, the alternative schemes must be compared on the basis of either equivalent uniform annual payments or equivalent capital investment at a certain rate of interest or on an equivalent capital investment at different rates of interest.

CHARACTERISTICS OF RADIO INSTALLATIONS

Radio engineering installations are characterised by very large equipment and plant investments that turn over very slowly and cannot be retrieved except by the slow process of 'write off' through depreciation channels. Radio equipment and plant is unique to a specific area of the communications industry and because of this has a very low residual or resale value. A large proportion of dismantled radio plant, and even a modern unit which may fail in service, is sometimes worth no more than scrap metal value. In the radiocommunication field in particular, the annual investments in new plant over the past 15-20 years has been very large indeed, yet the amount written off annually is relatively small, in most cases only a few per cent of the gross book value of the original investment. The result is that in many stations there are systems ranging from recent installations to various ages up to 20 years, and even more in some cases.

The point of this is that once the radio equipment is purchased, it invariably remains in service for a very long time and consequently the economic viability of the organisation is dependent to a considerable degree on the wisdom with which the equipment and plant is used. Hence, whether he is conscious of the fact or not, the engineer has considerable influence on the economic well-being of the organisation. He is not only called upon to decide how best a scheme should be carried out, but also, if it is really necessary, would it be better to maintain the existing scheme, or if the new scheme is necessary, should it be introduced at a particular point of time?

The principles of engineering economic studies are the same whether applied to internal equipment such as transmitters, amplifiers, studio facilities etc. or to external plant such as masts, towers, antennas, transmission lines etc. The economics used involve money, its time value and the interest rate applied to the money.

VALUE OF ECONOMIC STUDIES

Studies in engineering economics are useful not only in the direct comparison of the costs of several specific methods of providing the facility, but they can also be used to give valuable information on other general problems where a number of variable factors are involved, and it is desirable to determine the best values for a minimum overall cost. It is admittedly often difficult to anticipate future variations in some of the essential factors in an economic study, such as future costs of money, tax rates and average plant life, just as it is difficult for the engineer designing broadband radio relay systems to anticipate needs of future television stations, satellite earth stations and other unexpected broadband requirements which may have to be injected into even the most flexible design. However, in either case, the final result associated with a given set of initial assumptions is definite and factual; the arithmetic of economic comparisons is just as clear cut and rigorous as any engineering law.

When cost estimates are completed it gives the engineer a reasonably reliable picture of how the cost of a new system would compare with the cost of existing competing systems for various types of situations. This is important in giving assurance to management that there would be a real market for the system and an understanding of the conditions most favourable to its use. For example, in the case of communications circuit requirements between centres separated by mountainous country, lower towers and greater repeater spacing can often be used for a radio relay system. Calculations can be made to see how marked an effect this would have on the system cost. This type of terrain is favourable to the use of radio relay system as it is this type of country where an alternative scheme such a coaxial cable may prove uneconomic because of the high cable laying costs.

Another interesting example involves the choice between increasing transmitter power and increasing antenna gain of a television station to meet a specified field strength requirement. An increase in antenna gain would lead to a reduction in station operating cost by virtue of the reduction in transmitter power required.

Against this must be set a number of disadvantages. First, every increase in antenna gain increases the weight and wind loading on the support structure, which requires that the strength of the tower of mast should be increased. This in turn may add considerably to the cost of the structure. Moreover, the cross-section of the part of the structure on which the antenna is mounted will probably have to be increased to provide sufficient strength and this results in a more complex antenna design if a reasonably uniform horizontal radiation pattern is to be obtained. The distribution feeder system also becomes progressively more complex and costly with every increase in gain. Furthermore, as the gain is raised, the vertical radiation pattern becomes increasingly sharp, and it may become necessary to impose stricter requirements for tower rigidity, in order to limit the movement of the antenna under varying wind loading and so avoid fluctuations in received signal strength. This again adds materially to the cost of the tower.

It has also to be borne in mind that for every 3 dB increase in gain, the aperture of the antenna must be doubled, so that if the centre of the antenna is to be maintained at a fixed height above ground, the overall height of the tower, and hence its cost also, will increase rapidly with increasing antenna gain.

These factors, and several others, have to be taken into account and the performance and cost of various possibilities considered and compared.

THE BASIC QUESTIONS

Nearly all engineering proposals generate three basic questions:

Why do the job at all?
When should it be done?
What is the best method?

These and similar questions can only be properly answered on the basis of an economic study, even though the final decision may be influenced by various factors, such as service obligation, staff, public relations or availability of finance. Cost considerations, while only one of the many factors which are explored by management, are prone to be given considerable weight in reaching a decision to go ahead with a project at a given time and in a given manner if for no other reason than that they represent a tangible, quantitative answer rather than a qualitative one.

Where a choice can be made it is the responsibility of the engineer to determine the scheme which will meet the physical and technical requirements in the most economical manner and to take this into consideration in recommending the course of action to be followed. Management is as a general rule not greatly interested in all the technical details of design and analysis followed by the engineer in reaching his conclusions. His technical competence is assumed, otherwise he would not have been called upon to do the exercise. It therefore behoves the engineer to employ a high degree of skill, judgement, integrity and objectivity in setting up the alternative courses for study. Then, given the proper study techniques, the result of his work will prove to be a valuable aid to management decision making.

The collection of data for economic study purposes should be programmed like any other engineering operation. This requires that the main objectives must be identified and classified at the outset to minimise delay. Many engineers sometimes find it expedient to dovetail economic analysis into the project development period but this practice should be avoided. The economic viability of a project should be known before it is selected, not after.

THE OBJECTIVE OF COST STUDIES

Within the general framework of the organisation's policy, capital expenditure engineering projects will originate at appropriate levels within the organisation. The first step will be the recognition of a need for capital expenditure, whether demand inspired or cost induced. Various means of providing these needs will present themselves. It is at this point that the tools of economic studies which are available to the engineer must first be implemented. The engineering cost studies deal primarily with one thing–money–money to be expended or received in various amounts and at different times. It is significant to note that an engineering economic selection study does not indicate which proposal or scheme provides the most profit. It indicates which proposal or scheme is the least expensive.

It is the objective of cost studies to make a proper evaluation of the monies in the plans under consideration. It is important therefore that the engineer understands the basic rules which govern the comparison, in cost studies, of money expended or received at different periods of time. He must be able to determine the proposal giving the minimum cost commensurate with requirements.

Cost studies must consider not only the first cost of the installation, but the annual costs as well. By definition, annual cost is the total annual expense of owning equipment or plant and properly maintaining it in service. The principal components of annual cost are maintenance and operation, overhead administration, depreciation, interest, property rates and taxes. Interest and depreciation costs represent the annual expense of obtaining capital for the provisioning of the equipment and plant, and of maintaining the capital unimpaired throughout the life of the facility.

In making the economic study of alternatives, the only factors which require consideration are those which differ with each scheme. The common factors can often be ignored as it is only the real differentials which are significant in an economic study. It is important that the designing and estimating of alternative projects should be consistent. It has often occured that one alternative, the favoured one, has been investigated more thoroughly than the others. This may help eventual detailed design, but not economic analysis.

In some cases, equipment or plant which already exists and has been paid for may also be omitted because engineering economic studies are carried out to determine what future expenditure will have to be undertaken to gain a desired end. It is important to appreciate the difference between capital–money invested in equipment–and the equipment itself. Equipment can be retired but capital cannot be retired by scrapping or abandoning plant. The retirement of the equipment will however often have an affect on the overall costs. For example, power charges, property maintenance costs, rent, taxes and various other costs associated with the operation of the equipment will no longer be incurred.

RATE OF RETURN

The cost comparison having been carried out, the question then to be answered for management is: What rate of return can be expected from this particular project? If it is an expansionary investment, then the rate of return will be ascertained from an analysis of the expected flow of net revenue over the life of the project. If it is a cost reduction investment then the rate of return will be measured by an analysis of the flow of net reductions in costs. A problem encountered here is that of investment in projects on which a quantitative assessment can not be made of expected revenue return or the cost reductions to be effected. This is often referred to as strategic investment. Examples of this type of investment are training facilities for technicians, and office buildings, the need for which will certainly continue to grow but the return on which cannot be readily ascertained. However, cost comparisons can still be carried out to determine the most economical means in provisioning in these types of projects.

DEMAND FOR CAPITAL

The next step is the assessment of the demand for capital. 'Demand' for capital, in contrast to 'need', is more meaningful as it can measure the intensity of needful capital by its earnings. The investment proposals when arrayed in a ladder of return on investment, and when cumulated, form the demand schedule for capital. The demand schedule can be conceived as the total amount of money that can be invested at more than a specific rate. Outside the demand schedule are the 'strategic' investments–those in which a rate of return is usually difficult or impossible to measure largely because indirect benefits are inestimable. Because of these characteristics, such investments must be sheltered from the rigorous rate of return competition. This is an area in which capital budgeting must be done solely on the basis of judgement in response to pressures and opportunities. Defence and research laboratory expenditures are notable examples because returns from these cannot be predicted reliably and therefore the investment decision cannot be based on the cost of capital.

No organisation can claim an unlimited availability of capital. The amount available often depends in the final sense on community savings expressed in the form of the funds offering for investment within the economy. In preparing works programmes it may be necessary to introduce some system of rationing of these funds. Firstly the 'strategic' investments will be included. Then there will be need to trim the demand schedule to conform with the remaining capital available for profitable investments. This calls for the elimination of the projects at the bottom of the list which had been arrayed in terms of rate of return on investment.

There is frequently some confusion as to the distinction between 'cost comparisons' and 'rate of return' studies. Generally a 'rate of return' study answers the "Why do the job at all?" question about the project, and involves a calculation of the prospective rate of return. 'Cost comparison' answers the "Which is the best method?" question.

A rate of return study is carried out to determine the prospective rate of return from a particular project or total capital programme. For a particular project, a rate of return study would determine the prospective rate of return on that project for inclusion in an overall demand schedule for capital. In such a schedule, projects may be ranked in descending order of prospective return. In this case, the interest rate is not a tool for comparative purposes but the 'end product' termed 'the rate of return'.

A cost comparison is designed to determine the most efficient way to carry out a given project. The use of interest rates is to give correct financial weight to the comparison and to give recognition to the time value of money. For example, the use of 6% as the interest rate (or time value of money) in a cost comparison between alternatives 1 and 2 for project A does not mean that if alternative 2 is chosen that project A will earn a return of 6% in the capital invested. What the use of the rate of interest of 6% does achieve is, if the alternative with the high capital outlay is chosen, then the investment of the additional capital returns more than 6%, by way of reduced annual disbursements. This is not to be confused with the rate of return of a particular project.

COST COMPARISONS

Cost comparisons can be carried out by any one of three generally accepted methods, with the choice usually determined by the particular feature of the cost study. The three methods are outlined hereunder with a brief indication of the type of studies which come within each category. Interest rate figures used throughout the worked examples are not related to present day market figures or a particular desired rate of return. They simply illustrate the method of working.

Annual Cost Method

This is the method most frequently used in studies to determine the most economical method by which a project can be carried out (or a facility provided) when all capital costs are incurred at the same time. Different lives of the equipment or plant of the various systems being compared does not hinder cost comparisons by this method. Neither do different prospective salvage values invalidate this method of cost comparison. This method is to be preferred when annual disbursements, for example maintenance and operating costs, are substantial in relation to the capital cost.

Typical examples of this method of comparison are as follows:

EXAMPLE 14.1

Equipment with equal lives, uniform annual disbursements and no salvage value.

Two items of radio equipment are to be compared for a given 12 year period. The installed cost of Proposal A is £60 000 and the annual disbursements (including labour materials and incidental charges) are estimated at £11 000. The installed cost of Proposal B is £40 000 and the associated annual disbursements £16 500. Both proposals are estimated to have a zero salvage value after the 12 year period. The applicable interest rate is 5%.

Proposal A

Capital recovery
(£60 000 x 0.11283) = £ 6770
Annual disbursements for
operation and maintenance = £11 000
Total = £17 770

Proposal B

Capital recovery
(£40 000 x 0.11283) = £ 4513
Annual disbursements for
operation and maintenance = £16 500
Total = £21 013

Proposal A has a lower annual cost by £3243 and would be preferred, provided that other factors such as unavailability of spares, staff etc. did not outweigh the financial advantage.

EXAMPLE 14.2

The same equipment facilities are studied but for a 10 year period only.

Salvage values of the recovered equipment after this period are estimated to be £3000 for Proposal A and £2000 for Proposal B. Interest rate of 5% is applicable.

Proposal A

Capital recovery
(£60 000 – £3000) x 0.12950 = £ 7381
Interest on salvage value of recovered plant
(3000 x 0.05) = £ 150
Annual disbursements = £11 000
Total = £18 531

Proposal B

Capital recovery
(£40 000 – £2000) x 0.12950 = £ 4921
Interest on salvage value of recovered plant
(£2000 x 0.05) = £ 100
Annual disbursements = £16 500
Total = £21 521

Proposal A has the lower annual cost by £2990 under these conditions.

EXAMPLE 14.3

Proposal B is replaced by another arrangement of equipment, Proposal C, which has an installed cost of £100 000 and an economic life of 20 years. The estimated value of recovered plant for Proposal C is £4000 and annual disbursements of £500. The interest rate of 5% is applicable.

Proposal A

As per Examples 14.2 = £18 531

Proposal C

Capital recovery
(£100 000 – £4000) x 0.08024 = £7703
Interest on salvage value of recovered plant
(£4000 x 0.05) = £ 200
Annual disbursements = £ 500
Total = £8403

Proposal C has a lower annual cost by £10 128.

The point might be raised that the advantage of a longer economic life with proposal C is not reflected in the cost comparison. In fact this advantage is provided for by the use of a 20 year capital recovery factor 0.08024 for Proposal C as against the use of a 10 year capital recovery factor 0.12950 for Proposal A. The estimate of a 20 year economic life for Proposal C implies that a service of at least this long would be required. Although the annual cost of £18 531 a year for Proposal A is for 10 years only, the service must be continued after Proposal A is retired. It is presumed that the annual cost of continuing the service will be of the same general order of magnitude.

EXAMPLE 14.4

This example introduces two types of equipment with different installed costs, economic lives, salvage values and annual disbursements. Proposal D has an estimated installed cost of £25 000, an estimated economic life of 15 years and salvage value of £5000 at the end of its life. Because of the peculiar nature of the equipment it has an annual disbursement charge of £1500 p.a. for the first 5 years after installation and £2000 per annum for the remaining 10 years of plant life. Proposal E has an installed cost of £43 000, an estimated economic life of 25 years and salvage value of £3000 at the end of its life. Annual disbursement charges are constant at £1200 per annum. The applicable interest rate is 5%.

Proposal D

Capital recovery
(£25 000 – £5000) x 0.09634 = £ 1927
Interest on salvage value of recovered plant
(£5000 x 0.05) = £ 250

Annual disbursements
Present worth of £1500 for first five years
= £1500 x 4.329 = £ 6493
Present worth of 6th to 15th year inclusive
= £2000 x (10.380 – 4.329) = £12 102

Total present worth of annual disbursements
= £18 595
Re-expressed as the equivalent uniform annual
disbursements over the 15 year life of the
equipment = £18 595 ÷ 10.380 = £ 1791
Total = £ 3968

Proposal E

Capital recovery
(£43 000 – £3000) x 0.07095 = £2838
Interest on salvage value of recovered plant
(£3000 x 0.05) = £ 150
Annual disbursements = £1200
Total = £4188

This study shows that Proposal D has a lower annual cost by £220.

Present Worth (or Value) Method

This method is used when part of the expenditure is to be deferred or when the time of incurring the expenditure is different with the alternatives being compared. Often, present worth studies are used for a cost comparison in order to determine whether a proposed investment which has capacity in excess of present needs is economically justifiable. It also has application in situations in which the annual cost method would normally be used, except that present investments (or capital costs) are large in proportion to other disbursements. The existence of a prospective salvage value at the end of the estimated life of the equipment or plant or at the end of a study period is handled by treating it as a negative disbursement, that is by subtracting the present worth of the salvage receipts from the present worth of the moneys expended.

Difference in the lives of alternatives under comparison require special treatment. Otherwise it is impossible to compare the present worths of the costs of a limited number of years of service. One method of comparison is to determine the least common multiple of the lives and to assume that the first costs, salvage values, economic lives and annual disbursements for each renewal will be the same as for the asset renewed. A special extension of this method and one used when no convenient, that is less than 60 years, least common multiple is available for the estimated lives of all the various assets involved in the study, is to compare capitalised costs. The phrase 'capitalised costs' means the 'present worth of the cost of perpetual service,' and the assumption in such a calculation is that renewal assets repeat the cost history of their predecessors.

Typical examples of the various applications of the Present Worth method are as follows:

EXAMPLE 14.5

Equipment with equal lives

Two items of radio equipment are to be compared each with an economic life of 15 years. The installed cost of Proposal A is £150 000, the annual disbursements are estimated to be £5000 and the salvage value of the recovered equipment after the 15 year period is estimated at £10 000. The installed cost of Proposal B is £200 000, the annual disbursements are estimated to be £3000 and the salvage value at £2000. The interest rate applicable to the study if 5%.

Proposal A

Installed capital cost = £150 000
Present worth of annual disbursements at 5% (£5000 x 10.380) = £ 51 900
Present worth of all monies paid out for 15 years period = £201 900
Less present worth of salvage value at 5% (£10 000 x 0.4810) = £ 4810
Present worth of net disbursement for 15 year period = £197 090

Proposal B

Installed capital cost = £200 000
Present worth of annual disbursements at 5% (£3000 x 10.380) = £ 31 140
Present worth of all monies paid out of 15 year period = £231 140
Less present worth of salvage value at 5% (£2000 x 0.4810) = £ 962
Present worth of net disbursement for 15 year period = £230 178

Hence the present worth of Proposal A is less than that of Proposal B by £33 088 at 5% interest rate.

EXAMPLE 14.6

Equipment with unequal lives

Two items of radio equipment are to be compared to meet an expected 30 year demand. The installed cost of Proposal C is £39 000, the annual disbursements are estimated to be £3500 and the economic life of the equipment at zero salvage value is taken to be 10 years. The installed cost of Proposal D is £105 000, the annual disbursements are estimated to be £1000 and the economic life of the equipment is 30 years with a salvage value of £1000. The interest rate applicable to the study is 5%.

The least common multiple of the lives is 30 years. It is assumed that Proposal C will be renewed at 10 years and 20 years time respectively with the further assumption that the first cost, economic life and annual disbursements for each renewal will be the same as for the asset renewed.

Proposal C

First intalled capital cost	=	£ 39 000
Present worth of first renewal at 10 years (£39 000 x 0.6139)	=	£ 23 942
Present worth of second renewal at 20 years (£39 000 x 0.3769)	=	£ 14 699
Present worth of annual disbursements for 30 years (£3500 x 15.372)	=	£ 53 802
Present worth of all disbursements for 30 years		£131 443

Proposal D

Installed capital cost	=	£105 000
Present worth of annual disbursements for 30 years (£1000 x 15.372)	=	£ 15 372
Present worth of all monies paid out for 30 year period	=	£120 372
Less present worth of final salvage value (£1000 x 0.2314)	=	£ 231
Present worth of net disbursement for 30 year period	=	£120 141

Proposal D has a £11 302 advantage in present worth over Proposal C.

The rate of interest has an important bearing on engineering economic studies and had a premium been placed on capital expenditure with a consequent rise in rate to, say, 10% then the situation would have been reversed. This is shown in a rework of the problem in the following example where all other conditions remain unchanged.

EXAMPLE 14.7

Proposal E

First installed capital cost	=	£39 000
Present worth of first renewal at 10 years at 10 per cent (£39 000 x 0.3855)	=	£15 034
Present worth of second renewal at 20 years at 10 per cent (£39 000 x 0.1486)	=	£ 5795
Present worth of annual disbursements for 30 years at 10% (£3500 x 9.427)	=	£32 994
Present worth of all disbursements for 30 years	=	£92 823

Proposal F

Installed capital cost	=	£105 000
Present worth of annual disbursements for 30 years at 10% (£1000 x 9.427)	=	£ 9427
Present worth of all monies paid out for 30 years period		£114 427
Less present worth of final salvage value at 10% (£1000 x 0.0573)	=	£ 57
Present worth of net disbursement for 30 year period	=	£114 370

In this study with an interest rate of 10% in lieu of 5% the alternative proposal has been proved the more economical proposal by £21 547. This illustrates how the use of a higher interest rate favours the alternative with both the lower present investment and the shorter working life of the equipment. The 10% interest rate is also more appropriate for present day conditions.

Present Worth (or Value) of Annual Charges

As this name implies, this method is a combination of the other two main methods, that is annual charges or costs are calculated separately without reference to the point in time which disbursements, both capital and annual, take place, and are then placed on a comparable basis by being brought back or pushed forward to a common point in time by use of the present worth method. It has particular application in the public utility field where planning for growth is an important issue. Where the period covered by a growth forecast is shorter than the estimated life of proposed assets, economic studies comparing immediate with deferred investments may be made comparing the present worths of annual charges for a study period equal to the number of years covered by the growth forecast.

EXAMPLE 14.8

A building is required to house a radiocommunication terminal in a large city to meet the circuit needs for 20 years. The immediate requirement is for a floor space of 25 squares to cater for radio equipment, power plant, office and amenity facilities. To meet requirements after 10 years an additional 10 squares will be required for radio equipment, and an additional 5 squares for power room extensions. The cost of the site is £20 000, building costs are £1000 per square, maintenance and service charges are estimated to be £18 per square.

Proposal A

Build now for 25 squares to meet immediate requirements and add further 15 squares at the end of the 10th year of ultimate additional requirements.

Proposal B

Build 40 squares now to cater for immediate and future requirements. Proposal A would involve an additional capital outlay of £5000 at the second stage.

The applicable interest rate is 5% and the economic life of the building can be assumed to be 50 years.

Annual Charges

Proposal A

Capital recovery for years 1 to 10 (£25 000 x 0.05478) = £1369
Interest on site costs (£20 000 x 0.05) = £1000
Building maintenance and service charges (25 squares x £18) = £ 450
Total = £2819

Capital recovery for years 11 to 20
(£15 000 + £5000) x 0.05828 = £1165
Annual charges of first stage = £2819
Building maintenance and service charges (15 squares x £18) = £ 270
Total = £4254

Proposal B

Capital recovery (£40 000 x 0.05478) = £2191
Interest on site costs
(£20 000 x 0.05) = £1000
Building maintenance and service charges (40 squares x £18) = £ 720
Total = £3911

Present Worth of Annual Charges

Proposal A

Present worth of annual charges for years 1 to 10
(£2819 x 7.722) = £21 768
Present worth of annual charges for years 11 to 20
(£4254 x (12.462 – 7.722) = £20 164
Present worth of annual charges for 20 years £41 932

Proposal B

Present worth of annual charges for 20 years
(£3911 x 12.462) = £48 739

Hence Proposal A has an advantage in present worth of £6807.

Many factors can contribute to the selection of wrong economic plans. Experience has shown that these include the following:

(a) Selection of too short a study period.
(b) Incorrect average life of plant used.
(c) Incorrect salvage rate used.
(d) Incorrect annual charge rates used.
(e) Annual charge rates for depreciation not adjusted to fit the plans chosen.
(f) Inadequate consideration being given to the most economical reuse of recovered equipment.

RATE OF RETURN STUDIES

Any organisation which is in business to make a profit must take in revenue which is in excess of the needs to meet its operation and capital recovery costs. Revenues must exceed all other costs by a margin sufficient to provide earnings that will give a satisfactory return on the investment. The rate of earning that is adequate is dependent on many factors and its determination is a financial problem that must be resolved by the organisation.

Rate of return studies basically stem from the need for management, in planning its capital budget, to choose between doing something or not doing it, or doing either one thing or another. In the first case, the study is required to answer the question, "Why do the work at all?" This involves the calculation of the prospective rate of return on the proposed investment.

The most popular method of calculating the prospective rate of return on an investment is the 'Discounted Cash Flow' method which is basically an adaptation from present worth theory.

This method as the name implies is based on cash flows. The investment outlay is an outward flow which may be instantaneous or spread over a period. Net cash earnings provide the inward flow over the lifetime of the investment. The rate of interest is a measure of the return generated by the net earnings after repayment of the investment. It is important that depreciation must be excluded from the expenditure items as the method is concerned only with cash flows. Capital recovery (depreciation) is automatically provided for in discounting net earnings at a rate of interest that makes the present value of those earnings equal to the present worth of the investment.

For the purpose of an engineering economic study of the project, an attempt is made to determine a rate of return which will be reasonably representative of the long term future average. Sound judgment as to the probable future rate of return has its foundations in a survey of past and present earnings of the organisation and contributory factors such as trends in the money market. While the rate of return is an important factor in the engineering economic study, a high accuracy in the rate used is not needed because such costs studies involve many assumptions and estimates as to the future.

Examples of investment rate of return studies carried out by the discounted cash flow method are as follows:

EXAMPLE 14.9

A project calls for an investment of £30 000 in new radio equipment which has an estimated economic life of 12 years. The estimated uniform earnings from the investment is £3579 per annum.

This problem is the same as determining what interest rate would apply if a loan of £30 000 were to be repaid in 12 uniform annual payments of £3579.

It is evident that to find the annual payment necessary to repay a loan of £30 000 over 12 years at a given interest rate (i), the calculation would be:

Instalment = £30 000 × c.r.f. ($i, n = 12$)
The instalment in this case is = £3579

$$\text{Therefore c.r.f.} = \frac{£3579}{£30\,000} = 0.11928$$

If the tables are examined to determine at what interest rate the capital recovery factor for $n = 12$ is 0.11928, it is found that the rate is very nearly equal to a rate of return of 6% per annum. A rate so near to this is often not always so readily obtained and some interpolation may be necessary to determine the actual rate of return. The 6% rate in the above example can be proved as follows:

Year	*Investment at beginning of year* (£)	*Return* (£)	*Interest at 6%*	*Principal repaid* (£)	*Principal outstanding end of year* (£)
1	30 000	3579	1800	1779	28 221
2	28 221	3579	1693	1886	26 335
3	26 335	3579	1580	1999	24 336
4	24 336	3579	1460	2119	22 217
5	22 217	3579	1333	2246	19 971
6	19 971	3579	1198	2381	17 590
7	17 590	3579	1055	2524	15 066
8	15 066	3579	904	2675	12 391
9	12 391	3579	754	2825	9 566
10	9 566	3579	574	3005	6 561
11	6 561	3579	394	3185	3 376
12	3 376	3579	203	3376	Nil

This method is not applicable where the earnings on an investment are non-uniform.

EXAMPLE 14.10

A proposed work calls for an investment in new equipment of £30 000. The revenue from the service is estimated to be:

First year	£1000
Second year	£2000
Third year	£3000
Fourth year	£4000
Fifth year	£5000
Sixth year	£6000
Seventh year	£7000
Eighth year	£7000
Ninth year	£7000

At the end of the ninth year the equipment would have reached the end of its economic life.

In this case, it is necessary to take each year's earnings separately and discount each to its present worth value using an interest rate so that the sum of the present worth of the flow of earnings will equate the initial investment. It is a matter of trial and error at different interest rates over the period to obtain the required present value of £30 000.

(a) Present worth at 5%

Year	*Net cash inflow* (£)	*Present worth factor of single instalment*		*Present worth of earnings* (£)
1	1000	0.9524		952
2	2000	0.9070		1814
3	3000	0.8638		2591
4	4000	0.8227		3291
5	5000	0.7835		3917
6	6000	0.7462		4477
7	7000	0.7107		4975
8	7000	0.6768		4738
9	7000	0.6446		4512
			Total	£31 267

(b) Present worth at 6%

Year	*Net cash inflow* (£)	*Present worth factor of single instalment*		*Present worth of earnings* (£)
1	1000	0.9434		943
2	2000	0.8900		1780
3	3000	0.8396		2519
4	4000	0.7921		3168
5	5000	0.7473		3737
6	6000	0.7050		4230
7	7000	0.6651		4656
8	7000	0.6274		4392
9	7000	0.5919		4143
			Total	£29 568

The calculations show 5% is too low and 6% is too high. Through a process of interpolation one would expect a rate of return of the order of $5\frac{3}{4}$%.

UNCERTAINTY

It is generally assumed in making economic comparison studies that the risk of the competing investments is the same. In practice, however this may not always be so. The investment for a satisfactory return on one installation may be a much more risky procedure than the risk of getting a satisfactory rate of return from the investment in another installation. Decisions which are based on assumed certainty may be correct economic decisions but they depend on things working out exactly as planned. Decisions should be made in the light of calculated risks, gambling on the odds that the future will fulfill the engineers judgment.

Risk will depend on the following:

(a) The ability of the engineer to minimise bias.
(b) Accuracy in forecasting future growth, material prices, wage increases etc.
(c) The accuracy of the data used in the comparison study.
(d) Unforeseen obsolescence.
(e) Unforseen effects such as war, political influence etc.

Some projects are inherently less risky than others. Station upgrading and replacement investments are not likely to be as risky as expansion investments. When a demand already exists it is natural when estimating the future requirements to plan on the assumption of growth in the immediately preceding years. The usual method adopted is to graph the demand against time and then by various methods derive the growth curve which can be projected to the time for which the forecast is required.

Risk evaluation can be attempted by probability methods which involve recalculating results by varying one or more of the risk factors. The engineer can determine how sensitive the study results to changes in the variable factors. For instance, a particular application of a sensitivity study can be made in respect of investments which are proposed by arbitrarily varying components such as economic life estimates by plus or minus 5 to 10%.

COST/BENEFIT ANALYSIS

Cost/benefit analysis is a practical way of assessing the desirability of a project. It is a way of enumerating and evaluating factors which need to be taken into account in making economic choices. It assists management in determining whether or not a project is worthwhile, which is the best of the proposed alternatives and the optimum time at which to implement a proposal.

Although cost/benefit analysis is by no means a new management technique it has in recent years come into prominence with radio engineering projects which involve heavy expenditure, absorb a large amount of resources and because of their long life have a substantial effect on the form and functioning of further development. The main factors which have to be taken into consideration include:

(a) Costs and benefits.
    In the majority of situations the nature of the project is comparatively well defined but problems do arise in those cases where the implementation of the project has a cross flow of costs and/or benefits with another proposal or a scheme already in existence. For example, if the provision of additonal communication circuits between two major centres is being studied, and two alternatives are microwave radio system and coaxial cable system, a comparison would have to be made between radio system only, coaxial cable system only, or a combined radio and coaxial cable system.

In many large projects, particularly those associated with public service, there are often benefits and costs which accrue to people or organisations not associated with the sponsor of the project. It may well be asked to what extent should these benefits and costs be included in the analysis. Usual practice is for a benefit to be ascribed to a project only if:

(i) the specific expenditure would not have been incurred in the absence of the project.
(ii) resources that would not otherwise have been employed are utilised.
(iii) economic changes which would otherwise have taken place are not displaced.

As an example, if the establishment of a high power broadcast transmitter in an area where the power requirement would be such that the local town power generating plant could be run at greater efficiency, and so resulting in a tariff reduction to the local consumer, then the more efficient utilisation of the power plant can be considered as an allowable benefit. However, the increased profitability of the oil company supplying fuel to the power station cannot be credited to the radio station investment. Any net difference in profitability is simply a reflection of more engines being used for longer periods and this would already be included in the accrued benefits.

(b) Fixing a value on costs and benefits.

In making an analysis of costs and benefits associated with a project, many things which are incomparable in their original form have to be compared. In a typical situation, for example the provision of a radar system on a ship, the installation, operation and maintenance costs can be easily assessed in monetary terms. On the benefit side, savings resulting from the installation of the equipment may be presented as the number of avoidable fatalities, injuries and collisions with other ships etc. The problem is to fix an appropriate monetary value on benefits which do not have a real market value.

Other examples may be cited, for instance what value can be ascribed to the saving in time, particularly for a busy executive, where the provision of a broadband radio system will allow subscriber trunk dialling, instead of a manual operator service? Also, what value can be placed on the increased enjoyment of colour television compared with monochrome, sterophonic or frequency modulation broadcasting compared with amplitude modulation, and many other similar services?

For benefits which have no direct market value, use can often be made of other observable market prices in order to arrive at a value of these benefits. It is reasonable logic to assume that time saved by a busy executive using subscriber trunk dialling facilities can be equated to the salary of the executive and together with savings in office switchboard operator costs. For the private or social telephone caller the value of time saved is open to some argument but nevertheless there is still some value which a person phoning during leisure hours would ascribe to time saved.

For those costs and benefits associated with aesthetic or scenic effects resulting from say, the construction of a massive radio tower in or near a residential area for radiocommunication or television purposes, the only practical method appears to be to qualitatively weight these effects for the various alternatives. In many projects they may be important considerations, and the arguments for and against have to be submitted in the prose as they cannot be incorporated in the mathematical treatment.

(c) Applicable interest rate.

Much discussion has taken place over the years on an appropriate interest rate for cost-benefit studies, particularly where public projects are concerned. Sometimes a government borrowing rate may be used while at other times a market determined rate may be used. It is of course important to ensure that the same interest rate is used when comparing different projects. In some cases very awkward situations have developed where a government department has carried out a cost/benefit study using one interest rate while private enterprise has examined the same alternatives using a different interest rate. The inferior alternative of one has supplanted the superior alternative of the other. Because of this problem it is not unusual for analyses to be carried out with a range of interest rates so that the sensitivity of the project or alternatives can be determined for various rates.

(d) Relevant constraints.

Nearly all major projects are subject to some constraints. These may be physical constraints such as unavailability of equipment or staff, legal constraints such as site acquisition, environmental, administrative and budget constraints.

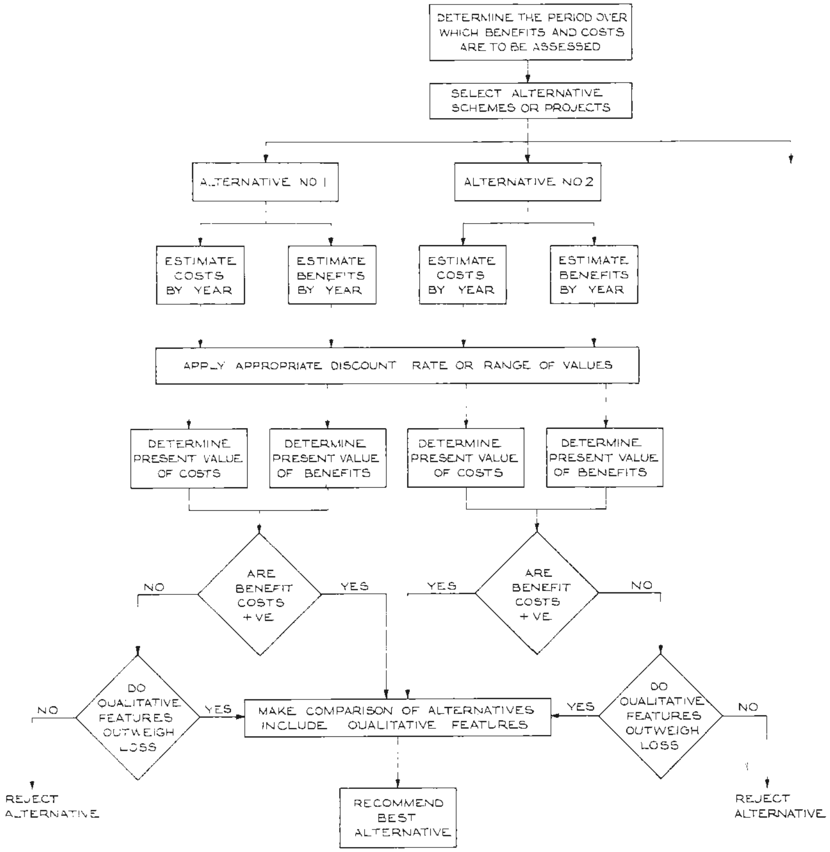

Figure 14.1 Flow chart for cost/benefit analysis

After completion of the analysis, the project would generally be economically worthwhile if the present value of all benefits less costs is positive. Where no projects are mutually independent or where there are no operative physical or time constraints, the choice can be made in such a way that the sum of the present value of benefits less costs is a maximum. Where there is no pre-fixed budget limitation all projects would be undertaken for which the present value of benefits exceeds the present value of costs. Where preset budget limitations do apply but there are no other constraints, the project priorities would be such that projects with the highest benefit to cost ratio or highest rate of return would be carried out first.

Figure 14.1 shows a typical flow chart used in carrying out a cost/benefit analysis.

FURTHER READING

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Chapter 15

Capital Costs

Capital cost is the first or initial cost and is incurred before the service it provides, becomes available. It includes the cost of materials, labour, incidentals, contractor's bills if any part of the work is carried out under contract, and associated engineering administrative charges. It also includes cash or short term investments which may be maintained to pay for new work and to meet current expenses in advance of receipt of revenues from equipment or plant. The capital cost has significance in four main areas:

(a) Competition with other projects for the available capital resources.

(b) The cost of raising capital.
When new loans have to be negotiated, some expenses are involved. In commercial undertakings, brokerage and other costs are incurred and a premium may have to be offered. In the case of Government loans the expenditure in raising capital is not so easy to assess, but it is undoubtedly present.

(c) The interest charges on the capital raised during the installation or construction period.
The material must be purchased and staff wages paid during the whole of the construction period before the equipment or plant is able to raise revenue. Interest charges which are incurred prior to placing the facility in service are just as much a cost of constructing or installing the equipment or plant as are the labour and material costs.

(d) Once spent, the capital involves a recurring annual charge providing for repayment over the economic life of the equipment or plant and for the payment of interest.

Although the amount of money required to be raised for any given provision of equipment or plant is increased by the costs incurred in raising the loan, it is not usual practice to add them to the cost of the equipment or plant provision, but to charge them to the organisation's operating expenses. However, interest charges on capital required for the installation or construction period are usually regarded as proper debits to the installation or construction costs.

ECONOMIC LIFE

Wear and tear or accelerated deterioration due to the elements over the years, results in increasing maintenance charges. Eventually the annual maintenance costs become so high that it is not economic to retain the plant in service. It is at this stage that it reaches the end of its economic life. The economic life may be determined by actual life, by technological advances that make it inadequate or obsolete, or by unsupportable increases in cost of maintenance and operation because of age. Although average lives of various items of radio engineering plant or equipment are available, there will be times when deviations from normal are known and in these cases it is usual for the planned life rather than the average life to be used. Equipment and plant are retired also at times when maintenance spare parts are no longer available.

Equipment or plant life may extend beyond the study period, or items may be removed for installation elsewhere. In these cases, not all capital cost is attributable to the plan under consideration and so the capital cost is converted to an equivalent annuity extending over the plant life. The present worth of those annual charges that fall within the study period is the portion of the cost that would be included in the plan.

Payments made before the beginning of the study period are not considered as part of the cost of a plan. These funds are already spent and remain unaffected by any later decisions.

COST CONSIDERATIONS

Typical of the points which may arise in considering the capital costs of radio engineering facilities are illustrated by the following which are applicable to a microwave radio relay system:

(a) The likelihood that the provision of additional radio equipment and plant at a later date, using the same sites and buildings, and in the case of a r.f. multiplex system the same mast and antennas, will be much cheaper than the initial provision.

(b) The likelihood that the provision of standby radio equipment and plant may add a relatively small percentage to the total cost.

(c) The possibility that a cost comparison between two radio systems, such as those operating in different frequency bands, may be influenced as much by site, building and antenna costs, as by the costs of the radio transmitters and receivers.

(d) The possibility that the siting of a radio station on a remote rugged site may cost almost as much as that of two stations on more accessible sites. This however will be an exceptional case and it will usually be cheaper to reduce the number of radio stations to the minimum, consistent with satisfactory performance.

RELIABILITY

Reliability and cost of operation are closely related and in many instances cost can be of equal if not greater importance. The value of spare parts can be very great for large installations and the extent of usage has a major influence on the cost of operations. Also, the life of major equipment items could reasonably be expected to be in service for 20 years or more and because spare parts are often difficult to obtain for superseded equipment in today's rapidly developing technology, unreliable equipment may have to be withdrawn from service before the planned time.

The overall failure rate of equipment is greater than that of any of the components used and it is important therefore to use components of proven low failure rate where equipment high reliability is required. However, setting a reliability figure higher than is necessary must be paid for in terms of cost as the capital cost and the failure rates of components are closely related. Since maintenance costs are a continuing charge against a facility and capital cost is a once only cost it may be necessary to trade off additional capital cost against reduced maintenance costs if annual charges are to be minimised.

The increasing cost of maintaining modern electronic equipment has called for a new approach to fault finding and repair work. For a television or broadcast station this would be done by local on-site staff or staff from a remote control point. Faults in transmitting cubicles or heavy components would be repaired on site if practicable, but small modular units may be taken back to the remote control or other repair points. For broadband microwave relay systems where small modules are used in considerable numbers for a major system, a centralised repair depot staffed by skilled people would almost certainly be economically viable.

Each new system or facility tends to be more complex than the earlier model it superseded with a result that the cost of maintenance has a tendency to rise. In many products complexity has increased without a corresponding increase in reliability. Field experience shows that the more complex a piece of equipment the more likely it is to malfunction. In one broadcast transmitter produced in the mid 1960s with about 1200 components the history log showed that it had a malfunction about every 1500 hours. As the transmitter operated for 18 hours per day this averaged about one malfunction every three months of service. In the 1970s the manufacturer brought out a completely new design as a replacement giving the same technical performance but incorporating sophisticated automatic monitoring and remote control facilities. The number of components in the transmitter increased 10 times and a malfunction occurred about every 600 hours or once per month. Although many of the malfunctions did not cause transmitter shutdown, the overall maintenance costs rose sharply because of the need for more frequent visits by the technical staff.

ESTIMATING FIRST COST

The estimated cost of carrying out a plan must be as close as possible to the actual cost which is incurred when the work is finally carried out. Unfortunately many estimates are too conservative and many examples can be quoted where estimates prepared by the engineer failed to be confirmed when contracts were let. Mainly because of inexperience, many young engineers, in particular, are apt to under estimate. The future of course is invariably full of unknowns, but the engineer, drawing upon his knowledge and experience and the facts available to him should have a sound basis for estimating the costs to a reasonable order of accuracy.

Some costs associated with radio engineering projects are more uniform in character than others and useful rules of thumb have been derived from the records of previous installations. For example, the cost of providing foundations for a broadcast radiator in a normal soil type environment may be approximated by using a price per cubic metre of concrete required for the thrust block and the guy anchor foundations. The cost per cubic metre would be independent of

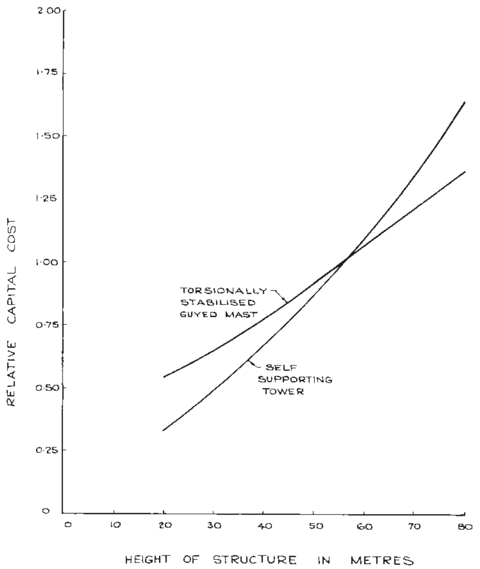

Figure 15.1 Relative capital cost of medium duty guyed masts and self-supporting towers

the height of the structure. However, the steel erection and material costs are influenced considerably by the height. This is shown in *Figure 15.1* which indicates the relationship between relative capital cost and height for typical medium duty masts and towers both capable of supporting two 4 m diameter antennas. Similarly, knowing the cost of a major item of a particular type, for example the cost of the copper wire for a broadcast radiator earth mat and the average laying rate, a fairly accurate cost may be estimated. Approximations of these types are seldom possible in works which involve complex circuit designs such as the conversion of a manually operated television transmitter to fully automatic control and monitoring using a micro-electronic processor.

The quantity survey, that is a compilation of the quantity of materials required for the project, is the first step in cost estimating procedure. All costs, however, cannot be easily reduced to quantity units such as cubic metres of concrete, metres of wire etc. and have to be estimated as lump sums. Nevertheless, a great majority of radio engineering estimates are based on unit prices, which applied to the quantity of each unit required, gives the total cost of the job. While there is little room for a difference of opinion on the quantites of materials involved in a particular work which has been properly planned and engineered, the estimation of a fairly accurate unit price is a very different problem.

The total cost of a project may often be very closely approximated through a knowledge of the cost of similar projects which have been undertaken. Every work generally has some features peculiar to itself, and the final estimated cost will be influenced by the experience and knowledge of the engineer preparing the estimate. Also, as material and labour prices, transport costs and travelling expenses vary from year to year and in cases of high wage rise, the overall costs may rise sharply. It is unfortunate that increasing labour costs tend to more than neutralise reduced equipment costs due to technological improvements in production. As a result, the unit cost of installation of many projects is steadily rising even though equipment costs in some areas have fallen considerably. Care is therefore required in utilising cost figures on projects which may be several years old, particularly when endeavouring to estimate the costs for works several years ahead.

Some radio engineering projects can involve considerable capital expenditure. One large international broadcast complex in the USA utilising two transmitting stations and a receiving station cost about US $25 million in 1962. A brief break up is as follows:

(a)	Site acquisition totalling more than 2500 hectares for the three sites	US	$ 1.2M	4.8%
(b)	Equipment including 22 transmitters (10 kW to 500 kW) and receiving station facilities and programme lines	US	$ 6.0M	24.0%
(c)	Antenna systems including 28 curtains, 41 rhombic and 4 log periodic transmitting antennas together with 20 rhombic and 2 log periodic receiving antennas	US	$10.2M	40.8%
(d)	Construction, installation and commissioning of the complex facilities	US	$ 5.5M	22.0%
(e)	Architectural, engineering, transport, incidental and administrative charges	US	$ 2.1M	8.4%

The very low frequency station used for naval communication purposes is another type which involves very high capital expenditure. The US Navy station Naval Communications Station Harold E. Holt commissioned in 1967 at North West Cape, Western Australia, employed a 2 MW transmitter giving a radiated power of 1 MW from an antenna consisting of 12 towers built in two concentric rings encircling one 387 m central tower, Tower Zero, the tallest man made structure in the Southern Hemisphere. The transmitter cost US $5 million plus US $1 million installation costs. The building housing the transmitter involved an expenditure of US $2 million. In the antenna system, Tower Zero alone cost about US $1 million. Power generating plant with a capacity of 18 MW was built at a cost of US $6 million and consumed about 4.8 million US gallons of diesel fuel per year.

TYPES OF ESTIMATES

The type of estimate prepared for the determination of the first or initial capital cost of a project in connection with an economic comparison study is the preliminary type as distinct from the approximate and the detailed estimates.

The approximate estimate is prepared with the very minimum of research and is generally an intelligent guess based on the engineer's experience of similar type works. It is normally prepared to allow the person seeking the information to get a rough idea only, of what the work is likely to cost, for example we may ask "Will it be nearer £500, £5000 or £50 000?"

The detailed estimate is prepared when a firm decision has been made to proceed with the work and involves the compilation of quantities of the various items of work associated with the project, the assessment of a unit rate of cost of each item, the extension of each item's total cost and the summation of these to ascertain the total estimated cost. The detailed estimated cost is particularly valuable for costing purposes and cost analysis throughout the progress of the work. It is prepared with meticulous accuracy, and management generally sets down the order of accuracy desired,. In some organisations, it is required that the total estimated cost be within 10% of the actual completed total cost of the work with allowable variations within the estimate of up to 20% for labour, materials and incidental costs.

The preliminary estimate involves a certain amount of engineering investigation of the proposed work. For a relatively minor project, such as the provision of a single radiocommunication circuit between two centres, the estimate under average conditions may be prepared from information available from maps etc. and a general knowledge of the area. For a much larger system involving, say, a 1800 channel radio relay system or a coaxial cable system between two centres 800 km apart, the engineering investigation may be carried out on an extensive scale and could involve reconnaissance survey of the route, bore hole investigations, propagation tests, location of materials such as sand, gravel and water, determination of tower heights, measurement of soil resistivities and so on. In another case, several sites may be available for the establishment of a medium frequency broadcast or television station and extensive tests with mobile transmitters and field surveys may be involved in deciding which sites are technically suitable to give the desired coverage. This would then be followed by local investigation of each site to accumulate data required for economic comparison studies.

The preliminary estimate investigations may be quite extensive for a large project, but not be so detailed as to waste money or effort in case the work does not proceed. These estimates are however of great importance for upon their accuracy depends the fate of many works. They should not be confused with approximate estimates but should be carefully compiled and checked as for a detailed estimate. The objective should be to achieve an accuracy of at least 10–15% of the detailed estimate.

MAIN FACTORS IN ESTIMATING

Two main factors associated with estimating are costs of material and labour. Labour charges change continually and this reflects a change in the price of materials, particularly those involving a large labour component in their manufacture. Because of this, standardisation by stabilised prices and performance is difficult. Other factors such as overhead and contingencies are also often difficult to estimate accurately. Overhead requires constant review from time to time. Contingencies of course by their very nature are difficult to estimate accurately and experience can be an important factor in arriving at a basis for these costs.

The importance of including all costs cannot be overemphasised and the inexperienced engineer is often at a disadvantage because every new job often requires the consideration of factors not present with previous projects. A complete data file with performance and cost records is an important aid. Also a check list similar to *Table 15.1* has been found useful by many engineers engaged in estimating projects for broadcast stations. The check list is invaluable

Table 15.1 CHECK LIST FOR BROADCAST STATION ESTIMATES

RADIO ENGINEERING EQUIPMENT

Transmitter Equipment
Basic Transmitter
Combining equipment
Programme input equip.
Frequency generating equip.
Monitoring equipment

Emergency studio facilities
Control desk
Dummy load
Heat exchanger
Auto control equip.
Voltage regulators
Localised screening
Transmitter hall ventilation
Air scavenging vault area
Inbuilt fire detectors

Special safety equipment
Special protection equip.
Water distillation plant
Mechanical aids for instal. work
Ducts and cabling ironwork
Installation materials
Low impedance earth system
Installation tools
Spare parts

Antenna System
Soil bearing investigations
Soil conductivity tests
Earth mat system
Foundations
Mast or tower steelwork
Guys
Insulators
Bonding
Aircraft warning facilities
Sectionalising equip.
Capacity loading
Lightning protection
Mechanical aids for erection
Deicing equipment
Pretensioning guy tests
Transmission lines internal
Transmission lines external
Pressure equip. for coax lines
Matching and phasing equip.
Line switching equipment
Special hardware
Dissipative lines
Concrete sampling costs
Tools and spare parts

SUPPORT ITEMS

Equipment
Battery equipment
Workshop facilities
Test equipment
Tube conditioner
Tube handling facilities
Vehicles
Vehicle servicing facilities
Emergency power plant
Power switchboards
Power sub-station
Cranes and gantries
Bin store equipment
Fuel supply and storage
Office equipment
Internal communications
Programme supply facilities

Building alarm displays
Installation and commissioning materials

Facilities
Site purchase
Site preparation layout
Buildings
Special floor loading
Oil drainage in vaults
Air conditioning
Air ventilation
Acoustic treatment
Building fire protection
Water reticulation
Power and lighting
Sewage disposal
Site roads and drainage
Access roads
Fencing
Telephone and programme line costs
Local transport
Building earth system
Building bonding and earthing
Screened rooms
Layout diagrams
Cabling diagrams
Accommodation for staff

Table 15.1 *(continued)*

CONSTRUCTION AND COMMISSIONING

Systems engineering and design
Propagation studies
Field intensity survey
Installation construction and erection
Commissioning and acceptance testing
Documentation
Staff recruitment and training
Locality index figure
Local authority and licence fees
Taxation and Duty charges
Insurance
Transportation
Administration and overhead

in avoiding oversights. Other oversights are caused by not taking into account all of the information about the project which is actually available at the time the estimate is made. This type of oversight can be avoided only by constant careful attention to all aspects of the project.

When considering estimates for the establishment of facilities in isolated areas and on a world wide basis the estimate is modified by a location index which takes into consideration variations in cost applicable to the local labour situation, transportation, to construction of support facilities and hire of local mechanical aid equipment. This location index would probably have a value of 1.0 for countries such as USA, Australia, United Kingdom, and may increase to 4.0 or more for isolated sites in the Pacific Ocean, Alaska, Antarctica and others.

CAUSES OF DEVIATIONS

Because an estimate is a forecast of the future it is unreasonable to assume that estimates of costs will be perfectly accurate. The deviations of actual costs from the estimated costs may be due to many causes, some of which are:

(a) Changes in the project during progress of the work.
Additional amplifiers might be provided to meet a future need or changes in the foundation plan of a mast or tower may be required following additional information obtained on the nature of the soil after excavation work has been completed.

(b) Unforeseen difficulties.
Exceptional wet weather conditions may introduce difficulties in the construction of mast foundations or other external plant facilities.

(c) Changes in economic conditions.
Industry award changes may cause a sharp rise in labour and material costs or may require the employment of staff with special skills on particular phases of the work.

(d) Accidents during construction.
A mast may collapse during the course of erection or a major transformer may fail during commissioning of a transmitter.

(e) Variations in effectiveness of project performance.
Difficulties may be experienced in meeting the specifications with a new equipment design or construction techniques set down in the office may not be practicable in the field situation.

(f) Imperfections in estimating methods.
Facilities which require considerable research and design effort are difficult to cost estimate. Also where the erection of a large number of towers for a long haul radio relay system is involved, an average cost figure for foundation works has often fallen short of the actual cost because of the very great differential between many of the sites.

(g) Oversight in estimating.
Inexperience on the part of the estimator or lack of proper co-ordination between sections could result in important items being overlooked in the costing analysis.

Also there are many factors which may cause the cost of two similar type projects to vary, sometimes considerably. These include variations in equipment costs by different manufacturers, local labour costs, site access problems, site construction problems, availability of local construction, and the degree of expertise of recruited local labour.

TYPICAL FIRST COST EXAMPLES

Costs of many radio engineering projects are seldom published. There is a great amount of data available on civil, mechanical and electrical engineering works but information in the radio engineering field is not easy to obtain. Some typical preliminary cost estimates which have been prepared for various projects are shown in the following examples. Because cost factors vary with current labour rates, location, climate, union jurisdiction etc. they should not be considered as firm costs or applicable to any particular situation. In most cases the item costs are shown as percentages of the whole rather than as specific monetary values. By adopting this approach, confusion in relation to exchange rates, cost escalation etc. should be eliminated.

The emphasis has been placed on the approach to the break-up of the work and the material requirements rather than actual cost amounts as these tend to become out of date very quickly.

The estimates are based on the use of good construction materials and methods. In some circumstances cheap construction may be warranted but in the long run it is usually better to save on operating and maintenance costs rather than on capital expenditure.

EXAMPLE 15.1

The supply, installation and commissioning of a high power medium frequency broadcast station complete with radio equipment, antenna system, power generating plant, buildings and civil engineering works. The station was to be located in an isolated tropical environment and to operate with an output power of 1 MW at a frequency of 700 kHz into a directional antenna system comprising twin 0.55 wavelength radiators.

	Radio Engineering Equipment	*Percentage*
Item 1	1 MW medium frequency broadcast transmitter with vapour cooling, designed to cover medium frequency broadcast band 525-1605 kHz, and capable of continuous operation.	19.1
Item 2	Programme input and monitoring equipment including amplifiers for sinusoidal and trapezoidal modulation and emergency programme equipment.	0.6
Item 3	Control desk complete with all necessary metering and control facilities.	0.4
Item 4	Antenna matching equipment to provide a horizontal radiation pattern in a figure eight form, housed in cabins at the bases of the two radiators.	2.0
Item 5	R.f. feeder lines capable of 1 MW plus 100% modulation continuous.	0.9
Item 6	Antenna system for carrier frequency 700 kHz, comprising two selfsupporting towers approx. 183 m in height.	10.0
Item 7	Dummy load for a dissipation of 1 MW plus 100% modulation complete with heat exchanger.	0.9
Item 8	Spare parts including tubes, semiconductor devices, depot spares, consumable unit spares for transmitter and dummy load and spare parts for antenna, transmission lines and matching equipment.	6.1
	Support Equipment	
Item 9	Workship equipment, including lathe, complete with all threading and turning tools, bench drill, bench grinder, anvil, welding equipment, sheet metal bender, portable hack-saw machine, tube bender, electric drills and necessary tools for the proper maintenance of the station equipment and plant.	0.6
Item 10	Test equipment, comprising portable cathode ray oscilloscope with trolley, r.f. impedance bridge, oscillator and detector, high voltage test set, receiving tube and transistor testers, high tension voltmeter, multimeters, field strength meters, noise and distortion sets, oscillators, attenuators, transformer oil test set, air velocity meters, clip-on ammeter, thermometers, resistance-capacitance bridge, r.f. ammeters, v.t.v.m. etc.	0.7
Item 11	Power generating plant for feeding the transmitter and the station auxiliaries and comprising: (a) 2 diesel engine generators in parallel, 1800 kVA output each together with the necessary electrical switchgear feeding the transmitter. (b) 2 diesel engine generators in parallel, 1500 kVA output each, as 'general supply' of the installation together with associated electrical switch gear.	16.7
Item 12	Spare parts for engine generating plant.	0.7

	Percentage
Support Facilities	
Item 13 Buildings and civil engineering works comprising: (a) Transmitter building of masonry construction and containing transmitter room, heavy spare parts store, air conditioning plant room, workshop, tube store, bin store, control room, test room, office for officer-in-charge, general office, battery room, locker room, toilets, kitchen and lunch room. Area approx 837 square metres. (b) Power house for housing the power generating plant —all steel construction and including office, spare parts store and servicing room, overhead crane and cooling towers. (c) Civil works for the two antenna huts and fencing around the towers. (d) Foundations for the two radiators. (e) Supply and installation of lighting equipment in the transmitter and power house buildings. (f) Water storage and distribution system. (g) Fixed and mobile fire protection system. (h) Air conditioning and ventilation system. (i) Fuel tanks with a capacity of 400 000 litres. (j) Internal communication facilities. (k) Local road, drainage and fencing works. (l) Two general purpose vehicles.	27.7
Installation	
Item 14 Construction and commissioning the station, including design, site survey, installation, erection, transportation, incidental expenditure, documentation, training, administration and overhead charges.	13.6
Total	100.0

The cost break up does not include any special provision for the normal programme facilities, Duty, Sales Tax or any other form of local tax charges or rates which may have been appropriate, or site acquisition costs.

Figure 15.2 shows a view of the final and output stages of a typical 1 MW medium frequency broadcast transmitter with all doors and screens removed. The coils and gas pressure capacitors for the final plate pi-filter circuits and the various components of the harmonic filter are arranged in a very accessible manner. In the fully assembled transmitter the components are accessible by an internal passage running the full length of the unit shown.

The major investment costs associated with the establishment of a medium frequency broadcast transmitting station include:

(a) Purchase of site.

This often involves the acquisition of a considerable amount of real estate owing to the requirements of antenna systems and earth mats. Soils with high electrical conductivity properties are desirable and these types are generally part of fertile land, the purchase price of which can be very high.

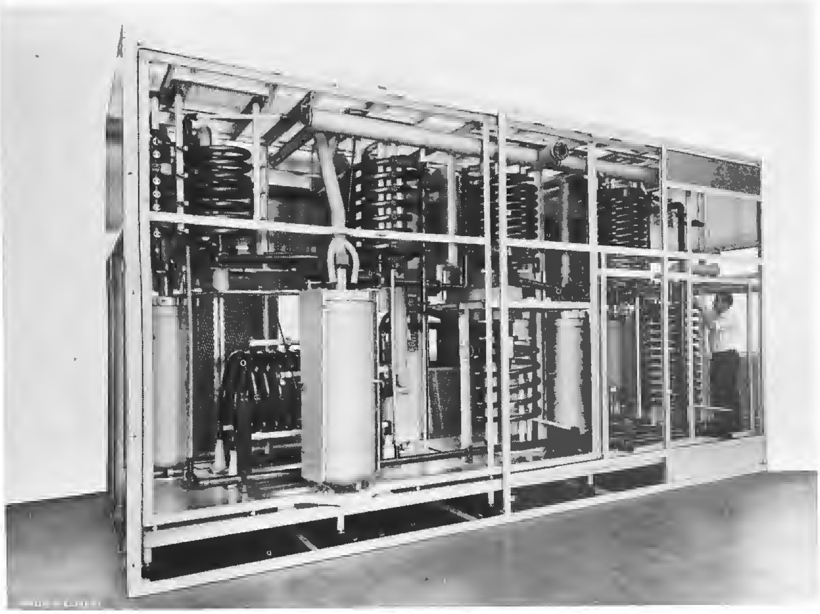

Figure 15.2 Final and output stages of 1 MW transmitter (Courtesy Brown, Boveri and Co)

(b) Preparation of the site.
With the exception of drainage requirements for building surrounds, little site preparation costs are generally involved. The nature and size of the land acquired is such that access roads are as a general rule not a major problem and in any event are usually of reasonable cost. On the other hand, for a television or radiocommunication station to be established on a mountain top, access road and site preparation costs sometimes exceed the cost of the technical equipment and buildings combined.

(c) Buildings required for the broadcast equipment, power plant and staff residences where necessary.
The associated services, such as water supply, sewerage, fuel supply and electric power sub-stations, form part of these costs.

(d) Transmitting equipment including transmitters, programme input equipment, studio programme circuits, spare parts, power generating equipment etc.

The cost of a broadcast transmitter varies with the amount of automation and control circuitry. For instance a transmitter under computer control will cost very much more than a standard manually controlled model. Recently, costs have been considerably influenced by the current state-of-the-art. High power transmitters employing solid state devices are however in many cases more costly than those utilising tubes, notwithstanding the decreasing costs of the solid state devices during the past few years. *Figure 15.3* shows the relative costs of medium frequency and high frequency transmitters supplied by one manufacturer.

(e) Radiating system including structures, foundations, sectionalising and capacity top loading, matching equipment, aircraft warning facilities, earth mat, transmission line and line switching equipment.

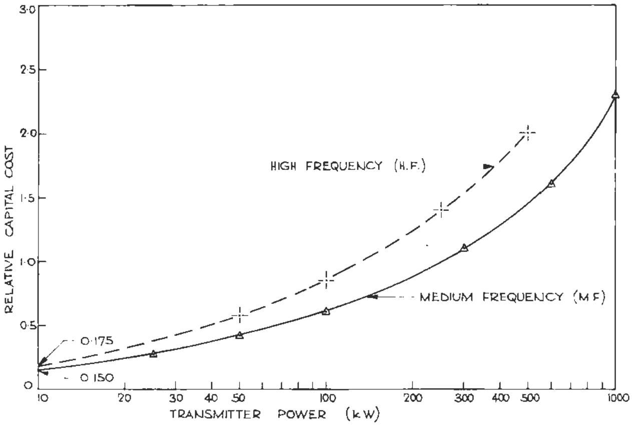

Figure 15.3 Relative cost of m.f. and h.f. transmitters compared with power output

Antennas operating at medium frequency are in most cases rather inefficient radiators. The greatest single factor leading to this inefficiency is usually the earth mat system. The problem of obtaining optimum design in a radial conductor earth mat system lies in attaining maximum power radiated per unit of overall cost. The optimum design of the earth system, when the design of the antenna and transmitter have been determined, is accomplished when the total annual expense of such a ground system is a minimum. The annual expense includes amortisation cost of the copper wire and its installation charges plus the cost of the power dissipated in the earth. The copper costs are governed by the wire diameter and the number of radials and extent of cross bonding. The wire diameter is generally dictated by mechanical laying considerations. The size commonly laid with a mole plough is 2.84 mm diameter but wire of 2 mm diameter has also been successfully put down on many sites. The cost of power dissipated in the earth is determined by adding the amortisation cost of the station, exclusive of the earth mat system, to the annual operating costs of the station, dividing the sum by the mean antenna input power and multiplying by the watts dissipated per square metre. This cost term rises with increased spacing of conductors.

Earth mats are also employed with some vertically polarised high frequency broadcasts antennas and in these cases the effect of frequency on the optimum mat size is important. The higher frequencies require grid wires to be closer together than for lower frequencies for the same efficiency. On the other hand, the lower frequencies require a physically longer earth mat. If a common earth mat is to be used for several antennas then a compromise is necessary for the best economic solution.

In arriving at the design of a broadcast station, it is apparent that there should exist an economic balance between cost and performance characteristics of the transmitter, programme input and control equipment, the antenna system, matching equipment and the antenna earth mat.

EXAMPLE 15.2

The supply, installation and commissioning of a medium power, medium frequency unstaffed broadcast station, complete with radio equipment, buildings, civil engineering works and standby power generating plant. The station was to be located on the outskirts of a city and to operate with an output power of 10 kW from twin 5 kW units, at a frequency of 1160 kHz, into a directional antenna system comprising twin 0.53 wavelength radiators.

Radio Engineering Equipment		*Percentage*
Item 1	Two 5 kW medium frequency broadcast transmitters, designed to cover the band 525-1605 kHz, capable of parallel operation and complete with combining unit and inbuilt dummy load.	15.7
Item 2	Programme input and monitoring equipment including limiting amplifiers, emergency programme equipment and phase monitoring equipment.	1.8
Item 3	Control desk complete with all necessary metering and control facilities.	1.1
Item 4	Antenna phasing and matching equipment to provide the desired horizontal radiation pattern and housed in two cabinets at that base of the radiators.	2.8
Item 5	R.f. feeder lines capable of 10 kW plus 100% modulation.	3.4
Item 6	Antenna system for carrier frequency 1160 kHz comprising two light duty guyed masts approx. 125 m in height.	15.7
Item 7	Spare parts, including tubes, semiconductor devices, depot spares, consumable unit spares for transmitter, and spare parts for antenna and matching equipment.	2.8
Support Equipment		
Item 8	Workshop equipment including bench drill, bench grinder, electric drill and necessary tools for the proper maintenance of the equipment and plant.	0.1
Item 9	Test equipment, comprising noise and distortion set, oscillator, attenuator, volume indicator, multimeter receiving tube and transistor checker, r.f. ammeters, cathode ray oscilloscope and v.t.v.m.	2.0
Item 10	Emergency power generating plant comprising 60 kVA, 240 V diesel alternator together with switchboard and spare parts.	2.7
Support Facilities		
Item 11	Buildings and civil engineering works comprising: (a) Transmitter building of masonry construction containing transmitter room, workshop, visiting staff room, toilet, store room and emergency power room. Area approx. 120 square metres. (b) Civil engineering works including fencing around building, site and antennas. (c) Foundations for two radiators. (d) Power connection from commercial mains. (e) Water connection from commercial reticulation.	

		Percentage
	(f) Fuel tank for emergency power plant.	
	(g) Local road and drainage works.	
	(h) Fixed and portable fire extinguishing system.	
	(i) Purchase of site.	25.7
Installation		
Item 12	Construction and commissioning the station including design, site survey, installation, erection, transportation, documentation, training, administration and overhead charges, setting the station to work.	26.2
	Total	100.0

The cost does not include any capital charge against the provision of programme circuits from studios, or any Duty, Sales Tax or any other form of local taxation which may have been involved.

EXAMPLE 15.3

The two previous examples are instances of well planned, designed and engineered installations which would give optimum performance, have a high reliability of operation and retain a high standard of technical performance over a long period of time. They do however involve a considerable amount of capital expenditure.

There are many cases where the engineer is called upon to provide a minimum cost installation to meet a situation where quite limited funds are available, and in keeping with the general economy of a particular locality. Such situations occur in the provision of broadcast services for many of the Pacific Islands where the population may be scattered over many islands of a group, funds are limited, skilled technical staff are at a premium and technical excellence is not a primary objective.

One such installation involved three studios, a medium frequency transmitter and a high frequency transmitter operating in the tropical broadcast band. The percentage break up of the capital cost of this particular installation was:

Radio Engineering Facilities		*Percentage*
	Studios	
Item 1	Three studios each complete with desk, two turntables, two tape recorders, microphone, studio type consolette, high frequency receiver, monitor speaker, programme amplifier, relay sets, jackfields, etc. and spare parts.	12.2
Item 2	Shipping costs, handling charges, hire of local vehicles etc. for Item 1.	1.3
Item 3	Installation and commissioning the studios including design, documentation, training, administration and overhead charges.	3.2
	Medium Frequency Transmitter	
Item 4	One 2 kW medium frequency transmitter complete with dummy load, spare parts, including spare tubes, and programme input equipment.	8.2

		Percentage
Item 5	Shipping costs, handling charges, hire of local vehicles etc. for Item 4.	1.0
Item 6	Installation and commissioning the transmitter, including design, documentation, training, administration and overhead charges.	2.2
	Medium Frequency Antenna	
Item 7	One 60 m guyed and insulated antenna system complete with mast, foundations, earth mat, transmission line and matching equipment, materials only.	2.9
Item 8	Shipping costs, handling charges, hire of local vehicles etc. for Item 7.	0.5
Item 9	Erection, installation and lining-up antenna system, including design, documentation, administration and overhead charges.	2.0
	High Frequency Transmitter	
Item 10	One 2 kW high frequency transmitter complete with dummy load, spare parts, including tubes, and programme input equipment.	12.2
Item 11	Shipping costs, handling charges, hire of local vehicles etc. for Item 10.	1.0
Item 12	Installation and commissioning the transmitter including design, documentation, training, administration and overhead charges.	2.2
	High Frequency Antennas	
Item 13	Two high frequency antenna systems (day and night freq.) simple dipole configuration complete with four masts, foundations, transmission lines, remote line switch and matching sections materials only.	5.0
Item 14	Shipping costs, handling charges, hire of local vehicle etc. for Item 13.	0.7
Item 15	Erection, installation and lining-up antenna system, including design, documentation, administration and overhead charges.	2.2
Item 16	Station workshop equipment, including bench drill, bench grinder, electric drill and necessary tools for proper maintenance of the equipment, delivered to site.	0.2
Item 17	Station basic test equipment required for proper maintenance and plant performance routining of studios and transmitters including noise and distortion test set, oscillator, attenuator, volume indicator, multimeters, receiving tube and transistor checker, meters, cathode ray oscilloscope and v.t.v.m., delivered to site.	0.6

Support Facilities

Item 18 Buildings and associated facilities comprising:

(a) Studio building, light weight completely pre-fabricated and assembled on site by local labour under supervision. Containing three studios with acoustic treatment

		Percentage
	and wall mounted low noise air conditioning units, record library room, dub. and edit room, managers office, general office, lunch room, workshop and toilets. Area approx 168 square metres.	17.2
(b)	Transmitter buildings, light weight completely prefabricated, and assembled on site by local labour under supervision. Containing transmitter room, workshop, store room, lunch room, and toilet, area approx 84 square metres.	11.0
(c)	Power connection from mains, water supply, portable fire protection facilities, local site works.	5.7
(d)	Shipping, handling and erection costs of prefab. buildings.	8.5
	Total	100.0

The cost does not include site purchase cost, capital costs involved in providing programme between studios and transmitter or any Duty or Sales Tax.

EXAMPLE 15.4

The fabrication supply and erection of two guyed steel mast radiators for a directional antenna system of a medium frequency broadcast station.

Each mast was to be 138 m in height, no rock was expected to be encountered in the ground, the structures were to be painted, and fitted with aircraft warning lights. Sand and gravel were available from local sources within 8 km of the site.

			Percentage
Item	1	Fabrication of steelwork and other materials for two masts.	33.6
Item	2	Construction of two sets of guy anchors and mast thrust blocks.	19.2
Item	3	Erection of the two masts including pretensioning of guys on ground before attachment to structures.	24.0
Item	4	Painting of the structures.	3.5
Item	5	Installation of mast lighting including provision of isolation transformer.	3.4
Item	6	Tools and appliances including tensioning gear for guys, and jacks.	0.6
Item	7	Spare parts including two mast base insulators with metal end pieces and four guy insulators complete with associated metal work.	0.7
Item	8	Survey work, design, transportation, inspection, hire of mechanical aids, concrete testing costs, incidental expenditure administration and overhead expenses.	15.0
		Total	100.0

The type of structure used is influenced by three main factors.

(a) The purpose for which it is to be used.

For a medium frequency broadcast project requiring an insulated structure, the guyed mast is invariably used although insulated self supporting towers may be preferred in some situations. Because of wavelength dictates, the structure is often of considerable height and a self supporting tower would be generally confined to radiators erected on top of buildings or other locations where the space available is severely limited. However, as a support for a large flat top type antenna system, a tower will produce less reduction in effective height, for a given antenna design, since the top hat capacity to earth can be kept somewhat smaller compared with a guyed mast structure.

(b) The area available.
A selfsupporting structure requires a base width of only about 10% of the height and so can be readily installed on most sites, particularly the difficult mountain sites often chosen for microwave, frequency modulation and television stations.

Structures to heights of 180 m are common for frequency modulation and television stations as guyed masts are an impracticable proposition on many mountain sites. A tall guyed mast requires considerable area to accommodate guys and foundations. For example, a 300 m mast may require guy foundations at a radius of 250 m or more from the thrust block.

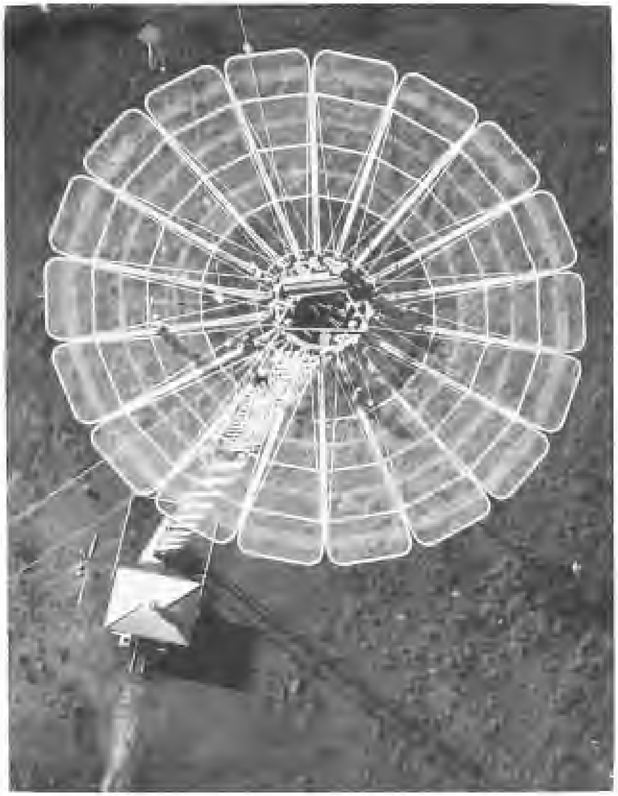

Figure 15.4 Dual frequency radiator 198 m high fitted with 18 m diameter armature (Courtesy Courier Mail)

(c) Ultimate cost.
For masts and towers to about 36 m in height, normal physical requirements are such that a uniform structure is employed, and costs are almost directly proportional to the height. Above this height, it is often necessary to increase the strength of the lower sections and costs rise at a much more rapid relationship, approaching a square law characteristics, with increasing height. With tall structures above about 200 m, compounding effects of high wind, erection problems, decreased work output etc. result in a cost relationship with a slope of 2 or 3. Unusual mechanical features such as sectionalising, capacity hats or armatures also add considerably to the final cost. *Figure 15.4* shows an aerial view of the 18 m diameter fitted to a 198 m structure used as a dual frequency radiator for 10/50 kW medium frequency broadcast transmitters. The armature which is mounted on double conical insulators is associated with a loading network installed in a cabin directly below the armature. The purpose of this arrangement is to ensure optimum performance of the structure as a dual frequency radiator.

The economic factors associated with masts and towers are subject to an

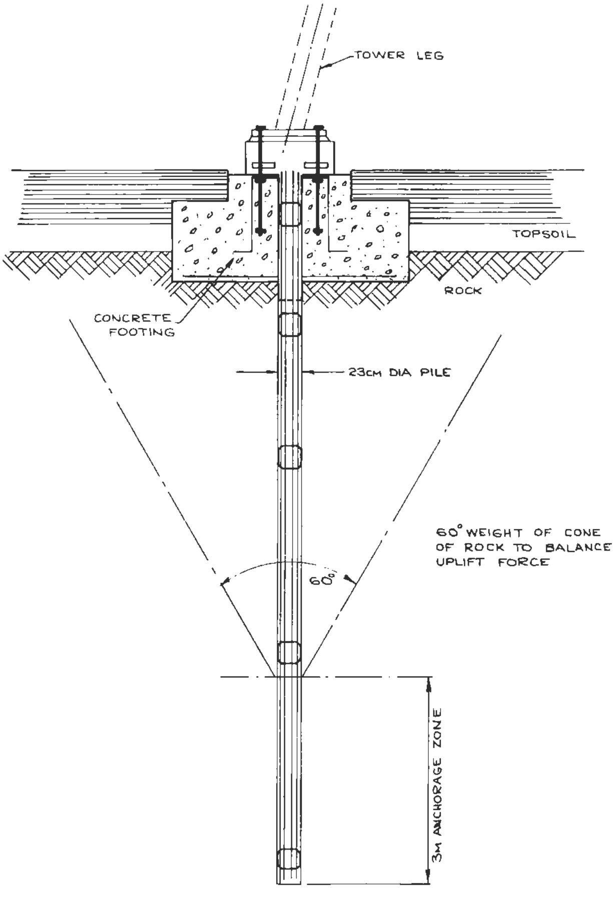

Figure 15.5 Typical rock anchor

appreciable degree of interpretation and in addition the cost of construction can vary appreciably, not only with geographical location but also with design details, availability and cost of local materials, such as aggregates for foundations, the degree of skill of the contractor's personnel involved in the actual work and the type of foundation necessary. For low bearing water logged sites expensive platform or outrigger type foundations may be required. At a mountain top site with firm bedrock a rock anchor arrangement similar to *Figure 15.5* may be more economical and safer than blasting. The most common procedure however is to excavate and pour concrete foundations to suitable dimensions. *Figure 15.6* shows a typical excavation and foundation for one leg of a 76 m tower.

Erection costs have a considerable influence on the overall costs of structures and only a general guide can be given as to the time taken for riggers to erect

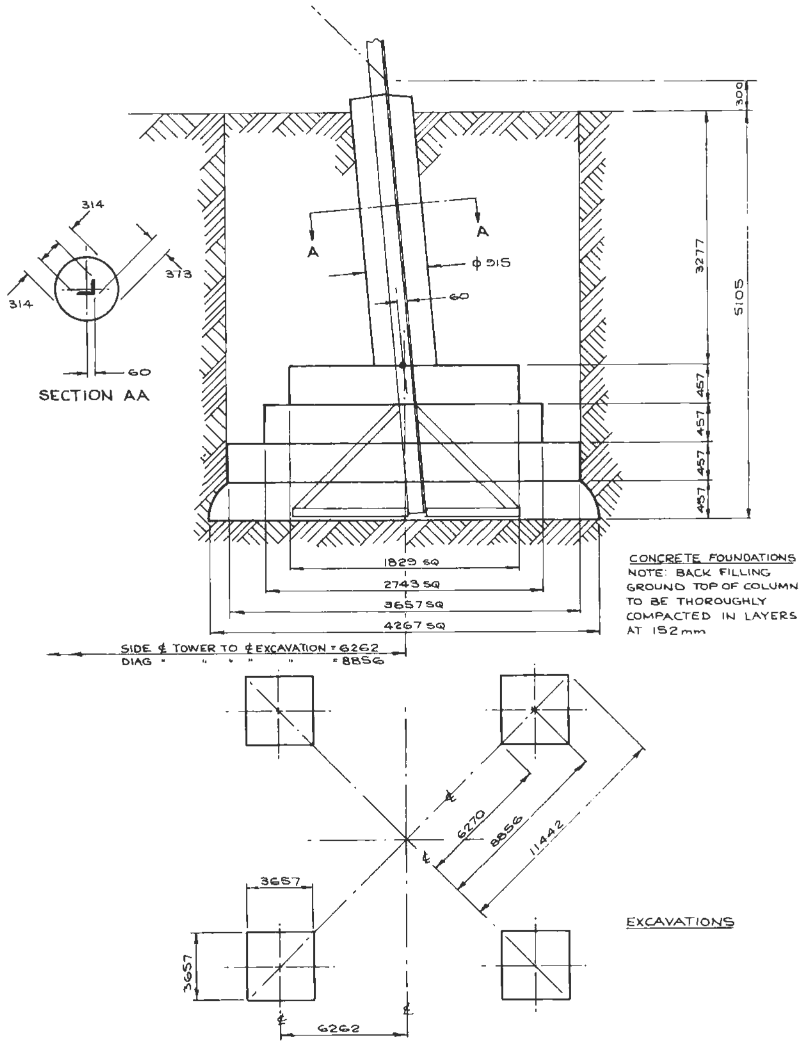

Figure 15.6 Typical excavation and foundation for 76 m tower

masts and towers of different heights and weights. However, for broad estimating purposes it may be taken that the time for erection of structures varies as the square of the tower height. Under ideal conditions a medium duty 30 m tower takes about 2-3 working days to erect with skilled riggers. Light duty structures to about 120 m height can be erected at the rate of about 15-20 m per day depending on weather conditions, particularly wind, and heavy duty types at about 10-15 m a day to the same height. Above 120 m the rate generally drops to about 5-10 m a day. The lower rates are particularly applicable to masts, because of temporary and permanent guy requirements.

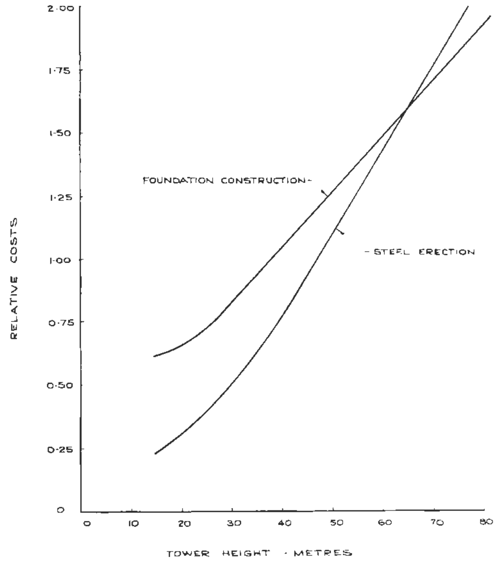

Figure 15.7 Relative costs of steelwork erection and foundation construction compared with tower height

Foundation construction costs also rise rapidly with increasing height of the structure. *Figure 15.7* shows the relative costs of steelwork erection and foundation construction compared with tower height up to 80 m high for a structure with a loading capability of two 4 m diameter dishes in a wind velocity of 53 m/s.

The use of mechanical aids plays an important role in the provision of masts and towers and other radio engineering structures such as large tropospheric scatter and radar antenna systems. In many cases these aids may be employed from the very start of the work. For instance the site may have to be cleared and levelled with bulldozers. This may be followed by tractors and mole ploughs for laying of earth mats, trench hoe excavators and compressors for excavating guy anchor and thrust block foundations, front end loaders for removal of spoil, trucks for cartage of aggregates, cement, steelwork, feeder cables, drums of wire etc., low loaders for transport of bulldozers etc., concrete mixers and concrete vibrators, cranes and winches for lifting mast sections, feeder cables, antennas, panels etc. At remote locations hire charges of these mechanical aids, if available, may be very high compared with costs when plant is obtained from a nearby commercial centre. Adequate incidental allowance has to be made when preparing the estimate.

For one project involving the erection of 13 torsionally stabilised masts varying in height from about 20 m to 76 m and one 53 m selfsupporting tower for a broadband radio relay system the percentage cost breakdown of mast and tower work was:

Steelwork	35%	Transport	3%
Foundations	30%	Establishment	17%
Erection	15%		

For television, frequency modulation and microwave radiocommunication requirements, the engineer has a choice between a lattice steel structure, a cylindrical steel plate structure or a cylindrical concrete structure. All three types are widely used, one being the most economical under certain situations. The steel or concrete cylinder is in some cases preferred as a structure to support multiple antenna arrays for several different transmitters, because the many feeders generally required to serve the arrays do not add to the wind loading on the structure, and they are easier to maintain, as equipment can be installed within the structure and a reliable lift service is available for all weather conditions. Lifts for lattice structures are severely restricted in their operation during periods of heavy ice formation and buildings are required to house the equipment.

Although the cylindrical structures are more costly than the lattice mast of equivalent height they require less ground space and are more economic to maintain. The lattice mast will show better economics than the cylindrical structures where the antenna array to be supported is limited in size. In practice it would most likely use steelwork of the type similar to that used for medium frequency radiators.

Costs associated with very tall masts are difficult to determine. In one particular case[1] a cost analysis was made of a design for a 915 m guyed mast which was to be used with a very low frequency transmitter. It was to be constructed of 3.8 m diameter welded tubular shaft and supported by a fifteen level guying system. The guys at the upper four levels which were also to serve as antennas were to comprise 8 cables each. The guy cables proposed were to vary in diameter from 50 mm to 100 mm. The total weight of the steel in the shaft was calculated to exceed 3500 tonnes. At the time of the design in 1963, it was estimated that the mast would cost more than US $14 million. This included the tower shaft, the guys and insulators, the foundations and adjunct framing, such as elevator, ladders, catwalks etc.

The cost breakdown was as follows:

	Cost (US$)	*Percentage*
1 Structural steel in tower shaft approx 3500 tonnes	1 137 500	8.0
2 Auxiliary framing, 250 tonnes	100 000	0.7
3 Guy cables and hardware	4 334 000	30.4
4 Guy cable reels	452 000	3.0
5 Guy insulators	3 983 000	28.0
6 Guy links and grading rings	1 091 000	7.7
7 Foundations	525 000	3.7
8 Freight costs	500 000	3.5
9 Erection charges	1 500 000	10.5
10 Contingencies	600 000	4.5
Total	14 222 500	100.0

Of this total, 8% accounted for the cost of the fabricated steel framing. Using this value as a basis for expressing the cost of the required welding work, it was found that all shop welding, including the longitudinal seams of the segments would amount to about 5%. In the estimate, only the costs of labour and electrodes were considered and two methods of welding were assumed. First, manually, then with the use of automatic or semi-automatic machinery. The corresponding costs were $21.66 and $15.48 per tonne of fabricated steel.

The estimate of cost for welding the field splices were $66 645. Here again, the estimate covered the cost of welders and electrodes only. The cost of the welding equipment and other related expenses were included in the cost of erection of the tower.

EXAMPLE 15.5

The supply, installation and commissioning of a 100 kW effective radiated power television transmitting station complete with transmitting equipment, antenna system, emergency power generating plant, buildings and civil engineering works.

The station was located on an isolated mountain, and construction of an access road was involved.

Radio Engineering Equipment		*Percentage*
Item 1	Television transmitter for Channel 2 operation, comprising two parallel 10 kW video transmitters and two parallel 2 kW sound transmitters complete with all ancilliary plant and paralleling equipment, programme input equipment and control desk.	25.5
Item 2	Spare parts for Item 1 including three sets of electron tubes.	2.3
Item 3	Selfsupporting tower 168 m including transportation, complete fabrication and erection of steelwork, concrete foundations, lightning earth system, aircraft warning lighting equipment and painting.	20.1
Item 4	Transmitting antenna supplied complete and erected	5.4
Item 5	Spare parts, tools etc. for Items 3 and 4.	0.1
Item 6	Two coaxial feeders with 100% spare length, fittings, attachments and supports. Supplied and erected.	1.3
Item 7	Slide scanner complete with spares	1.5
Support Equipment		
Item 8	Test equipment, including insertion test signal generator, sync. pulse gen., waveform monitor, differential phase and gain measuring set, colour gain and delay test set, deviation monitor, G.R. bridge, v.h.f. attenuator, grid dip meter, tube tester, v.t.v.m., e.s. voltmeter, multimeters, component bridge, video oscillator, cathode ray oscilloscopes, video attentuator, audio attenuator, s.b.a., reflector coef. meter, camera, noise and distortion set, audio oscillator and including spare test equipment parts.	3.4

		Percentage
Item 9	Workshop equipment including bench drill, bench grinder, vice, electric drills and necessary tools for the proper maintenance of the equipment.	0.1
Item 10	Emergency power generating plant comprising 170 kVA, 415 V diesel engine alternator, together with switchboard and spare parts, installed	3.2
Support Facilities		
Item 11	Buildings and civil engineering works comprising (a) Transmitter building of masonry construction, comprising transmitter room, control room, elec. and mech. plant room, screened test room, store, workshop, engine room, office, lunch room and toilet. (b) Access road to mountain top site. (c) Connection of power to commercial mains (d) Purchase of site. (e) Water supply. (f) Fixed and portable fire extinguishing system. (g) Fencing of building and tower. (h) Vehicle.	29.6
Installation		
Item 12	Construction and commissioning the station including design, survey work, installation of television equipment transportation, documentation, training, vehicle charges, administration and overhead charges and setting the station to work.	7.5
	Total	100.0

The cost does not include any capital charge against the provision of programme circuits from studios, or any Duty, Sales Tax or other form of local taxation which may have been necessary for the project.

EXAMPLE 15.6

The supply, installation and commissioning of 50 W television translator station complete with television equipment, antenna system, building, and civil engineering works at an isolated mountain site. The translator was to receive on Channel 5 and transmit on Channel 3.

Radio Engineering Equipment		*Percentage*
Item 1	Translator complete with directional filter, adaptors, tools, spare tubes and semiconductors	9.1
Item 2	122 m selfsupporting tower complete with foundations, aircraft warning lighting system and including painting and erection costs.	45.4
Item 3	Transmitting antenna with test adaptors.	7.2

		Percentage
Item 4	Coaxial cable 40 mm, 275 m length with connectors and clamp.	1.8
Item 5	Gas pressurising plant.	0.3
Item 6	Receiving antenna complete with combining unit.	0.5
Item 7	Coaxial cable 153 m length for receiving antenna.	0.3
Item 8	Test equipment including cathode ray oscilloscope, v.t.v.m., multimeter and monitoring receiver	0.7
Item 9	Mains power regulator 5 kVA	0.3
Support Facilities		
Item 10	Buildings and civil engineering works comprising	
	(a) Translator building, approx. 11 m^2	
	(b) Access road, approx. 1 km from existing road	
	(c) Connection to power mains, approx 1 km	
	(d) Fencing around tower and building	
	(e) Purchase cost of site	22.7
Installation		
Item 11	Construction and commissioning the station, including design, installation of equipment, antennas and feeders, earthing system, field survey, transportation, incidental expenditure, administration and overhead charges	11.7
	Total	100.0

The cost does not include any Duty, Sales Tax or any other form of local tax which may have been appropriate.

EXAMPLE 15.7

The supply, installation and commissioning of a complete 2 GHz 600 channel radio relay telephony bearer, with protection bearer, between two centres and comprising radio equipment, antennas, waveguides, towers, power plant and equipment shelters.

Table 15.2 TEST EQUIPMENT FOR RADIO RELAY REPAIR CENTRE

Baseband
Oscillator and level measuring sets
White noise test sets
Transmission measuring set
Selective level meter
Waveform generators
Noise and distortion meter
Oscilloscope and camera
Picture monitor
RMS voltmeter
Spectrum analyser

Radio frequency
Noise figure meter
Power meter
Signal generators
Spectrum analyser
Wavemeter
Frequency counter
Attenuators
A.m./f.m. modulation meter
Microwave link analyser

General purpose
Transistor test set
Multimeter
VTVM with probe
Digital voltmeter
Reflectometer bridge

The centres were 960 km apart and the path survey indicated that two terminals and 23 repeater stations were required, together with an intermediate control station. Commercial power could be economically extended to the terminals and five repeaters. The remainder were to be equipped with diesel engine generating plant, and batteries with wind driven generators as emergency back-up. Masonry type buildings were to be provided at terminals and the intermediate control station, and prefabricated equipment shelters provided at the repeaters.

The route was across undulating country, virtually treeless and devoid of range top sites with eight hops, involving thirteen stations required diversity facilities.

Maintenance of the route was to be carried out from the intermediate control station where suitable repair and maintenance facilities were to be provided.

Radio Engineering Equipment		*Percentage*
Item 1	Radio and supervisory equipment to provide two way broad band bearer system for 600 telephony channels with facility for occasional television transmission on the protection bearer.	20.8
Item 2	Selfsupporting towers, including support structures for wind driven generators, transport to site, site investigation, foundations, and erection.	21.6
Item 3	Antennas, waveguides and nitrogen gas pressure system including diversity facilities at 13 stations.	6.6
Item 4	Spare parts, including station and depot spares for radio equipment, supervisory equipment and power equipment.	2.8
Support Equipment		
Item 5	Mobile emergency repeater complete with radio equipment, portable antenna support structure, and equipment shelter.	2.0
Item 6	Mobile a.c. power units for emergency and plant maintenance purposes.	0.3
Item 7	Power plant at 18 sites complete with diesel engine generating equipment, batteries and fuel tanks.	4.3
Item 8	Test equipment comprising recommended units to properly maintain the complete route and carry out equipment repair. See *Table 15.2.*	2.0
Item 9	Workshop equipment and facilities necessary to maintain equipment at two terminals and one intermediate centre.	0.1
Item 10	Spare parts for engine generating and wind generating plants.	0.2
Support Facilities		
Item 11	Building and civil engineering works comprising:	
	(a) Two terminal and one intermediate station buildings of masonry construction containing equipment room, air conditioning plant room, office, toilet, lunch room, store, power room and workshop.	2.8

		Percentage
	(b) Equipment shelters for repeater stations.	5.0
	(c) Site works including levelling and drainage.	0.5
	(d) Access roads to sites.	7.0
	(e) Water storage.	0.1
	(f) Extension of a.c. mains to seven sites.	3.5
	(g) Security site fencing.	0.4
	(h) Fire protection facilities.	0.1
Item 12	Cost of sites including terminals.	0.5
Item 13	Path survey.	1.6
Item 14	Three fitted-out vehicles for route maintenance.	0.3
Item 15	Initial fuel supply for diesel engine generating plant.	0.1
Installation		
Item 16	Transportation of radio equipment to sites.	1.2
Item 17	Transportation of power plant to sites.	0.5
Item 18	Installation of radio equipment, antennas, waveguides and gas pressure systems.	2.2
Item 19	Installation of power plant, including engine driven. generators, batteries, switchboards, fuel tanks and wind driven generating plant.	1.3
Item 20	Construction and commissioning the system including design, installation works not itemised, transportation not itemised, incidental expenditure, vehicle hire, documentation, training, administration and overhead charges.	12.2
	Total	100.0

In this project the breakdown of costs of major activities was as follows:

Masts and shelters	37%
Antennas and feeders	9%
Radio equipment	45%
Power plant	9%

In another project completed more recently involving 13 repeaters and a much more expensive power plant at repeaters in the form of a solar system the break up was:

Masts and shelters	35%
Antennas and feeders	9%
Radio equipment	34%
Power plant	22%

This reflects the fall in price of modern broadband equipment and the higher cost of solar power systems compared with conventional engine set systems.

The cost does not include any provision for multiplex equipment, Duty, Sales tax or any form of local tax charge, rates, or rentals for access roads.

The main frequency bands in current use for radio relay systems are the 2, 4, 6, and 7.5 GHz. The 4 and 6 GHz bands are generally used for high capacity long haul systems with the 4 GHz band being preferred because of its better propagation characteristics. The 2 and 7.5 GHz bands are generally but not always used for short haul application; the choice of frequency being determined by route and capacity. As far as practicable, the use of the 2 GHz band is restricted to capacity of 960 channels or less due to the difficulties in obtaining good antenna/feeder performance for more than 960 channels.

Fully solid state equipment conveniently provides system capacity of 300–1800 telephony channels depending on route and frequency. The solid state systems with travelling wave tubes provide system capacities of up to 2700 channels, depending on route and frequency.

The problem of planning a radio relay system generally resolves itself into satisfying the following criteria:

(a) The establishment of the minimum number of intermediate repeater stations consistent with acceptable outage time due to fading problems over the paths. The overall cost of each repeater may be very high, and a reduction in the number of stations by a good path survey can show considerable savings in both capital and annual maintenance charges.
(b) The selection of sites which give maximum accessibility for maintenance staff and involves minimum capital expenditure in the establishment of the site. The engineer will always be faced with the problem of compromise on the site selection work. The highest peaks may result in fewer repeaters or lower tower heights but expensive road access costs may greatly exceed savings in technical equipment costs.
(c) The selection of sites for terminals and intermediate demodulating stations as close as possible to the local network.
Cable systems to connect traffic between the local network and the radio link are expensive items and, in many awkward situations, the cable costs may be greater than the provision of an additional radio repeater.

Although the acquisition of sites for radio relay repeaters do not generally involve a great capital outlay in real estate, the costs associated with the use of the site can be considerable. Site factors which have a bearing on the ultimate station establishment costs include the following:

(a) Distance of the site from existing roads.
(b) Type of soil and rock and its suitability for foundations.
(c) Extent of levelling and clearing required.
(d) The extent of work necessary to construct the access road.
(e) Local meteorological conditions. Heavy rainfall could result in expensive road maintenance due to wash-aways. High winds may require a heavier type tower. Ice might also require additional expenditure on the tower and antenna system.
(f) Proximity of commercial power mains.
(g) Availability of fuel for engine generating plants.
(h) Availability of aggregates and sand for tower foundations.

Installation activities particularly those associated with the construction of roads, buildings, towers and antennas can be affected significantly by weather conditions. Unfavourable conditions such as rain, wind and ice, can add considerably to the capital establishment cost, as well as delaying the commissioning date. Some sites will be affected to a greater degree than others and a well planned works programme can do much towards minimising over-expenditure and disruption to schedules.

For a typical repeater station the main works associated with installation and commissioning are:

(a) Construction of access roads and preparation of the site.
(b) Installation of tower and buildings foundations.
(c) Construction of the building. Some engineers prefer the building to follow erection of the tower, due to the possibility of damage to the building from falling objects.
(d) Erection of towers and installation of tower and station earth systems.
(e) Installation of antennas, waveguides and gas pressure system.
(f) Installation of radio equipment.
(g) Installation of power plant including engine driven generators, batteries and fuel tanks, if local power generation is necessary. If commercial power is to be provided the connection of this would be carried out immediately after completion of the building even though mains extension work may have been carried out earlier.
(h) Adjustment and testing of individual items of station equipment.
(i) Adjustment and testing of radio equipment and antenna systems over each path.
(j) Adjustment, alignment, testing and commissioning of the radio relay system as a whole from terminal to terminal.

The overall performance of a radio relay system is governed partly by the parameters of the equipment itself and partly by the manner in which the equipment is applied to the system. It is of considerable importance therefore that both the route and the installation of the equipment be properly engineered.

Because of the siting requirements peculiar to radio relay systems, many stations are often located in areas where commercial power supply may be unavailable within economic extension or it may be unreliable. An independent reliable power source is therefore invariably required as either primary source or as emergency supply. The most practical supply for major high capacity links is a diesel engine generating plant feeding power directly to equipment or to batteries operating on a charge/discharge basis. However solar power units have now become an economic proposition. For an important mainline route carrying data and automatic telephony traffic, and fed with mains power, momentary interruptions of power can be intolerable and the power supply will generally include a no-break source.

The investment in spare parts and test equipment for long haul high capacity main line systems is considerable. On top of this, there are workshop and other support facilities necessary for maintenance purposes once the system has been commissioned. In the example it was proposed that the intermediate control station be the maintenance centre for the route. The terminals were to hold only maintenance and test equipment peculiar to their special needs, such as for multiplex equipment.

The basic parameter which determines the quantities of spare units provided for maintenance is the delay in restoration time. This is set by some system operators to have a statistical limit of about four hours, once per year. In deriving the actual quantities, a binomial model is used for each of the maintenance units and is based on the following data:

(a) Unit failure rate.
The failure rate is ordinarily expressed in terms of the number of failures per unit of time, usually 1 hour, 100 hours or 1000 hours or as a percentage of failures per 10 000 hours. When calculating the failure, it is important to consider the age of the product. Failure rates of new link equipment are apt to be high because of such factors as production errors, defective parts, faulty installation and improper adjustment. After a normal break-in period, failures become less frequent and failure rates then tend to remain relatively constant during the useful life of the equipment. When the system reaches the end of its economic life, the failure rate begins to rise sharply.

(b) Population determined by equipment design, that is upon maintenance units. The essential properties of maintenance units are:
   (i) replaceability with a minimum of service effort. Modules, subassemblies and plug-in cards are recent developments which have improved downtime in failed equipment.
   (ii) standardised interface.

(c) Time taken to repair equipment, including time involved in transportation to the central repair depot.

Roads leading to many sites often leave much to be desired and this is an important aspect in the transport of spare equipment and test equipment. Specially fitted-out vehicles with properly designed transit cases are essential.

Table 15.3 shows a typical proforma used in the preparation of cost estimates for broadband radio relay systems.

Table 15.3 BROADBAND RADIO RELAY SYSTEMS COST ESTIMATE PROFORMA

System: Project no.:

System description:

Estimate prepared by: Tel. no.: Issue no.:

Route schematic: Date:

Cost escalation dates: Radio Towers Power Civil

	Item	*Unit price*	*Qty*	*Total*	*Remarks*
1	*Site Acquisition*				
	Escalation (%)				
					Sites total
2	*Provision of a.c. Mains*				
	Escalation (%)				
					Mains total
3	*Access Roads*				
	Flat				
	Undulating				
	Mountainous				
	Escalation (%)				
					Roads total

Table 15.3 *(continued)*

	Item	*Unit price*	*Qty*	*Total*	*Remarks*
4	*Equipment accommodation*				
	Brick building				
	Shelter				
	Escalation (%)				
					Accom. total
5	*Towers Type Ht*				
	Escalation (%)				
					Tower total
6	*Waveguide gantries*				
	Type 1				
	2				
	3				
	4				
	Escalation (%)				
					Gantry total
7	*Power plant*				
	Solar				
	Charge/Discharge				
	Continuous				
	AC Mains				
	Escalation (%)				
					Power plant total
8	*Radio equipment*				
	Terminal				
	repeater				
	S.V.S/SVC				
	Diversity				
	Spares				
	Other (specify)				
	Escalation (%)				
					Radio eqpt.total
9	*Installation, testing and commissioning of radio equipment*				
	Terminal				
	Repeater				
	Diversity				
	Other (specify)				
	Escalation (%)				
					Radio install. total
10	Contingencies %				
11	Total capital cost				

EXAMPLE 15.8

The cost percentages shown in the previous Example were for the installation of a 600 channel radio relay bearer with a protection bearer over a distance of 960 km comprising two terminal stations and 23 repeating stations. The following Example sets out the cost percentages of one of the terminals in that system and also one of the repeater stations with local power generation.

Terminal Station	*Percentage*
Item 1 Radio and supervisory equipment	16.7
Item 2 Tower: 60 m antenna, waveguide and gas pressurising equipment.	13.8
Item 3 Power plant including commercial power connection, standby generating plant, switchboards etc.	5.3
Item 4 Spare parts—where station is not a major repair centre	1.6
Item 5 Multiplex equipment	32.4
Item 6 Test equipment, where station is not a major repair centre.	3.4
Item 7 Workshop equipment and facilities.	0.2
Item 8 Building and fencing.	11.5
Item 9 Fuel storage.	0.2
Item 10 Access road.	2.3
Item 11 Site purchase, grading and drainage.	1.8
Item 12 Transportation.	1.1
Item 13 Engineering, installation, documentation, training, incidentals, vehicle hire, administration and overhead charges.	9.7
Total	100.0

Repeater Station	
Item 1 Radio and supervisory equipment.	17.8
Item 2 Tower: 76 m antenna, waveguides and gas pressurising equipment, diversity one way	43.5
Item 3 Power plant including generating plant, batteries and back-up wind generating plant.	5.3
Item 4 Fuel supply.	0.4
Item 5 Spare parts, average for route, although not necessarily held at the repeater site.	2.9
Item 6 Test equipment, average for route although not necessarily held at repeater site.	2.4
Item 7 Shelter.	6.6
Item 8 Access road, average.	7.5
Item 9 Site purchase, grading and drainage.	1.7
Item 10 Transportation.	2.2
Item 11 Engineering, installation documentation, training, incidentals, vehicles hire, administration and overhead charges.	9.7
Total	100.0

Figure 15.8 shows a typical repeater station employing prefabricated shelter and diesel generating plant with a back-up wind generator.

Considerable advancement has been made during the past 10 years with regard to improved efficiency and reliability of radiocommunication systems. In the late 1960s broadband systems were available with all solid state equipment which met stringent transmission requirements, consumed minimum power and fulfilled operational requirements in modular design and reliability.

Figure 15.8 Radio repeater station

More recent equipment have higher efficiency, for example 10 W radio frequency output rather than 1-2 W for the same power consumption. Some remote repeaters using low power drain equipment with bearers for telephony (960/1260 channels), standby and unidirectional television relay now have a power consumption of about 130 W. Mean times between failures have improved by about an order from approximately 20 000 hours to 200 000 hours in some cases. Reduction of maintenance costs has been assisted by improved modular design allowing minimum time to be spent in field visits for restoration of faulty bearers.

There has also been changes in the type of accommodation provided for equipment. In remote areas the conventional brick building has been superseded by above-ground and under-ground shelters of various designs. The thermal design of the shelters has been determined by the heat dissipated by the equipment and the maximum temperature the equipment will withstand without damage, considering the environment of the particular radio relay station.

Above-ground shelters vary from partly or fully insulated shelters with or without temperature control to enclosed equipment rooms with large shelters or screens. Further temperature control has been achieved at some dry hot inland stations by using ice banks and controlled air flow. Below-ground shelters have proved satisfactory but cost of installation can be high at solid rock sites. Use of a shade screen above the shelter location is an aid to temperature control.

Underground shelters can handle equipment power dissipation of about 500 W without temperatures exceeding equipment limits. Small above-ground shelters with additional cooling will handle equipment power dissipation up to 1200 W and the large shelter of the type shown in *Figure 15.8* can handle up to 2500 W of heat dissipated by the radio equipment.

EXAMPLE 15.9

The supply, installation and commissioning of a staffed medium capacity tropospheric scatter repeater in an isolated area between two terminals. To meet circuit requirements and performance, parameters were 18 m antennas, quadruple diversity and 10 kW output from each transmitter. Operating frequency was 900 MHz and no commercial power was available at the site.

Radio Engineering Equipment		*Percentage*
Item 1	10 kW P.As and 1 kW P.As, complete with transmitter diplexers and modulator exciters.	11.2
Item 2	Performance monitor control fault indicator equipment.	2.2
Item 3	Four 18 m diameter antennas including feed horns.	14.9
Item 4	Receiving systems complete with low noise pre-amplifiers.	6.7
Item 5	Installation materials for Items 1-4 and miscellaneous items of equipment.	3.7
Item 6	Wave guides including all ancilliary supports etc. transmission lines and gas pressurising system.	3.7
Item 7	Dummy loads for power amplifier units.	1.1
Item 8	Spare parts including tubes, semiconductor devices, and unit spares. Depot spares held at terminal station.	3.7
Support Equipment		
Item 9	Workshop facilities including small lathe, bench drills, grinders, anvil, welding equipment, electric drills and necessary tools for proper maintenance of equipment and plant.	0.7
Item 10	Test equipment, comprising recommended items required for plant performance measurements, fault finding and maintenance.	2.2
Item 11	Power generating equipment comprising 3 units each 200 kVA and including fuel storage and switchboards.	7.5
Item 12	Spare parts, tools and workshop facilities for Item 11	1.1
Item 13	Installation materials for Item 11 including foundations and transportation of all equipment and plant to site.	1.5
Support Facilities		
Item 14	Buildings and civil engineering works comprising:	
	(a) Repeater building including transmitter room, receiver room, workshop, office, lunchroom, toilet and store, approx. 135 m^2.	5.9
	(b) Power house including area for engines, store room switchboard, gantry, work area, approx. 126 m^2.	3.7
	(c) Water storage.	0.3
	(d) Sewerage disposal.	0.7
	(e) Fire protection facilities.	0.3

		Percentage
(f)	Site purchase, clearing, preparation, drainage and fencing.	7.5
(g)	Access roads.	3.7
(h)	Antenna foundations.	2.2
(i)	Vehicle and garage.	1.1
(j)	Air conditioning of office and lunch room area.	0.3
(k)	Building surround works.	1.5
(l)	Air duct work for transmitter room.	0.7

Installation

Item 15	Construction and commissioning station including design, propagation studies, survey work, installation, erection, documentation, training, incidental expenditure, vehicle expenses, administration and overhead charges, proportion of total system.	11.9
	Total	100.0

It is interesting to note that system costs have shown a significant fall in recent years. Some unattended repeaters with shelter type buildings and external power sources have recently been installed for about half the cost of stations installed 10 years ago.

The important characteristics of tropospheric systems are:

(a) The bandwidth available may be up to several megahertz under suitable conditions. With large narrow beamed antennas, up to 300 telephony channels or a television circuit can be provided with equipment currently available.
(b) A high degree of security is offered compared with some other long distance communication systems. Radio interference or jamming is difficult unless the signal is within the beam and range of any one repeater or terminal station.
(c) It is ideal for use across paths involving sea and inhospitable terrain as terminals or repeaters can often be located at sites where suitable facilities are available.
(d) Consistent signals can be received for ranges up to 800 km over a single hop when sufficient transmitter power output, high gain antennas and sensitive receivers are employed.
(e) The propagation characteristics are such that signals can be received over a wide frequency range, at least 100 MHz to 3 GHz. Frequencies around 900 MHz and 2 GHz are currently popular for tropospheric services.
(f) Properly engineered systems will provide a high order of reliability.

The system parameters for a tropospheric scatter system are the same as for any other type of communication system, that is the power available at the receiver is equal to the transmitted power plus all system gains less all system losses. The engineer in his design study must select the best possible values for parameters within the physical or cost limitations imposed by the particular problem.

As with microwave radio relay systems using line-of-sight principles, buildings, site accessibility, and availability of commercial power are important considerations. However, tropospheric scatter equipment generates much greater radio frequency power, the equipment is physically larger and consequently greater costs are incurred in the provisioning of buildings, power generation where local generation is necessary, and site works. The power requirements for a typical 10 kW tropospheric repeater with quadruple diversity may be as much as 120 kW compared with about 100 W for some duplicated transistorised 960 channel microwave line-of-sight systems. The antennas required for tropospheric systems are larger but the type of supporting structure varies considerably from line-of-sight requirements. One important factor is the trade-off between radio frequency power and antenna gain.

If increased system gain is acquired by increasing the size of the antenna only, the cost of the antenna and installation will have to be reckoned with. The increase in annual maintenance charges may be relatively small. If however the increased gain is obtained through the equipment, the cost of the power amplifier and its installation, increased power consumption which may require an increase in generating capacity of the power plant, circuit breakers, cables and also building floor space, must be considered. The cost of additional fuel or commercial power and building upkeep must also be added to the annual operating cost.

Because of the many variables associated with a tropospheric scatter installation, system performance is sometimes traded for cost, within limits imposed by the path loss and supportable bandwidth of the propagation mechanism. Path loss can be directly attacked by higher power and greater antenna gains but there is a very real limitation on supportable bandwidth.

Another important consideration is reliability. There are installations in service in which the propagation reliability exceeds 99.9% for up to 300 telephony channels over paths of about 240 km. There are also installations of high order reliability providing up to 96 telephony channels over 450 km paths and even some providing up to 48 channels between points 900 km apart.

EXAMPLE 15.10

The design, supply of materials and erection of three wire transmitting and receiving rhombic antenna systems to cover bands 7 to 11 MHz forming part of a high frequency broadcast relay station. The transmitting and receiving stations were located about 18 km apart. Transmitter power was 100 kW carrier and length of transmission line in both cases was approximately 300 m. The transmitting antenna was terminated in a dissipative line type load and both systems were designed for 175 km/h wind conditions. No site clearing was necessary.

Transmitting Antenna		*Percentage*
Item 1	Design and fabrication of four 36 m medium duty masts complete with guys.	19.2
Item 2	Construction of guy anchors, mast thrust blocks and lightning earth system.	7.1
Item 3	Three wire antenna materials comprising 12 mm dia. alumoweld stranded cable, strain and spreader insulators with corona shields, prefabricated wire halters and all necessary attachment hardware.	4.5

		Percentage
Item 4	Transmission line materials comprising open wire four conductor 300 ohm line and including copper wire, insulators, mounting bolts, cross arms, and necessary fittings.	4.1
Item 5	Transmission line poles comprising 100 mm galvanised iron pipes, concrete foundations and stays.	1.2
Item 6	Dissipative line materials comprising exponential downlead, stainless steel wire, strain and support insulators, pole guys and anchors for dead-end poles, line tension sheaves, counterweight hanger, all necessary hardware, line support poles and concrete foundations.	2.8
Item 7	Spare parts, including hardware, insulators etc.	0.5
Receiving Antenna		
Item 8	Design and fabrication of four 36 m light duty masts complete with guys.	13.1
Item 9	Construction of guy anchors and mast thrust blocks	5.0
Item 10	Three wire antenna materials comprising 4 mm dia. alumoweld stranded wire, strain insulators and all necessary hardware, exponential downlead and terminating resistor.	0.7
Item 11	Transmission line materials comprising 200 ohm 4 wire open wire type, including copper wire, strain, spacer and line support insulators, tension equaliser, sheaves turnblock line supports, balanced to unbalanced transformers, coaxial cable and pole hardware.	2.8
Item 12	Transmission line poles comprising 75 mm galvanised iron pipes, concrete foundations and stays.	0.7
Item 13	Spare parts including hardware, insulators, etc.	0.2
Item 14	Freight and transport charges.	3.1
Item 15	Construction and commissioning the two systems, including design, site survey and layout works, erection, concrete testing, measurements, hire of mechanical aids, vehicle costs, documentation, administration and overhead charges.	35.0
	Total	100.0

The cost does not include any special provision for Duty, Sales Tax or any other form of local tax charges or rates, or site acquisition charges which may have been appropriate.

EXAMPLE 15.11

The supply, installation, erection and commissioning of a high frequency broadcast system including 250 kW transmitter, test load, four curtain antennas, transmission lines and switching matrix. The site was located about 400 km from the nearest capital city. Buildings and mains power were already available on site and no clearing was required for the antenna systems.

Radio Engineering Equipment		*Percentage*
Item 1	Semi-automatic 250 kW high frequency transmitter complete with r.f. stages 5.9–26.1 MHz, frequency synthesisers, audio frequency stages with clipper amplifier for trapezoidal modulation, voltage regulator and low voltage distribution system, auxiliary rectifiers, electronic control and motorised tuning system, 24 V battery and charger, high tension thyratron rectifier, crowbar, high tension rectifier transformer for 22 kV 50 Hz supply, modulation components, cooling system including air-steam heat exchanger, safety system, one set of working tubes and one set of maintenance and test equipment.	25.2
Item 2	Audio equipment and transmitter ancillaries.	0.8
Item 3	Calibrated transmitter test load complete with soda solution and water heat exchanger. Maximum power capability 600 kW continuous over range 30 Hz to 30 MHz.	1.3
Item 4	Antenna support structures including two 60 tonne towers 99 m, one 47 tonne tower 87, one 20 tonne tower 56 m and one 13 tonne tower 43 m. Steelwork galvanised and each tower fitted with aircraft obstruction lighting, lightning protection for each system and painted.	13.0
Item 5	Support structure foundations.	6.7
Item 6	H.f. antenna system comprising four curtain antennas type HR 4/4/0.5 with frequency ranges as follows: Antenna 1 : 6/7/9 MHz Antenna 2 : 7/9/11 MHz Antenna 3 : 11/15/17 MHz Antenna 4 : 15/17/21 MHz each comprising radiators, screen reflectors, side and top catenaries and all necessary steel parts for the counterweight guides and earth anchoring system, slewing switches and facilities for slew angles ± 22 degrees, eight electric winches mounted on counterweights with push button control stations at each tower for each winch and system spare parts.	16.8
Item 7	R.f. transmission lines 300 ohm impedance and line support system including 1.4 km of 500 kW line with 15 terminal poles, 7 unilateral poles and 19 T poles.	1.6
Item 8	Antenna switching system including ten 500 kW switches vertically mounted for installation indoors arranged for two inputs and five outputs, remote control equipment including control desk, screened feeder and balun.	5.3
Support Equipment		
Item 9	Mains power connection equipment.	2.6
Item 10	Spare parts including transmitter depot spares, two sets of r.f./a.f. tubes and one set rectifier tubes.	5.7

Installation		*Percentage*
Item 11	System installation and commissioning including transmitting equipment and radiating system.	18.8
Item 12	Project management.	2.2
	Total	100.0

Part of the 300 ohm transmission line from the transmitter, a 212 ohm matching section and two slewing switches are shown in *Figure 15.9.*

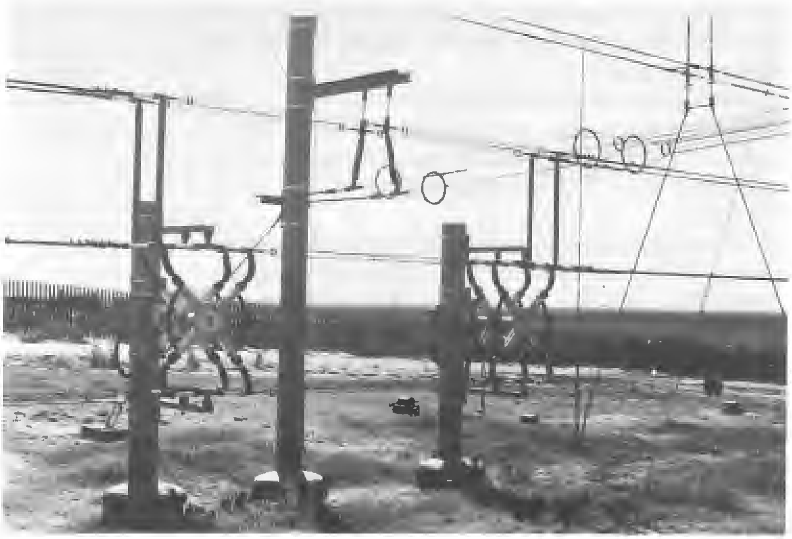

Figure 15.9 Open wire transmission line matching section and slewing switches

EXAMPLE 15.12

Portable microwave equipment for temporary link in a broadband telephony network comprising two terminals and one repeater with capacity for 1200 FDM voice channels.

		Percentage
Item 1	Terminal, both-way, unduplicated for telephony operation comprising two transmitters, two receivers and two branching units.	28.2
Item 2	Repeater both-way unduplicated for telephony operation comprising two transmitters, two receivers and two branching units.	28.2
Item 3	R.f. units to plug into control unit for converting to another operating frequency band comprising four transmitter, receiver and branching sets.	25.0
Item 4	Remoting equipment comprising transmitter, and television remote units including 90 m cables.	4.0

		Percentage
Item 5	Portable antennas for tower or pole mounting including illuminators, adaptors and cabling for four 1.8 m dia. systems.	3.3
Item 6	Auxiliary equipment for telephony including up to 6 v.f. multiplex service band channels for four stations.	0.8
Item 7	Handbooks, three sets	0.5
Item 8	Test harness, one set	0.5
Item 9	Spare parts.	8.7
Item 10	Portable power supply, one set including engine generator. and 24 V battery eliminator.	0.8
	Total	100.0

The costs indicate only the percentage break up of the capital cost of the equipment and does not include any installation or equipment housing costs.

Portable microwave equipment designed specifically for temporary link service have many applications. These include:

(a) Temporary links for emergency restoration of seriously disrupted existing system in a broadband network.

(b) Temporary links to provide short term telephone relief, for example where delayed equipment deliveries for permanent fixed service systems affects inservice timing for critical projects.

(c) Temporary links for television services.

(d) Temporary links to permit major modifications to existing fixed service systems.

Equipment need for temporary link purposes must be sufficiently versatile to meet a wide variety of situations. Desirable features include the following:

(a) Containers should be sufficiently rugged to protect the equipment during transit to the site and during installation.

(b) Equipment should be sufficiently light weight and compact to enable transport by light aircraft or station sedan vehicle to site.

(c) The equipment should be so designed and constructed that it can be assembled and set to work with the minimum of effort and adjustments.

(d) Maximum flexibility should be built in to allow one-way or both-way modes of operation and it should be capable of interfacing with either baseband or i.f. frequencies at the input/output terminals.

(e) The equipment performance should permit telephony operation up to 1200 channesl or more or television plus two sound programme channels.

(f) In order to allow interfacing with existing systems which may cover the bands 1.8–8 GHz, the equipment should be capable of being set up to suit the particular operating frequencies as required.

(g) The equipment operating frequencies, levels and performance should meet appropriate CCIR recommendations.

(h) Power consumption should be as low as possible to permit the use of highly portable power plant in places where no equipment power supply is available.

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Chapter 16

Maintenance and Operating Costs

COST FACTORS

The costs of keeping facilities in good order and condition, and operational, are accounted for as maintenance and operating expenses. These expenses which occur throughout the working life of the equipment or plant result from the following:

(a) The purchase of material and components associated with the upkeep of the facilities.
(b) The cost of maintenance and operating labour.
(c) The training of staff for maintenance and operating purposes.
(d) Performance measurements and testing of facilities.
(e) Transportation, handling, storage and inspection of materials.
(f) Rearrangement and modification of installed equipment, plant and facilities.
(g) Allowances for loss of materials due to natural forces, such as evaporation of liquids during storage, deterioration of cement etc.
(h) Workship operations, repairs, tool expenses etc.
(i) Maintenance works associated with the equipment, buildings and sites, including cleaning and building servicing.
(j) Power and other energy costs.
(k) Costs associated with the preparation of programmes of annual surveys of maintenance requirements and the keeping of maintenance records.
(l) Taxation and duty charges, patent charges, royalties etc., associated with the use and purchase of materials and services, salaries etc.
(m) Supervision activities associated with the operation and maintenance.
(n) Rates, local taxes, right-of-way costs, rents, fire insurance and other charges levied by local authorities and others, on property.
(o) Transportation, travelling allowances, overtime, payroll tax, superannuation, provisioning for recreation leave, long service and sick leave etc., for the maintenance and operating staff.
(p) Administration and overhead charges including engineering supervision, accounting, insurance expenses etc.

In the case of overheads that vary directly with labour usage, there are certain overhead elements that are common to all staff in the organisation and other overhead elements that are relevant to particular staff categories and not to others. In many administrations with a large staff complement it has been found that a loading of 40% represents a reasonable approximation to those elements that are common to all staff. This is made up as follows:

Superannuation committments	17%
Furlough liability	5%
General administration	4%
Paid leave	12%
Others	2%
	40%

For various categories of staff however there can be a considerable increase on the 40% figure when allowance is made for such things as office type accommodation, protective clothing, training, shift allowances etc. Examples are:

Professional engineers, clerical and other office based staff	47%
Technical staff	65%
Radio operators and others receiving shift allowances	70%

These loadings are applied to the direct labour cost when this has been determined using normal pay and the actual number of manhours required to perform the task.

When assessing maintenance and operating costs for incorporation in an economic comparison study, all or only some of the above costs may be taken into account. The decision as to what costs should be included is based on their effect on the study. Maintenance and operating costs which are common to all schemes may be ignored, but if a particular factor will cause a change in the aggregate cost difference, then it should be included in the study. After all, the purpose of an economic comparison study is to estimate the difference in costs of alternative facilities. Therefore, any items of cost that are the same in either case and have the same origin may well be omitted. It is required that only real differentials be included. Also, where the cost of an item is very small and other related charges are very substantial, then the small cost often may be ignored. In general, the economic comparison study serves mainly as an aid to judgment and the accuracy required by management is that which will lead to a sound decision.

NEED FOR CO-ORDINATION

Care should be taken to ensure that costs of operation and maintenance used in the economic comparison are co-ordinated. For example, in a study of two types of high power transmitters, one with highly automated control facilities which would reduce the operating staff requirements and the other, a standard manual control transmitter, the reduction in labour effort in the case of the automatic model should be reflected in the operating labour cost and appropriate increased maintenance costs for the added sophisticated control equipment should be included. One of the design objectives in the modernisation of equipment and plant is the reduction of maintenance and operating expenses. Often this reduction in expenses is brought about through higher first cost of the equipment.

If the cost estimates of equipment includes items which will reduce maintenance charges, such as a greater factor of safety on antenna matching transformers because of severe local lightning conditions, this should be reflected in the maintenance cost of the equipment. On the other hand, if investment cost is based on a design using equipment that increases the probability of damage from the lightning, such as transistors and integrated circuits in programme line amplifier equipment, this should also be reflected in the overall maintenance costs.

Similarly, in the determination of costs associated with electric power consumption or losses, co-ordination is necessary. If the power cost is based upon the cost of an installation with high efficiency, this efficiency should be reflected in the power cost. For example, the efficiency of high power broadcast transmitters has shown considerable improvement in recent years but, notwithstanding, there is a significant difference in efficiency between transmitters of the same output power made by different manufacturers to their various designs. Efficiency is an important factor in the case of a high power transmitter. The power consumption of a 1 MW medium frequency broadcast transmitter may be 2000 kW unmodulated, and an improvement in efficiency of only 1% could result in considerable saving in operation costs, the exact amount being dependent upon the kWh power cost and the annual operating hours.

At one large medium frequency transmitter station, management called for an economic study to be made to determine the most favourable means of enlarging the station service area in order to double the number of people served. The existing antenna caused fading at distances of about 80–150 km from the transmitter and about 750 000 people were included within this range. A technical examination showed that the installation of an anti-fading radiator would enable the fading radius to be moved out to about 150–200 km thus enlarging the service area to include about 1 500 000 people. The existing 150 kW water cooled transmitter equipment which was about 20 years old fell short of the performance required of high power transmitters. Its power efficiency was only 22% and as modern transmitters have power efficiencies of the order of 55 to 65%, it would be possible to nearly treble the antenna power without increasing the consumption of electricity from the mains. Furthermore, the old transmitter required staffing and continuous supervision during transmission, whereas a new transmitter could be operated unattended and remotely controlled. The economic study showed that a modern 300 kW vapour cooled transmitter would permit an annual saving in operating labour and power costs of some £25 000.

ADDING NEW EQUIPMENT

When the installation of new equipment is proposed to supplement existing facilities, the effect of maintenance and operating costs of the existing plans must be taken into account in the study. In many studies, so much attention is often focused on the economics of the new equipment to be installed that the effect on the existing establishment which is to be retained, is overlooked. An outstanding instance of this is in the case where a higher power transmitter is proposed to improve the signal strength—a 500 kW unit may be proposed in lieu of an existing 50 kW model. Not only would the operational charges associated with the increased power be greater, but the unit may also result in increased maintenance labour cost, even though the number of men remain the same. Many organisations have a grading arrangement, whereby the status and salary of the senior technical personnel are related to the transmitter power. In one typical organisation, the salary to the officer-in-charge of a station when the transmitter power is increased from 50 to 500 kW is increased by 8%.

Another factor is that the installation of additional equipment units may result in a decrease of overall operating costs. At one broadcast station, four 10 kW transmitters were operated for the full daily transmission period, without any standby units. Transmissions normally commenced at 6 a.m. and it was necessary for the maintenance and operating staff of 3 men to commence duty at 3.30 a.m. in order to carry out routine maintenance and plant performance measurements on the equipment. The installation of standby units resulted in the staff being rostered to commence duty at 5.30 a.m. in lieu of 3.30 a.m., with the maintenance being carried out at more convenient hours during the day. Considerable annual labour cost saving resulted from the installation of the extra equipment.

These examples show that although maintenance costs do have some relationship with the quantities and types of equipment in operation, averages of maintenance and operating costs obtained from relating total maintenance and operating costs to total installed costs do not necessarily hold when specific items of equipment or situations are considered. For instance, in the case of the four installed standby transmitters quoted above, it would not be correct to assume that the station operating and maintenance total costs would increase by, say, 10% of the capital cost of the new installed plant. In practice, it led to a very substantial reduction in the total station operating costs with only a minor increase in the total equipment maintenance costs. Therefore in a cost comparison study, the operating and maintenance expenses as an annual charge must be considered to be independent of the capital requirements. Of course maintenance and other expenses derived as a percentage of the total installed cost may be helpful as a comparative check for reasonableness of the detailed calculations if the study represents a cross section of the equipment or facility on which the average percentage was based, provided also that they represent the particular study situation. As an instance of this, some engineers when checking economic studies associated with the provision of fully solid state microwave radio relay equipment strike an annual maintenance charge of about 5.0% of the capital cost.

ESTIMATING FUTURE CHARGES

The objective of an economic comparison study is to determine which proposal will give the lowest overall cost throughout the life of the equipment or facilities covered by the proposal. An estimation of future expenditures is necessary to determine these costs. Accurate assessment of future costs is in many cases extremely difficult because several factors may be involved.

As an example of this a new microwave radio bearer added to a route may have a lower maintenance cost than existing equipment due to technological advances and therefore the new system produces a greater benefit for the same traffic. However, in making economic comparisons of such an installation, allowance should be made for future replacement installations on the route as these may have even greater advantages.

A similar situation sometimes arises when calculating administration, supervision, accounting and other forms of overhead expense. For instance, suppose that alternatives offered in a tender for a long haul microwave radio relay system of high capacity between two large towns are transistorised type equipment and tube type equipment. One involves small charges for maintenance while the other could involve substantial charges. Now, the percentage of overheads is no small figure. In some cases, total overheads have been known to exceed 70-80% of the direct charges for maintenance. If the estimated direct charges for the maintenance for both alternatives are increased for a particular reason by say 75%, it means that installation of tube type equipment is estimated to cause a substantial increase in costs of general supervision, accounting expenses, clerical costs etc. Obviously that is not a valid conclusion. At the same time it is difficult to justify omitting the overheads altogether, but if they are estimated as a percentage of direct expense there is this real danger of unrealistic estimates, as above. It is equally easy to show that the same danger lies in estimating these overheads as a percentage of higher first cost of a facility having greater reliability, lower maintenance and greater efficiency than the alternative.

Future cost estimates should also include allowances for major maintenance items which occur infrequently. For a large transmitting station these would include such items as rewinding and oil changes for large transformers, damage to coupling hut equipment by lightning, breakage of antenna elements in high winds, replacement of wooden transmission line poles, and repainting of masts and towers for aircraft warning purposes.

MAINTENANCE PROGRAMME FACTORS

From an economic standpoint, a reasonably good balance is needed between the complement of test equipment and maintenance spare parts. If test equipment is available to permit fault finding to a component part level on a major unit, then those parts should be available in spares if field replacement is feasible. Conversely, there will be little object in having a large stock of many component parts in spares stock if the station complement of test equipment is so limited that fault finding capability cannot identify the failure of such parts.

The following are some of the factors of a maintenance programme which influence the annual operating and maintenance charges of a typical large broadcast station:

(a) Test equipment items and special test facilities available on the station.
The repairable level of each major unit is directly related to the test facilities and test equipment maintained on site, since the ability to satisfactorily complete a repair depends on the capability of identifying a faulty component or unit. A typical list of basic test equipment provided for one high power high frequency broadcast station is shown in *Table 16.1*. Most of the items of test equipment in the Table are individual items and would be used in special set-ups as test requirements dictate. Other items would usually be combined into fixed test facilities for greater all round utility. The items include all the equipment necessary to demonstrate most specified transmitter performance characteristics.

(b) Test facility space requirements and test equipment storage.
Certain of the test equipment items may be combined into test facilities and, in many cases, not used merely nearby the transmitting or control equipment. Examples are:

(i) Mobile test equipment rack which is a rack on wheels for ease in moving

Table 16.1 TYPICAL TEST EQUIPMENT FOR HIGH POWER H.F. BROADCAST STATION

Qty	*Description*	*Qty*	*Description*
1	Audio oscillator 20–20 000 Hz	2	Volt-Ohm-Milliamp meter
1	Resistance impedance bridge	1	Square wave generator with h.v. probe
3	Current transformer	1	Megohmeter
1	Industrial tester	2	VTVM-audio frequency
1/Xmtr	Modulation monitor	1	Ammeter d.c. precision
1	Distortion analyser	1	Voltmeter a.c. precision
1	Oscilloscope-single beam with associated input amps, input probes, adaptors and camera	1	Ammeter a.c. clamp-on
1	Digital voltmeter	1	Variable transformer
1	Frequency counter to 30 MHz	1	Manometer
1	Low power r.f. load 5 W	1	Tachometer
1	Attenuator 110 dB	1	Hi-pot tester 0–70 kV
1	Noise and field intensity meter with tuning heads 3.5–300 MHz	1	Corona detector with general purpose oscilloscope
1	Fundamental reject filter 3.5–30 MHz	1	VTVM-high voltage
1	VTVM 2.0–30 MHz with probe kit	1	Oil tester unit
1	Signal generator 2.0–30 MHz	1	Water conductivity test set
1/Xmtr	Capacitive voltage divider	1	Crowbar test device
1	Portable d.c. power supplies	1	Microammeter
1	Portable a.c. power supplies	1 set	Thermometers
1	Mobile test instrument cart	1	H.f. receiver 3.0–30 MHz
1 set	Extender cables	1	Pulse generator
1 set	Test instrument cables	1	Bridge r.f. 400 kHz–60 MHz
		1	Mobile test instrument bench
		1 set	Probes, adaptors and auxiliary attachment to extend the usefulness of the basic test equipment

between equipment areas and the workshops, test rooms or storage areas.

(ii) Hi-pot test facility.

Essentially all the use of this facility is for testing components which will be brought to the hi-pot tester. This heavy equipment may therefore be located in a specific area of the building as an essentially fixed installation. Other individual items of test equipment will require storage space. Usually a test equipment room is provided for such a large complement of equipment.

(c) Spare parts, sub assemblies (printed circuit cards etc.) and spare units to be maintained.

The recommended spares list will consist of items selected according to the likelihood of failure within a given length of time, and of quantity expected to be required over a specified period ranging from 3 months to one or even more years. Unless otherwise specified in a contract, a manufacturer would generally recommend that the unit spares list for a new type installation contain items and quantities adequate for at least one year of service. The capital cost of all spare parts held at a large transmitting station may be of the order of £150 000 although one very large transmitting station with 19 transmitters has a stores inventory of £300 000 which includes £115 000 spare tube stock.

Spare parts may be divided into the following two groups:

(i) Depot Spares.

One set of depot spares would generally be provided per station. These would include:

Large transformers and reactors
Tubes
Vacuum capacitors and large filter capacitors
Blower motors, servo motors and pumps
Steam condenser or other heat exchangers
Circuit breakers, including high voltage vacuum switches
Interface equipment assemblies or units
Printed circuit cards
Sub assembly units or plug-in units

(ii) Unit Spares.

One set of unit spares would be provided for each transmitter installed. These include component parts required for day-to-day maintenance and minor sub-assemblies. Factors which will have an effect on the spare items and quantities used at a station include the number of hours per day that the station operates, environmental conditions such as temperature, humidity and rainfall of the locality, dust conditions on site, amount of airborne salt, the care with which maintenance staff perform their duties in part replacement and the thoroughness and care shown in routine maintenance.

(d) Spare parts storage.

Part of the capital cost of providing the station buildings should provide for adequate space for the storage of spare parts with accessibility generally arranged in accordance with demand. Where building construction costs are high, the use of outdoor storage areas for items such as transformers may be mandatory. However, while cost may be saved by not providing indoor shelter for these items, experience has shown that maintenance costs are increased. Paint work deteriorates, insulators are often damaged by careless workmen, and they are not always readily accessible for oil and insulation testing purposes during heavy and prolonged periods of rain, particularly as exist in many tropical areas.

It is of considerable convenience, and the most economic to the maintenance function, to have spare parts stored close to the operational equipment. Large heavy components such as transformers may however be located in a separate area, but decisions in this regard are largely of a logistics nature and are influenced by many factors.

(e) Replenishment of spare parts stock.

It is good management to ensure that the rate of use of spare parts is closely monitored so that the cost of maintaining the equipment can be checked against usage, estimated costs and budgetary allowance. Also, it allows for proper scheduling of replacement items in suitable quantities. Some items will be readily available, when ordered, from suppliers shelf stocks, but others will be in a long-lead category if stocks are limited or manufacture-to-order is involved.

(f) Clerical functions.

There is a considerable amount of clerical work associated with the overall station maintenance activities. The main functions may be classified as follows:

- (i) Recording of equipment failures and notation of faults found.
- (ii) Analysis of failures and summaries of action taken to minimise a recurrence.
- (iii) Preparation of despatch and receiving records and associated transfer records for items repaired off-site.

  If any shipments of materials must be made to foreign countries, for repair for example, the shipping and receiving function is further complicated by the need for preparation of customs paperwork in addition to the usual waybills and other shipping paperwork.
- (iv) Maintenance of records of spares on hand, recording usage and re-ordering.
- (v) Maintenance of special inventories for items such as vacuum tubes and capacitors, the regular tests such as oil tests on transformers etc.
- (vi) Maintenance of records of test equipment and the control of calibration routines.
- (vii) Updating of drawings, instruction manuals and handbooks for all equipment installed, or held spare and also for all test equipment.
- (viii) Keeping of records of fuel usage, power and water consumption and other items associated with the station operation.
- (ix) Keeping of records associated with the servicing of buildings and site.
- (x) Maintaining asset registers for test equipment and tools.

(g) Staff training.

Modern radio equipment incorporates many circuits of advanced design, particularly in the control and supervisory circuits. Some interface equipment associated with highly automated computer controlled transmitters, for example, involves design disciplines noticeably different from those involved in the transmitter proper, and includes complex circuitry of advanced and sophisticated nature. Some manufacturers prepare training courses to enable local maintenance staff to be instructed in the proper operation and maintenance of the equipment.

The cost of preparation of material including instruction books, slides etc. and for providing highly skilled instructors can be an expensive item. However, without properly instructed staff in charge of the equipment the full advantages of the installation might not be fully achievable.

It is also obvious that the maintenance technician plays an important role in ensuring reliable and satisfactory operation of the installed equipment and facilities, and his effectiveness ultimately depends on his calibre and the soundness of the training he has received on the equipment.

(h) Repair work.

Many equipment components or items which may fail within a period of operation will be discarded items where repair is not possible or economically feasible. Certain other items however will be repairable, depending on the nature and extent of failures, and when repaired these items may be returned to service or to spare parts holding. Economics will not always govern a decision whether to proceed with an expensive repair or purchase a new unit. In some cases, models may be obsolete and manufacturers may not be in a position to supply an identical replacement part or unit.

The workshop at the station will be able to handle repairs, depending on the facilities available and capabilities of the staff. Many stations have elaborate workshop plant to facilitate repair work and at least one station has silver plating equipment to cater for repairs to matrix switch contacts and coils. There will always be some items which will have to be sent outside where specialist facilties are available.

In many cases, failed items have to be returned to the original manufacturer for repair or adjustment. This however can be an expensive maintenance charge, particularly when long distance overseas shipment is involved. It is important from an economic point, at least, to develop sources of repair as close as possible to the station. This also saves time which can be extremely important if the station does not possess a spare for the unit which has been sent away. Three important items which fall under this category are:

(i) Transformers and heavy machines.
Repairs for such items as transformers, reactors, and motors, are usually more economical than complete replacement, unless very extensively damaged. Some items of this type used in transmitting equipment are quite large. An e.h.t. transformer for a 250 kW transmitter may weigh 8 tonnes or more, and the development of repair sources at or close to the station is a factor of economical importance. Shop facilities to carry out the work must be adequate as much work would be of a specialist nature. The availability of adequate handling equipment on the station is an obvious necessity.

(ii) Vacuum capacitors and switches.
The availability of repair facilities for these components at other than the manufacturer's workshop is highly unlikely since facilities and techniques required for repair are essentially the same as those required for the original manufacture of the item. Manufacturers of large vacuum tubes and similar vacuum capacitors are possibilities however, where return to the original manufacturer represents a considerable economic factor. Such local sources of repair could be well worth investigating.

In the case of failure within warranty, the original manufacturer would undoubtedly be employed. However, the value of the remaining warranty life should be balanced against the cost of return to the manufacturer for repair.

(iii) Vacuum tubes.
Comments for vacuum capacitors apply with equal force to the repair of vacuum tubes. The larger tubes used with high power transmitters are economically repairable especially if the value of remaining warranty life exceeds the cost of returning to manufacturer's facilities. Where spare supplies of tubes are sufficient, the time required for repair and return will be of small importance and the least expensive means of transportation for repair can be used to advantage.

PREVENTATIVE MAINTENANCE

Past amounts of maintenance expenditures are sometimes not a good guide in determining how much is enough. Mistakes in past spending can go undetected for long periods of time. The results of expenditure on maintenance, particularly on equipment performance, are often not visible. Too little spending may be as bad as too much. In this area the test of reduced costs is not valid.

A certain level of preventative maintenance is desirable in the form of routine inspections and systematic recording and review of selected parameters. Such procedures help to provide warnings of approaching end-of-life conditions. They also help to serve as a continuing training aid in the rapid testing and correction of troubles that may occur on the equipment.

Preventative maintenance suggestions are nearly always included in the equipment manuals supplied by the manufacturer. Such maintenance is often termed 'routine' maintenance since it should be done at regular intervals as part of station routines. The outlines and suggestions for preventative maintenance given in equipment manuals can only be interpreted as manufacturers' suggestions and recommendations to be used as a guide for station maintenance personnel in the preparation of preventative maintenance schedules at the particular stations.

The circumstances and conditions at different station locations vary widely, directly affecting maintenance needs at each station and requiring corresponding alteration in maintenance schedules. For example, the frequency of performing certain maintenance tasks may have to be increased at stations where maintenance personnel are subject to frequent reassignment to other duties or stations, and time spent at the station is short. Also, cleaning and lubrication procedures are generally based on a specified number of operating hours, but where local temperatures are high, and dusty conditions prevail, an appropriate change in the maintenance periods may be desirable. Decisions in these areas must be made by station management, using the instruction manual as a guide only.

Station maintenance supervisory personnel should use the equipment manual information as a basis, supplemented by a thorough familiarisation of the mechanical and electrical features of the equipment, to prepare the preventative maintenance schedule applicable to the station needs. The schedule should identify the mechanical attention necessary and the electrical performance tests by reference to sources of detailed information in the manuals and commissioning reports to ensure that results obtained are dependable.

Table 16.2 shows a basic routine maintenance schedule recommended by the manufacturer of a water cooled 500 kW high frequency broadcast transmitter installed in the mid 1960s. The working schedule used by the station staff was expanded into much greater detail. Many high power water cooled installations have now been replaced by more efficient vapour cooled installations.

In the case of a long haul microwave radio relay system, special maintenance problems exist because of the separation of the stations. For a long route the establishment of several maintenance centres may be necessary. The numbers and location would be dictated by several factors which would include geographic and economic factors, demands of the system, availability of technically competent staff and the time taken for staff to reach stations. For many large modern systems it is practice for only minor maintenance or adjustment tasks to be carried out on equipment at the repeater stations. Workmen are generally provided with only sufficient test equipment to localise troubles and with spare panels or units to replace a faulty unit. The defective units are taken to a central repair centre specially equipped and staffed to carry out any necessary work. To be effective, this type of organisation requires vehicles, special transport crates for the equipment, mobile power plants, and often a complete mobile repeater with antenna and transportable tower in case of a major plant fault, if traffic on the route justifies such equipment.

Table 16.2 TYPICAL BASIC ROUTINE MAINTENANCE SCHEDULE FOR 500 kW H.F. BROADCAST TRANSMITTER

DAILY

1 General inspection after shut-down. Check blower bearings and filter screens.
2 Check pump glands.
3 Check air gaps and clean any arc marks.
4 Check contacts on all inductors and clean inductor turns.
5 Clean glass and ceramic of all power tubes and vacuum capacitors.
6 Check water level in distilled water tanks.
7 Check trip plunger on mains circuit breaker to make sure it is free to operate smoothly.
8 Check for arc marks on contact fingers of p.a. tank line shorting contactors.
9 Check distilled water leakage current.
10 Operate each tuning servo mechanism separately to check tuning motor operation.
11 Dust-off panels and meters.

WEEKLY

1 Check and record specific gravity of circuit breaker storage batteries and adjust charging rate. Check battery water level and refill with distilled water as necessary.
2 Clean internal parts of transmitter including all insulators, insulating panels, transformer and capacitor bushings and secondary 'goose neck' of 15 kV rectifier filament transformers.
3 Inspect all relays, clean and adjust.
4 Inspect contact fingers of all contactors, clean and dress as necessary. Clean pole faces of magnetic types. Check operation manually.
5 Clean all terminal blocks and terminal boards.
6 Clean transfer switches in 15 kV rectifier.
7 Test air flow interlocks.
8 Test door interlocks by tapping doors to make sure vibration will not cause momentary interlock circuit interruption.
9 Check contacts and operation of earthing switch.
10 Check operation of all relays and contactors associated with amplifier transfer system and service as necessary.
11 Make overall frequency noise, and distortion measurements.
12 Check calibration of output power meter.
13 Check foreign matter content in distilled water.
14 Tighten set screws in motor tuning mechanisms and inspect limit switches and helipots.
15 Clean output tank line.

MONTHLY

1 Clean power tube prongs and sockets.
2 Clean all blower blades including the small type blowers.
3 Check grease and oil in all rotating machinery including tuning motors and clocks.
4 Check all air filters and change if necessary.

QUARTERLY

1 General detailed close inspection of every unit in transmitter, with whatever tests of parts seem advisable.
2 Check spare power tubes in operating circuits.
3 Clean transmission line insulators and check all grounding or bonding joints for corrosion or electrolysis.
4 Check all wire terminals for loose connections and tighten if neccssary.

SEMI-ANNUALLY

1 Test transformer oil, and filter if necessary. Use standard 22 kV flash test.
2 Clean the bakelite bases of the tube transfer switches in rectifier unit and coat these bases with the recommended compound.
3 Drain the distilled water system, clean thoroughly. Refill with new water.

As far as the external plant provided for radio installations is concerned, experience indicates that the reliability of the plant in service and therefore the cost of maintenance is essentially determined during the plant design and construction stage. Due to its nature, some external plant such as masts, towers, line switching systems, antenna systems, transmission lines, waveguides, underground control cables etc, lends itself only to a limited degree to preventative maintenance. Where the station is operational for long hours the maintenance of high power external plant can be hazardous because of induced voltages from nearby working systems. The preventative maintenance cost of external plant tends to be much higher than for internal equipment per unit because of extensive safety precautions required when staff are working in the field. A line switching matrix in particular, when handling high powers, often causes problems because of high induced voltages, difficulties of access to some parts, remote control features and high speed switch movement.

The regular measurement of the electrical parameters of antenna systems can also be considered as a form of preventative maintenance. It has been found in practice that deterioration of the efficiency of an omni-directional antenna system generally shows up as a change in base impedance and similar easily measurable changes are likely to occur in the individual radiators of a directional system. Therefore with directional systems, periodical checks of the self impedance of each radiator should show any deterioration of either or both radiators—if it is a two element system—but unfortunately the self impedance is not of significance in the direct calculation of antenna input power, as it is in an omnidirectional system.

Annual maintenance inspection of a directional system would generally include measurement of the following:

(a) The self impedance of the individual radiators. This will enable any deterioration of the individual radiator characteristics to be checked.
(b) The amplitude and relative phase of the individual radiator base currents.
(c) The power input to the antenna system common driving point.
(d) Field intensity measurements at some four or more points, preferably those points included in the initial station commissioning and the field survey.

Some examples of preventative maintenance activities on external plant include monitoring of gas pressure alarm systems fitted to coaxial feeders, coaxial transmission lines and waveguides, the painting or galvanising of structures, preservative treatment of wooden transmission line and antenna support poles, corrosion mitigation of underground plant and treatment of threads of guy anchor tensioning rods. A considerable proportion of the plant, particularly antenna systems, is located high above ground level or enclosed in an outer sheath and so is not easily accessible for direct or immediate maintenance effort except at specially provided access points. For such plant, maintenance effort is largely limited to fault clearance.

In cases of mechanical damage to existing plant, due for instance to heavy winds, it is often not economically possible to relocate the plant or to give it additional protection once it is installed. In other cases, particularly with regard to antenna and line jointing and terminating operations, it is possible to improve the plant reliability by correcting weaknesses revealed by past fault performance.

Since reliability and maintenance cost of external plant is essentially determined by the form of initial construction, it is necessary to closely relate fault information to material design and installation practices, to permit modifications at an early date and avoid unfavourable fault incidents and maintenance costs trends being prolonged. Before new types of external plant are introduced into general use, controlled field trials may be required to gain experience in installation techniques and information about their reliability and maintenance costs.

An example of the importance of this aspect occurred with the introduction of epoxy loaded support insulators for a 106 m medium frequency radiator at a 50 kW broadcast station. The epoxy insulators at the base and sectionalising points collapsed within six days of commissioning the station. Fortunately the mast did not fully collapse, but nevertheless considerable expenditure was involved in restoration of the structure. The epoxy insulators were unsuitable for the particular application and standard porcelain units were later installed.

Preventative maintenance programmes must be carefully and regularly scrutinised to ensure that a balanced programme is followed. Excessive maintenance activity can often result in poor overall system performance and many also place increased financial burden on overhead operational charges. Some unnecessary maintenance routines result from:

(a) Repetitive routines being performed too frequently. An examination of some routines scheduled for monthly intervals has shown quarterly performance to be quite adequate.
(b) Additional routines being injected into the programme following a fault occurrence. There is a tendency to increase routine frequency or to add routines, following a fault, in an attempt to prevent a re-occurrence of the fault.
(c) Overhaul works being carried out under the guise of routine maintenance, and subjecting the equipment to accelerated deterioration.
(d) Additional routines being performed in order to give training to new staff and trainees.
(e) Use of working equipment to carry out routines on equipment or components such as tubes, transformers and modules held as spare parts.
(f) Unnecessary logging of parameters and status reports requiring excessive use of automatic or manual recording and switching devices.

CORRECTIVE MAINTENANCE

Corrective maintenance consists of fault finding and of subsequent repair processes. The fault finding process is the act of isolating a fault to a defective component, assembly or module after equipment has failed to operate at maximum efficiency or has failed to operate at all. The repair process consists of the replacement of the defective item in order to return the equipment to service.

In general, the fault finding processes require personnel who possess a good understanding of the equipment and who are experienced in diagnosing the indications of failure. These personnel must be appropriately qualified to work on the particular equipment, they must have adequate and proper test facilities and equipment and be experienced in the use of this test equipment in order to be able to function efficiently. The extent to which fault finding is possible in modern complex radio equipment depends heavily on these maintenance personnel, their knowledge, experience, and the facilities available to them. The test equipment necessary for this work can be a very expensive item in the maintenance expenditure.

The repair process is essentially a physical and mechanical procedure, requiring manual and physical dexterity appropriate to the work to be performed. The replacement of a multi-terminal thin film or integrated circuit device on a printed circuit card and the replacement of an 8 tonne oil filled modulation transformer represent opposite extremes. Tools, plant and facilities appropriate to the work to be performed are an obvious necessity and the operation, maintenance and ultimate replacement of these, form part of the overall maintenance and operating expenses of the establishment.

Some modern high power transmitters are provided with digital control systems which not only provide control, monitoring and logging but also fault isolation. Such installations use a computer with the control equipment provided as common equipment for all the station transmitters. It has also the capability of similarly controlling programme input and antenna switching systems.

In this particular control system, critical voltages, currents, temperatures, off-on sensors etc, inside each transmitter or installation are continuously scanned to determine if any faults are present and if selected operating parameters are within limits. If an abnormal condition is detected, action is automatically taken to notify the operator and to initiate appropriate steps to identify the condition and the print out information relating to the occurrence so that a hard copy is obtained of the fault location and status of the equipment. A detailed fault isolation diagnostic routine for use in locating faults within the transmitter is also provided by the computer program. On detection of an abnormal operational condition, the diagnostic routine is initiated and the operator receives a print out of the location and type of fault. Also, the operator can request a controlled test condition that modulates the transmitter with a known modulation percentage and allows all analogue readings to be compared against specific limits.

Figure 16.1 Control room of broadcast station equipped with digital control system

Selected analogue readings can be automatically logged at predetermined intervals, the program compiles a list of required analogue readings and a set of readings is printed out for each transmitter in operation at the time to provide a permanent record of the parameters. This type of repetitive control and monitor function is performed more efficiently, accurately and rapidly by the system than could be carried out by the maintenance staff.

From a maintenance and operation viewpoint, the main advantages of the system may be summarized as:

(a) Fewer operations and maintenance personnel are required to staff a large station.
(b) It standardises maintenance schedules and routines.
(c) It reduces diagnostic or fault location time and so allows off-air time to be kept to a minimum.
(d) Reduces the possibility of operator error in tuning, switching, adjustment etc. compared with a manual system.
(e) Provides continuous routining and fault logging.

The control room of a high frequency broadcast station employing this type of digital control system is shown in *Figure 16.1*. The equipment associated with the system is installed against the far wall of the room.

FAULT ANALYSIS

A system providing prompt and accurate indicators of plant and equipment performance is required for both the direction of attention to facilities in service which are showing weaknesses in construction and performance and for the modification of current designs and methods with a view to overcoming the revealed weaknesses. These indicators should be used for:

(a) Local follow-up action to deal with particular situations revealed by the system.
(b) Modifications of existing materials and installation practices to overcome weaknesses found in service.
(c) Introduction of new materials and installation practices designed to improve equipment and plant performance.

It is most important that weaknesses in design or installation practices with new materials are recorded and studied through a quick and accurate scheme of fault recording and analysis. In addition it is necessary that engineers be able to make the installed equipment and plant more reliable by correcting the weaknesses shown by the fault recording system. This requires that they know both the type of weaknesses occurring and its location in the equipment. It is well known that equipment reliability can never be better than that of the weakest component.

Fault reports prepared by the maintenance staff are of particular importance to the controlling engineer. In order to obtain data on which to assess failure probability, he must be provided with fault reports from the field. Field reports are essential if reliability is to be improved. They are used in what is virtually an information feedback system in order to keep designers, manufacturers, installers and of course the maintenance group, aware of the ways in which the equipment failed and to pinpoint items which can be improved.

Another important use to which the fault report is put is that, as a result of analysis, some guidance is afforded to the maintenance group as to what spares should be kept in the supply line. With one large operating organisation an investigation showed that for every tube in use in their equipment there were four in the supply line. A knowledge of the probability of failure could have guided the ordering staff on which spares to order rather than to take a random guess and have certain items over-ordered and others inadequately supplied.

The development of modern computing machinery has opened the way to the rapid, economic and accurate summation of radio equipment fault records and the analysis of these records for determination of the most reliable and economical maintenance and installation practices. This analysis is produced from data which is essentially prepared by the maintenance staff responsible for the system. The computer program for, say, a broadband radio relay system takes into account times and outages on both the main and protection bearers and correlates traffic time lost, main bearer outages and protection bearer utilisations as they occur. Information presented to the engineer allows him to readily assess the effectiveness of the maintenance being carried out on the route, the reliability and usage rate of various components.

An analysis carried out of the major causes of equipment failures, other than tubes, associated with broadcast, television, radar and radio communication equipment has shown that the cause can be classified under the following headings:

(a) Engineering.
About 35% of the total causes could be placed in this group and were due mainly to omissions, miscalculation, incorrect design approach and poor judgment on the part of designers.

(b) Installation, Construction, Operation and Maintenance.
In this group 30% were traced to incorrect handling or procedures because of inadequate instruction, materials, testing procedures or training.

(c) Components.
About 25% were due to components which failed because of inherent defects.

(d) Manufacturing.
This accounted for the remaining 10% of causes and resulted from plant and equipment not being manufactured, built, tested or inspected in accordance with the specifications.

TYPICAL MAINTENANCE AND OPERATION COST EXAMPLES

The following examples are indicative of maintenance and operational costs associated with various types of radio equipment and plant. They do not all represent the latest state-of-the-art equipment but are taken from typical installations some of which have been in service for many years. The costs apply only to the equipment and plant operation and maintenance, and do not include capital recovery charges, rates or taxes. Because cost factors vary with current labour rates, location, climate etc. and as there is frequency wide variation between different countries, the figures should not be considered as firm but simply as a guide to the method of cost determination or calculation as practised by many radio engineers. In some of the examples nominal values only have

Table 16.3 TRANSMITTING TUBES, AVERAGE LIFE FIGURES

Tube type	*Average life (10^3 hrs)*	*Tube type*	*Average life (10^3 hrs)*
F8388	10.0	4–125 A	5.0
F8133	5.0	6146	5.0
4CX3000 A	5.0	5763	5.0
4-400A	5.0	5879	5.0
QBL5/3500	5.0	RK25	10.0
TBL6/20	3.2	RW3	12.0
V238A/1K	4.0	EC157	6.0
W7/3G	4.0	V239C/1K	4.0
Z239/1G	4.0	Z237/1K	4.0
5J/180E	4.0	KR761	9.0
KR762	10.0	V233A/1K	4.0
KR763	9.0	4CX350A	5.0
4CV100 000C	10.0	4/400A	3.0
4220Z	6.6	124 A	5.0
4222Z	8.0	5563 A	5.0
4279Z	8.0	2K56	12.5
4270A	10.0	V230A/1K	6.0
3C/270A	6.4	V190C/1M	6.0
4078Z	22.0	QB5/1750	5.0
833 A	12.0	CR192	3.4
3Q/221E	4.0	2V/561E	6.0
TG10	19.0	3J/192E	6.6
3J221E	10.0	3J/261E	5.0
3C/150A	11.0	9C25	6.0
TB/1250	5.0	5976	9.0
357 A	5.0	3X2500F3	4.0
827R	6.5	3X3000A1	5.5
857B	8.5	BR189	6.0
880	4.2	CV2383	4.6
889R	3.0	N1001	5.0
892R	4.0	N1002	6.0
5762	5.5	TWC3	10.0
6166	7.0	QY4/250	9.0
13E1	3.0	CR1100	10.0
ML-5682	10.0	GL8701 A	10.0

been used but with knowledge of local charges applicable at the time, the real cost can be easily determined by substitutions in the worked examples.

Most of the transmitting tube average life figures used in the examples have been taken from the list shown in *Table 16.3*. The figures have been averaged on a 7 years basis, but a few of the tubes, for instance some vapour cooled tubes, are of only comparatively recent manufacture and long term average figures are not yet available. The figures are useful guides in estimating the annual costs associated with transmitting tube replacements at broadcast, television and radio communication stations.

EXAMPLE 16.1

Medium frequency broadcast transmitter, water cooled model, with output power of 1 MW. Power supplied at a rate of 1.75 pence per kWh. Staff comprised two men on each shift. Transmission hours 6000 per year.

Power

(a) Power required for say 40% average programme modulation = 2200 kW
(b) Rate of 1.75 p per kWh
Hourly rate for power = £38.50 = £38.50

Power Tubes

(a) 18 tubes at £2900 = £52 200
(b) 12 tubes at £1550 = £18 600
£70 800

(c) Filament life of 10 000 hours for major tubes
Hourly cost of major tubes = £7.08
(d) Cost of minor tubes in transmitter = £900
(e) Filament life of 5000 hours for minor tubes,
Hourly cost of minor tubes = £0.18
Total hourly cost for all tubes = £ 7.26

General Maintenance

(a) Replacement parts taken over an average of 5 years = £4200
(b) Miscellaneous, including distilled water, nitrogen gas, lubricants, transformer oil, silver plating etc. = £1800
Total cost per year = £6000
(c) For 6000 hours of operation per year, then hourly cost of maintenance = £ 1.00

Staff

(a) For a basic labour cost of £4.50 per manhour (excluding administration and overhead) and assuming average 2 workmen on duty for full period
Hourly rate for staff = £ 9.00

Total hourly operations cost = £55.76

Annual operating and maintenance charges for this 1 MW transmitter equipment only amount to 6000 × £55.76 = £334 560.

∴ Cost per watt output = 33p.

Modern vapour cooled transmitters of this power range are much more efficient than water cooled models. A typical transmitter would have an efficiency better than 60% for 40% modulation conditions and consequently the hourly power charges would be substantially less than the £38.5, as in the example. Fewer tubes are used in the more recent designs and this also contributes to an overall maintenance cost saving. The physical size has been substantially reduced and this is a further advantage in that building floor space requirements are reduced.

Reliability of operation and a minimum of maintenance is a feature of modern high power broadcast transmitters. This is brought about by:

(a) Close attention to detail in the design of individual components making up the transmitter.
(b) Special attention to the manufacture, inspection and testing of these components.
(c) Selection of components of appropriate ratings in relation to the electrical stresses under both normal and abnormal operating conditions and to their environment during storage, handling, transport, installation and operation.
(d) A reasonable degree of inbuilt redundancy.
(e) High quality of assembly, installation, inspection and testing of the transmitter after installation on site.

EXAMPLE 16.2

High frequency broadcast transmitter, vapour cooled model, with output power of 250 kW. Power supplied at a rate of 1.8 pence per kWh. Staff comprised average of two men on each shift employed on the operation and maintenance. Annual programme transmission hours were 6000.

Power

(a) Power required for say 40% average programme modulation = 575 kW
(b) Rate of 1.8 pence per kWh
Hourly rate for power = £10.35 = £10.35

Power Tubes

(a) 4 tubes at £3600 = £14 400
(b) 3 tubes at £ 600 = £ 1800

£16 200

(c) Filament life of 10 000 hours for (a) and 5000 hours for (b),
Hourly cost of major tubes = £1.80
(d) Cost of minor tubes in transmitter = £200
(e) Filament life of 5000 hours for minor tubes
Hourly cost of minor tubes = £0.04
Total hourly cost for all tubes = £1.84 = £ 1.84

General Maintenance

(a) Replacement parts, taken over an average of 4 years = £3100
(b) Miscellaneous, including filters, deionized water, rubber gaskets, lubricants = £750
Total cost per year = £3850
(c) For 6000 hours of operation per year,
Hourly cost of maintenance parts = £0.64 = £ 0.64

Staff

(a) For a basic labour cost of £4.50 per manhour (excluding administration and overhead) and assuming average 2

workmen on duty for full period,
Hourly rate for staff = £ 9.00

Total hourly operations cost = £21.83

Annual operating and maintenance charges for this 250 kW transmitter equipment only, amount to 6000 × £21.83 = £130 980.

∴ Cost per watt output = 52p.

The efficiency and reliability of transmitters are being continually improved by manufacturers. Many short wave and medium wave 250 kW transmitters have only four power tubes, two of which are in the final stage of the modulator and the other two being driven and final output stages in the radio frequency amplifier. Even 500 kW transmitters are now in service with only one tube in the radio frequency output stage.

EXAMPLE 16.3

Medium frequency broadcast transmitter, air cooled, twin 5 kW units in parallel. Power was charged at rate of 2.5 pence per kWh. Transmitter was operated on an unattended basis and equivalent daily manhours spent on maintenance averaged over a full year was 0.3 men. Transmission hours were 6000 per year.

Power

(a) Power required for say 40% average programme modulation
13.5 kW per 5 kW unit i.e. Total = 27 kW
(b) Rate of 2.5 per kWh, Hourly rate for power = £0.68 = £0.68

Power Tubes

(a) 6 tubes at £185 = £1110
(b) 10 tubes at £ 30 = £ 300

£1410

(c) Filament life of 5000 hours,
Hourly cost for tubes = £0.28 = £0.28

General Maintenance

(a) Replacement parts taken over an average of 6 years = £1400
(b) Miscellaneous, including filters, lubricants etc. = £250
Total cost per year = £1650
(c) For 6000 hours of operation per year
Hourly cost of maintenance = £0.28 = £0.28

Staff

(a) For a basic labour cost of £4.50 per manhour (excluding administration and overhead) and assuming average 0.3 equivalent men on duty for full period,
Hourly rate for staff = £1.35

Total hourly operations cost = £2.59

Annual operating and maintenance charges for this two parallel 5 kW transmitter equipment only amount to 6000 x £2.59 = £15 540.

∴ Cost per watt output = £1.55.

The main reasons for the introduction of automatic and remote control of broadcast transmitters are primarily economic considerations and staffing difficulties. However, the engineering reliability 'trade-off' requires analysis, and before changing an existing transmitter over to automatic working, it is essential to record and analyse the performance data. Improved techniques, such as the use of solid state devices, lead to higher reliability but to take advantage of this, additional training of maintenance staff with emphasis on the functional approach to equipment maintenance may be necessary.

Unattended operation of transmitters involves a somewhat different approach to equipment and plant performance compared with the situation where skilled staff are continuously in attendance. The equipment performance can be considered as being in four main levels of classification:

(a) Commissioning level.
This is the optimum level to which the installation is capable of being adjusted and is obtained at the commissioning stage just prior to placing the equipment in service.

(b) Annual inspection line-up level.
It is normal practice with the majority of organisations for each transmitter installation to be subjected to a detailed annual inspection which includes adjustment, alignment and extensive performance measurements. After completion of the inspection, the equipment will have been adjusted to a level which is optimum when taking into account the operational situation and life of the equipment.

Whenever a fault has been rectified in the equipment it should be readjusted to this line-up level condition.

(c) Minimum performance level.
In addition to annual inspections, it is normal for maintenance staff to visit unattended radio equipment at about quarterly intervals to ensure that the equipment is maintaining a performance above a minimum level which will vary with the type and nature of the installation. Should the equipment be found on test and inspection to be of performance below the set minimum, action is taken to restore it to a higher level, preferably the annual line-up level.

(d) Action level.
At this level the performance of the equipment has fallen below the minimum performance level or has developed a fault. Both conditions would be detected by the monitoring facilities and would require immediate action by maintenance staff. In order to ensure that the monitoring facilities are functioning properly it is often practice for maintenance staff to make a routine safety inspection, at about monthly intervals, of important major installations.

EXAMPLE 16.4

VHF television transmitter, twin 10 kW vision transmitters in parallel and twin 2 kW sound f.m. transmitters. Power was supplied at a rate of 2.5 pence per kWh. Staff comprised two men continuously employed during hours of transmission. Hours of operation were 5000 per year.

Power

(a) Average power required for vision transmitters = 52 kW
(b) Average power required for sound transmitters = 10 kW

Total average power = 62 kW

(c) Rate of 2.5 pence per kWh,
Hourly rate for power = £1.55

Power Tubes

Vision
(a) 2 tubes at £875, fil. life 7000 hours
(b) 6 tubes at £30, fil. life 9000 hours
(c) 20 tubes at £25, fil. life 3000 hours

Sound

(d) 4 tubes at £250, fil. life 10 000 hours
(e) 4 tubes at £30, fil. life 6000 hours
(f) Hourly cost of major tubes = £0.55
(g) Cost of minor tubes in transmitters = £650
(h) Filament life of 5000 hours.
Hourly cost of minor tubes = £0.13
Total hourly cost of all tubes = £0.68

General Maintenance

(a) Replacement parts taken over an average 5 years = £3000
(b) Miscellaneous including filters, lubricants etc. = £410
Total cost per year = £3410
(c) For 5000 hours of operation per year
Hourly cost of maintenance = £0.68

Staff

(a) For a basic labour cost of £4.50 per manhour (excluding administration and overhead) and assuming average 2 workmen on duty for full operational period,

Hourly rate for staff = £9.00

Total hourly operations cost = £11.91

Annual operating and maintenance charges for this 10 kW/2 kW transmitter equipment only, amount to 5000 x £11.91 = £59 500.

EXAMPLE 16.5

A solid state broadband microwave radio relay bearer with protection bearer and supervisory facilities was to be installed between two terminals 1600 km apart. There were to be 40 repeaters and one intermediate repair centre about midway between the terminals. Panel repair for the whole of the route was to be carried out at the intermediate repair centre. Each terminal staff was to maintain the route 280 km out, approx. 7 repeaters, and the intermediate repair centre was to be responsible for the remainder. All stations were to generate power locally. The equipment manufacturer had guaranteed a reliability index of 0.14 failures per site per annum per bearer, and the ratio of degradation faults to outage faults was assumed to be 3:1;

The estimated cost of maintaining the proposed system was determined as follows:

Labour, Radio and Power Equipment.

(a) Fault clearance, LF

The number of visits per site per annum for 1 + 1 two way system = $0.14 \times 4 \times 4 = 2.2$

Because the equipment to be installed was a new development by the manufacturer, it was expected that it would be about two years before the guaranteed reliability would be achieved and in view of this, the upper figure of 3 visits was assumed for the study.

Staff loading for fault clearance purposes is equal to (3T + 3) manhours per site per annum where T is the average travelling time per site and allowing one hour at each site per visit for checking equipment, changing plug-in units and reporting to the maintenance control centre.

To the above loading must be added an allowance for attending to power equipment and from past experience on similar power equipment, this was assumed to be equal to the radio equipment commitment. Hence total fault clearance loading.

$$LF = 2(3T + 3) \text{ manhours per site per annum}$$

For No. 1 terminal (one terminal, seven repeaters)

$$LF = \frac{8 \times 2(3 \times 280 \text{ km} + 3)}{40 \text{ km/h}} \text{ manhours}$$

$$= 384 \text{ manhours per annum}$$

For No. 2 terminal (one terminal, seven repeaters)

$$LF = 384 \text{ manhours per annum}$$

For maintenance repair centre

$$LF = \frac{27 \times 2(3 \times 1040 + 3)}{40} \text{ manhours}$$

$$= 4374 \text{ manhours per annum}$$

Total manhour requirements for fault clearance = 384 + 384 + 4374

= 5142 manhours p.a.

(b) Performance Measurements, LP.

Monthly tests would involve demodulating stations only. For three demodulating stations and two terminals and assuming two men were involved at each station, LP = 10 men × 12 monthly tests × 2 bearers × $\frac{1}{2}$ day plus travelling time. ∴ LP = 996 manhours.

Six monthly end-to-end tests were assumed to be done in connection with monthly tests and take an additional 4 hours per bearer so that additional manhours required would be 10 men x 2 tests x $\frac{1}{2}$ day = 80 manhours.
Total manhour requirements for performance measurements

= 996 + 80

= 1076 manhours per annum

(c) Power plant Inspections and Maintenance, LB.
To be carried out bi-monthly by power plant specialist staff, assuming 4 hours per site plus travelling time.
LB = 43 sites x 4 hours x 6 inspections per year plus travelling time (80 hours)

= 1112 manhours per annum

(d) Annual Inspection and Line-up, LI.
These series of measurements would involve tests on the equipment within each site, test from each site to adjacent repeaters, tests from each site to the adjacent radio terminal and also baseband section tests. It was expected that this work would involve a two man inspection team for 12 weeks per annum including travelling time.

LI = 2 x 8 x 5 x 12 manhours

= 960 manhours per annum

(e) Special Visits, LS.
These visits would probably arise from a situation where a failure does not respond to the normal treatment or where an obscure fault has to be tracked down through a number of stations before the faulty unit is located. They may also follow a particularly severe weather disturbance.

Experience has shown that a two-man team involving about 400 manhours per annum plus say 40 hours travelling should be allowed.

LS = 440 manhours per annum.

(f) Units Repair, LR.
As seen above, it was expected that 3 units from each site would require repair action each year. If 3 units per site per year require attention and if average repair rate is 2 per week.

LR = 3 units x 43 sites x 20 manhours

= 2580 manhours

Manhour summary

= LF + LP + LB + LI + LS + LR

= 5142 + 1076 + 1112 + 960 + 440 + 2580

= 11 310 manhours

Because of the long distances to be travelled, the remoteness of many stations and safety aspects in connection with certain work, and also the need to train apprentices, etc. there would be many occasions where more than one man would embark on some journeys. An additional loading of about 15% is justified from experience with similar routes.

Hence total manhour requirements = 13 000 manhours per annum.

For a basic manhour rate of £4.50 excluding administration and overhead charges;

Labour = 13 000 × £4.50

= £58 500 per annum

Labour, Towers, Antennas and Sites, LT

Annual visit would be involved by radio lines group comprising four men. Full day would be spent at each site on checking tower, bolts etc., antennas, feeders, cleaning-up site etc.

Total manhours including travelling

$$LT = (43 \times 8 \times 4) + \frac{(3200 \times 4)}{40}$$

$$= 1376 + 320$$

$$= 1696 \text{ manhours.}$$

To allow for at least one visit per annum on the route for fault on waveguide, antenna etc. or special site attention on the route, 304 manhours were allocated.

Hence total manhour requirements = 2000 manhours.

For basic manhour rate of £4.50 excluding administration and overhead charges,

Labour = 2000 × £4.50

= £9000

Materials

From experience gained with solid state system operating under the same environmental conditions, material estimates for the route were:

Radio equipment	£105 × 43	=	£4515	
Towers, antennas, sites etc.	£8 × 43	=	344	
	Total	=	£4859	(say, £5000)

Power

Estimated power costs = 10p per kWh. For an overall average of 500 W for each station.

$$\text{Power cost} = 43 \times \frac{500}{1000} \times \frac{10}{100} \times 24 \times 365 \text{ per annum}$$

$$= £19\,000 \text{ (approx.) per annum}$$

Motor Vehicles

32 000 km at 6.25p per km = £2000

Summary Annual Costs

Labour	=	£67 500
Materials	=	£ 5000
Power	=	£19 000
Transport	=	£ 2000
Total	=	£93 500

$$\text{Cost per route kilometer} = \frac{93\,500}{1600}$$

$$= \text{£}58.4 \text{ per annum}$$

Some of the factors which influence the time taken to correct faults include:

(a) The promptness of notification of a fault or non-standard condition to the maintenance staff.
(b) The existence of a coincident fault on other equipment such as the protection bearer or supervisory alarm system.
(c) The amount of information regarding the particular trouble which is fed back to the maintenance staff and also available at the site.
(d) The time taken by the maintenance staff to travel to the site.
(e) The type and availability of spares. Spares which comprise complete units or modules will allow much more rapid restoration of service because considerable time can often be spent in isolation of a particular component.
(f) The testing facilities and equipment available at the site.
(g) The ability of the technician despatched to correct the fault.
(h) The availability of transport and staff at the time.
(i) The number of repeaters. Experience has shown that as the number of repeaters on a route increases, the standard per repeater provided by the maintenance organisation tends to decrease.

Solid state bearer equipment is noted for the following properties:

(a) Reliability is very high.
(b) Performance does not degrade steadily with time to the same degree as tube equipment.
(c) Lower capital and operating costs.
(d) Lower power consumption for equivalent output.
(e) Smaller physical size resulting in less building space requirements.
(f) Because of the complexity of some components (integrated circuits etc.) and miniaturised characteristics, equipment is not suitable for field repair.
(g) Replacement units may be large to reduce that number of interfaces or small to improve the flexibility of spares holding.
(h) Interface between units may have complex specifications (impedance, level, frequency, amplitude response, group delay response, isolation performance etc.)

There is a basic difference between the maintenance requirements of solid state equipment and tube equipment. This requires a complete re-assessment of the maintenance practices which have developed for tube type systems if the full potential of solid state equipment is to be realised. The difference in maintenance requirements arises from the different ways in which the two types of equipment are repaired. Tube type equipment is invariably repaired on site, usually by a local technician or occasionally by a visiting specialist from a remote central station. This is the traditional method of maintenance for tube equipment and is adopted because faults can usually be cleared locally and the equipment cannot often be readily moved to a repair centre.

On the other hand, the on-site repair of solid state equipment is generally impractical, if not impossible. However, the equipment can be readily transported to a remote repair centre because of the plug-in unit construction and compact form of equipment. The two basic facts about solid state equipment are:

(a) Only a small number of units will need repair.
(b) Repair must be done by a specialist in a well equipped centre.

Experience has shown that a single repair centre is the best arrangement and duplication of centres is only permissible when work load or perhaps excessive transport problems make it necessary. Underloaded repair centres will be doubly inefficient because the staff will not get sufficient experience to do their job properly. In the Example, the repair centre was to be located approximately midway between the two terminals and although each terminal would hold spare plug-in units to service about 7 repeaters, the repair of the faulty units would be carried out at the repair centre.

The main functions of the repair centre may be classified as follows:

(a) To provide a centralised area of environment appropriate for the work to be performed, and staffed with skilled personnel.

   To ensure careful quality control of workmanship and testing processes, the following are important:
   (i) The use of clean air conditioned areas for repair, adjustment and testing.
   (ii) Training of the maintenance staff to high standards.
   (iii) Strict control of the storage, handling and transport of materials, equipment and testing instruments.
   (iv) Stringent visual, mechanical and electrical inspection and testing of repair, adjustment, alignment or performance testing.
   (v) Recording of all equipment faults on history sheets.
   (vi) Thorough environmental testing of units before return to the field.

(b) Repair and re-alignment of plug-in units returned from the stations.

   Provided that the equipment is purchased to a specification which controls interchangeability of units, the alignment of repaired units in the repair centre should include the following techniques applied to every unit to ensure its suitability as a replacement:
   (i) Alignment to factory tolerance limits.
   (ii) Sweeping and spectrum analysing tests.
   (iii) High temperature tests and temperature cycling.
   (iv) Vibration tests.

(c) Investigation of causes of faults and development of modifications to eliminate faults and maintain performance level.

   Progressive deterioration of performance over the life of the equipment should not be an acceptable objective. Replacement units must be quality controlled to ensure that when used in normal proportions, they cause negligible overall deterioration in performance. Such residual deterioration, which could be cumulative over the years, should be removed by on-site re-alignment at the time of the annual inspection.

(d) Revision of test procedures being carried out on the route.

(e) Maintenance and calibration of test equipment.
In addition to normal electronic test gear it is desirable that the repair centre should be fitted out with a Heat chamber, Cold source, and a Vibration tester.

(f) Provision of expert advice and guidance to staff associated with the maintenance of radio relay equipment.
Because the performance and reliability of solid state radio relay systems are largely dependent on the quality of the repair and alignment carried out at the repair centre, it is usual to employ highly skilled and experienced technical staff who possess the most expert knowledge in the radio relay repair field.

EXAMPLE 16.6

Repainting of 220 m guyed medium frequency broadcast radiator in accordance with aircraft obstruction marking requirements. The mast was triangular cross section with 2.4 m sides.

Materials

Paint, thinners, turpentine, paint brushes, wire brushes, scrapers, garnet paper, cleaning rags, rope etc.	= £1050

Labour

Removal of old loose paint by scraping and brushing (200 manhours), application of primer, undercoat and final gloss coat (75 manhours per coat) plus ineffective time due to climbing, travelling to job 15 km per day, cleaning-up at £4.50 per hour excluding administration and overhead.	= £2870

Incidentals

Vehicle	= £ 30

Management

Including supervision, inspection, documentation etc.	= £1150
Total	= £5100

In a repaint work the condition of the old paintwork is a major factor in the overall cost of the project. The removal of blistered, cracked or powdered paint is a time consuming exercise. Repaint works on some 168 m selfsupporting towers have been as high as £30 000 involving some 4000 manhours.

If specific cost data based on past experience is not available, it is necessary to determine the area to be cleaned or painted before the estimate can be prepared. Paint has only about 80% effective covering capability when applied aloft due to losses from high wind, spillage and inadequate brushing.

Mast and towers used for radio engineering purposes are generally described in terms of weight and linear dimensions. Angle steel commonly used in these structures varies from about 10 to 90 kg weight per square metre of painting area. The lower range is minimal for the smaller lattice type structures and the upper range for the larger more massive types. Thus if the weight of the steelwork of the mast or tower is known, a fair approximation may be made of the painting area.

A primer will not adhere to a surface which has rust, grease or loose paint and these should be cleaned off and the surface wire brushed. The final coat consists of a hard enamel, white and international orange, in alternating bands of equal width. Black and white bands are frequently used in lieu, where the surrounding terrain is of a reddish-brown colour.

First class enamel when correctly applied with primer and undercoat has good wearing qualities. The life is influenced considerably by the environmental factors. Paint on structures close to the sea, particularly in tropical locations, seldom has a life exceeding 3-4 years, whereas for a dry inland rural environment a life up to 10 years may be obtained before repainting becomes necessary.

The cost of painting masts and towers is high and consequently illconsidered and badly applied schemes will result in short life and often the removal of old paint can be a very expensive operation. The normal methods of paint removal, with chemical solutions and flame, are seldom used on structures because of hazards in their use during the high wind conditions experienced on tall structures.

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Chapter 17

Retirement

REASONS FOR RETIREMENT

Reasons for retirement of equipment or plant may be classified as follows:

(a) The installed equipment or plant has failed in service and will no longer function.

Equipment and plant fail for many reasons. Moving parts such as motors, relays, contacts, switches etc. fail from wear and tear. Wooden poles used for antennas and transmission lines fail as a result of decay, steel work of antenna systems fail from corrosion or overloading, wires may fail from fatigue or corrosion, dielectric materials may fail as a result of excessive internal heating, filaments of tubes and lamps fail from burnout, and batteries fail from chemical and physical changes. There are many other examples and it will be noticed that a common feature in this group is that many of the failures may be considered to be roughly proportional to time. This division is a simplification of the actual facts, since hardly any sort of deterioration is a function of time alone, or of use alone. The deterioration of oil in an oil filled transformer, for example, though mainly a matter of time depends also upon temperature and therefore use, while items normally proportional to use such as transmission line switches are also affected to some extent by time. Failure may also be caused by the action of elements, such as high winds, lightning, ice, floods, earthquake, vibration etc. particularly on external plant.

Although many failures can be corrected by replacing the faulty unit it is not always the case. The equipment may be so old that vital replacement parts or units may no longer be obtainable. Also in the case of a structure, corrosion may be so extensive that the structure is a hazard, if left *in situ*. In these cases there is no alternative but to retire the plant. A mast or tower which has collapsed would also be in this category.

(b) The equipment or plant does not have sufficient capacity to meet current needs.

The equipment may be unable to cope with growing service demands, due to exhaustion of capacity. A microwave radio system may not have capacity to cater for an unexpected increase in traffic loading, a generating unit may have insufficient output to meet the demands of additional installed transmitters and transmission lines and antenna matching equipment may be unable to handle an increase in transmitter output power. These are some typical examples.

Careful forecasting of growth and proper initial planning can reduce retirements in this category, but it is generally acknowledged that the liability to retirement from this cause is related to the development rate, a high rate increases the liability and vice versa. Any undertaking involving the borrowing of money and its conversion into equipment to provide service is dependent for its profitableness upon a delicate calculation as to the relative suitability of various types and capacity of equipment and plant, and the probable public demand for the service. Even though these may be all correct at the time of the investment, they may be upset by new circumstances and it may then be worth while to retire the equipment even though still in working order. Probably the most outstanding cause of radio equipment and plant retirement has been inadequacy caused by the growth of service.

(c) The equipment may be obsolete because of changes in conditions or service it must now render.

This type of depreciation is distinguished from those previously considered by the fact that it is a change not in the asset itself, but in its environment, which destroys its economic suitability. It just as certainly results in the asset becoming inadequate, but it is frequently due not to the asset itself getting worse, but to the alternatives getting better. Familiar examples of this include the considerable advantages obtained in a point-to-point service by changing from double side band to single side band operation, frequency modulation operation compared with amplitude modulation operation, log periodic antenna compared with a large number of separate dipoles and air cooled tubes compared with water cooled types for transmitter powers to about 100 kW.

The four main reasons often advanced for retirement of equipment on the grounds of obsolescence are:

The non-availability of maintenance parts.
Excessive utilisation of expensive floor space.
High mains power consumption.
Higher overall operational and maintenance costs.

There is not necessarily any connection between the depreciation of equipment and its efficiency. The service life of equipment may be nearly exhausted and yet that equipment may be functioning as efficiently as new. Many engineers and museums have very early models of radio equipment which are just as efficient in their operation as when orginally constructed. In cases where equipment is retired for functional reasons its service efficiency may be quite impaired, but its capacity for service is just as certainly exhausted if it is inadequate or fails to conform with technical requirements, as if it had deteriorated through wear and tear decay, corrosion or by the action of the elements.

(d) More efficient equipment or plant which will operate at lower cost is available.

If out-of-date equipment costs more to run than its modern equivalent replacement, the degree of depreciation from this cause can be ascertained by capitalising the additional annual charges at the rate proper to the modern equivalent. Examples of more efficient equipment which may give more economical overall operation include transistorised equipment in place of the tube type, vapour cooled high power transmitter in place of a water cooled installation and automatic transmitter control equipment in place of a manual system.

(e) Changes in the art.
Because of the rapid advancement in radio and electronic technology in recent years, changes in the state-of-the-art have a considerable influence on the retirement of equipment and plant. Duplication of spares, test equipment, maintenance techniques and training effort are involved in keeping several versions of equipment in service together. The problems associated with interface equipment to allow various versions of equipment to work together is a major problem in many areas and it has often been found to be more economic to retire some plant, even though only a few years old, because of the high cost of design and manufacture of interface equipment.

(f) Some new method of providing service may become available.
The satellite is an outstanding example of this reason. Not many years ago, high frequency radio bearers carried a large percentage of overseas traffic. Improvements in submarine cable techniques and particularly amplifiers with long life led to a large cable laying programme, to challenge radio methods. This was shortly followed by satellite developments with microwave radio bearers. Not only is the satellite playing an important role in overseas communications including television relaying, but the techniques are also being used to handle large volumes of internal traffic in many countries.

The first two reasons allow no alternative in the decision which must be made. If service is to continue or to be increased, new equipment has to be purchased. The economic study in these circumstances is confined to the alternative investment type.

The third situation is one in which the necessity for replacing the existing equipment is usually apparent. If designs have changed so that the existing equipment provides an inferior type service, the only alternatives are either to buy new equipment or probably to go out of business.

The remaining reasons, where matters of efficiency and improved technology are involved, do not lend themselves to clear cut decisions without proper detailed study. If no change were to be made to the installation, service would continue to be provided even though the cost would be higher than with a more efficient installation. To determine whether or not such equipment should be replaced, it is necessary to compare the annual charges that must be met if the existing equipment is retained, with those which would occur if new equipment were employed. A correct answer depends upon a proper determination and analysis of the charges in the two cases.

At some time in the life of nearly all equipment and plant a decision must be made as to whether it should be retired and replaced, and it is necessary for the engineer to have a means of determining when is the most economic time for the retirement and replacement to take place. A knowledge of depreciation procedures and service life is necessary in order to make this decision on rational grounds.

RETIREMENT COST

The retirement cost is the estimated cost of recovery of equipment or plant, net of any residual value remaining at the end of its estimated life. The cost of recovery of a facility at the end of its life occupies a position analogous to that of capital cost in that it is part of the cost of providing service over the life of the equipment. It should be noted that we are concerned here with its value at the end of its economic life and should not be confused with the end of the study period. It should be taken into account even when it occurs after the end of the study period. The retirement cost may be a negative value if the residual or scrap value of the equipment is estimated to be higher than the costs of removal and disposal.

An unusual retirement situation occurs when it becomes necessary to dismantle towers which have been erected on buildings or in other such difficult situations. In one exercise it was necessary to dismantle a 55 m insulated self-supporting tower from the top of a tall building in a large city. The tower was originally provided some 20 years earlier at a cost of £5500 to serve as the radiator for a medium frequency broadcast transmitter located in the building. The cost of recovery of the structure was £8500 and the steel realised £200 as scrap metal.

REPLACEMENT BASED ON ANNUAL COSTS

The annual cost of keeping existing equipment or plant in service consists of the sum of those costs associated with the maintenance and operations. The annual cost for new plant will include the estimated maintenance and operation charges plus the annual capital recovery payments for the new capital. The capital recovery payments on the existing installation are not taken into consideration in an economic study based on annual costs because these will have to be paid whether or not the replacement is made. The capital investment of the existing plant was paid for at the time of installation and any future change of policy will not affect this. This aspect is illustrated in the following example.

EXAMPLE 17.1

A second hand transmitter purchased to meet a point-to-point communication need was estimated to have a life of 5 years and at the end of that period to have a nil residual value after dismantling costs had been considered. Thus it was necessary to replace the installed cost of the transmitter, in this case £3000, at the end of the 5 year period and also pay interest on the loan required to purchase and install the unit.

Twelve months after placing the equipment in operation, it was found that the removal and re-installation had had a serious affect on the performance. The old wiring had broken away at many points, insulation on wiring which had hardened over the years had cracked and broken away, and a considerable amount of dust had entered control circuit relay sets during road transport to the new site. The maintenance and operating costs were greatly in excess of the estimates. An economic study was required to determine whether to continue with the existing installation or to invest in a new transmitter estimated to cost £6500 installed. Because of the poor condition of the existing installation, it was estimated that the residual value would still be zero even after only one years' service. The estimated residual value of a new transmitter after 5 years was estimated to be £3500. Applicable interest rate was 5%.

Existing Transmitter

(a)	Annual material maintenance costs based on expenses of previous year	= £ 900
(b)	Annual operating costs	
	(i) Power 6 kW at 4p per kWh continuously	= £ 2 102
	(ii) Labour for maintenance and operations, 2000 hours at £4.50 per hour excluding administration and overheads	= £ 9 000
(c)	Incidental costs, associated with external dummy load	= £ 23
	Annual cost	= £12 025

New Transmitter

(a)	Installed cost of transmitter = £6500	
(b)	Estimated residual value after 5 years service = £3500	
(c)	Capital recovery payments (£6500 – £3500) x 0.23097	= £ 693
(d)	Interest payment on residual value £3500 x 5%	= £ 175
(e)	Estimated annual material maintenance costs including tubes	= £ 525
(f)	Annual operating costs	
	(i) Power 5 kW at 4p per kWh continuously	= £ 1752
	(ii) Labour for maintenance and operations, 800 hours at £4.50 per hour excluding administration and overhead	= £ 3600
(g)	Incidental costs associated with internal dummy load	= £ 13
	Annual cost	= £ 6758

The study showed that it was more economical to invest in the new transmitter although this involved incurring a large debt and continuing to pay off the orginal one. The repayments on the original investment will have to be met whether the existing transmitter is used or not. To consider the repayments in the study would mean adding them to both calculations and this would not in any way change the cost differences. The original transaction is a sunk cost. The reasons that warranted the original transaction have changed.

In replacement studies the time involved is the future, which is unrelated to the past. In some instances the past history of equipment or plant performance is valuable in estimating future costs, but any costs included in the past have no effect on the present turn-in value of the existing facility. Its book value and present value would be the same only under the extremely rare condition that the equipment depreciated in exactly the same manner predicted when it was installed, employing the same value for money. Thus any annual capital recovery calculation made at the time of the original installation is discarded.

LIFE OF EQUIPMENT OR PLANT

This period is usually the anticipated average life of the equipment or plant. It is sometimes called the economic life of the plant and is a current estimate of the period over which the plant will be needed to provide potential or actual service, including any period between installation and utilisation. The life may be spent in more than one location and extends from initial installation to final retirement.

In many new cases the life may be defined by the conditions of the problem. For example, a study may call for installation of a thin-line microwave radio relay system to feed a television transmitter one hundred and fifty kilometres away pending the provision of a permanent system to be installed five years later to provide for both telephony circuits and the television channel. Obviously the study must provide that capital invested in the installation, engineering and in any material not expected to be reused in the permanent installation or another location, will be repaid in five years.

It is quite impracticable to predict the economic life period of a particular piece of equipment based on a formula. For example, the fact that a well engineered steel pole open wire transmission line deteriorates very little with time does not preclude the possibility of an early decision to replace it with a coaxial transmission line because of, say, a particularly bad problem of cobwebs and heavy dew in a humid forest area. Similarly like-for-like equipment can be displaced by sudden obsolescence prior to the optimum life established by its

Table 17.1 AVERAGE SERVICE LIFE OF RADIO EQUIPMENT AND PLANT

Item	*Average service life* (yrs)	*Item*	*Average service life* (yrs)
Amplifiers		Antennas	
(i) Tube type	15	(i) M.f. mast and towers	40
(ii) Transistor type	25	(ii) H.f. wire type	18
		(iii) H.f. rotatable	18
Radio relay equipment			
(i) Tube type	15	Base station, 500 W	15
(ii) Solid state type	25	Mobile transceivers	
		(i) Tube type	10
		(ii) Solid state type	15
Channelling equipment, solid state	25	Transmitters	
Meters	18	(i) 500 W m.f.	18
Tape recorders	10	(ii) 500 W h.f.	15
Programme input equipment	25	(iii) 2000 W m.f.	20
Transformers, oil filled	25	(iv) 2000 W h.f.	18
Accumulators, 500 Ah.	12	(v) 10 000 W m.f.	25
Teletype-transmitter control	15	(vi) 10 000 W h.f.	22
Control desks	20	(vii) 50 000 W m.f.	25
Portable test equipment	15	(viii) 50 000 W h.f.	22
Fixed test equipment	20	(ix) 250 000 W m.f.	25
Tools		(x) 250 000 W h.f.	22
(i) Hand	10	Antenna coupling units 10–250 kW	20
(ii) Portable elec.	12	Earth mats	35
Receivers, m.f.–h.f.	20	Diesel engine generating plant	
Transmission lines		(i) Charge/discharge	20
(i) High power		(ii) Emergency 200 kVA	20
Open wire	30	Wind driven generators	12
Coaxial above ground	35	Woodpoles-pressure treated	30
Coaxial buried	30	Buried lead covered control cables	20
(ii) Receiving		Buried galvanised iron ducts	25
Open wire	20	Buildings	
Coaxial buried	25	(i) Brick	75
Mechanical aids	12	(ii) Shelter types	35
		Air conditioner	
		(i) Package	12
		(ii) Fixed plant	20

deterioration gradient. A tube type radio relay system can be displaced before the date necessitated by its increased operating costs, when high reliability, low operating cost solid state equipment becomes available. Also, the life of some items may depend on the life of other items, for instance the life of a solid dielectric coaxial cable system may be limited by its voltage handling capability. The applied voltage may be increased beyond the safe limit due to an increase in the station transmitter power.

Table 17.1 lists some items of equipment and plant used in radio engineering together with typical economic lives. In particular cases equipment or plant may wear more rapidly than normal or may have to be abandoned prematurely for any number of reasons. Also, some comparisons may involve special plant with designed lives to suit particular circumstances, for instance to cater for a high isoceraunic environment. In these cases and also in cases involving plant not listed in the Table, the planned economic life should be assessed, and adopted as the life for use in economic comparison studies.

The economic life should be distinguished from the physical life of the equipment or plant. The physical life may exceed the estimate of economic life and relates to a capability to provide a service. On the other hand, the economic life is over when it is no longer required for serving its designed purpose. This may arise because the plant has been superseded, for example tube type portable radio receiver sets, or has become technologically obsolete, for example manually controlled filament transformers for transmitting tubes. The concept of economic life embraces a consideration of the physical life of the equipment or plant and the above modifying factors. The termination of economic life signals replacement but not necessarily disposal of the equipment.

OPTIMAL REPLACEMENT AGE

In the operation of practically any asset, the nature of which involves expenditure on the maintenance and operation through its life, the costs will as a general rule increase as the life of the asset increases. It is frequently desirable to know at the time that new equipment or plant is being commissioned, just how long it should be kept operational before being replaced, in order to achieve maximum economy. An assessment of the appropriate time to replace the equipment or plant with one performing similar duties can be made if the relevant information concerning operating costs and the residual value can be estimated.

In making this study three assumptions must be made:

(a) The equipment or plant is replaced by an item approximately identical with the original type.
(b) The same standard of maintenance to ensure dependability, and that proper operation is maintained throughout its life.
(c) Standards of operating conditions are established.

EXAMPLE 17.2

To illustrate the point, a study is to be made to determine at what age an item of radio equipment should be replaced to obtain the most economical annual cost. For simplicity, the operation, maintenance and replacement costs have been grouped as one cost which is assumed to increase with time. The realisable value is reduced with age which means that some loss is sustained by deferring the retirement of the equipment from service.

The capital installed cost of the equipment is £12 000 and because of the severe environmental conditions, it is estimated to have a physical life of 12 years. The annual maintenance costs and changing realisable values over this 12 year period are shown in *Table 17.2.*

Table 17.2 ANNUAL MAINTENANCE COSTS AND REALISABLE VALUE

Year	*Annual maintenance costs* (£)	*Realisable value at end of year* (£)
1	280	9000
2	375	7000
3	450	5000
4	550	4000
5	750	3000
6	1000	2500
7	1500	2200
8	2200	2000
9	3000	1500
10	4000	1000
11	4500	500
12	5000	Nil

In order to compare the annual costs necessary to retain the equipment in operation for the various ages of its life, the expenditure for maintenance and the reduction in realisable value are converted to a present worth at the beginning of the installation period. The resultant present worths can then be reconverted to an equivalent uniform annual payment over the various ages by using the capital recovery factor. The results are shown in *Table 17.3.*

With an interest rate of 5% the study shows that the least annual cost of maintaining the equipment is when it has a life between 7 and 8 years. The equivalent uniform annual payments may be plotted in graph form for simplicity and *Figure 17.1* represents the results of *Table 17.3*. However it should be noted that the age of minimum annual charge is not necessarily the economic life of the equipment after which it should be replaced. What it does indicate is that this will be the minimum annual charge in the life of new equipment and this can be used for comparison with the cost of maintaining existing equipment in service.

RE-USE OF EQUIPMENT OR PLANT

Radio equipment and plant may be replaced for several reasons. In some cases, for example in increasing the power of a broadcast station, it may be desirable to buy new equipment rather than redesign and build-up the existing installation, even though the equipment may be capable of providing many more years of useful service. This applies particularly where transmitters, receivers and engine-generators have been provided for standby purposes and often receive comparatively little use over a long period. They would not be as efficient as modern units because of technological improvements.

Table 17.3 CALCULATION OF EQUIVALENT UNIFORM ANNUAL CHARGE

Year n	*Payments in year n*	*P.W. factor 5%*	*P.W. of payments in nth year*	*P.W. of all payments for n years*	*Residual value after n years*	*P.W. of residual value*	*P.W. of expenditure*	*Capital recovery factor*	*Equivalent uniform annual charge*
0	12 000	1.0000	12 000						
1	280	0.9524	267	12 267	9000	8572	3695	1.05000	3880
2	375	0.9070	340	12 607	7000	6349	6258	0.53780	3366
3	450	0.8638	389	12 996	5000	4319	8677	0.36721	3186
4	550	0.8227	452	13 448	4000	3291	10 157	0.28201	2864
5	750	0.7835	588	14 036	3000	2351	11 685	0.23097	2699
6	1000	0.7462	746	14 782	2500	1866	12 916	0.19702	2545
7	1500	0.7107	1066	15 848	2200	1564	14 284	0.17282	2469
8	2200	0.6768	1489	17 337	2000	1354	15 983	0.15472	2473
9	3000	0.6446	1934	19 271	1500	967	18 304	0.14069	2575
10	4000	0.6139	2456	21 727	1000	614	21 113	0.12950	2734
11	4500	0.5847	2631	24 358	500	292	24 066	0.12039	2897
12	5000	0.5568	2784	27 142	Nil	Nil	27 142	0.11283	3062

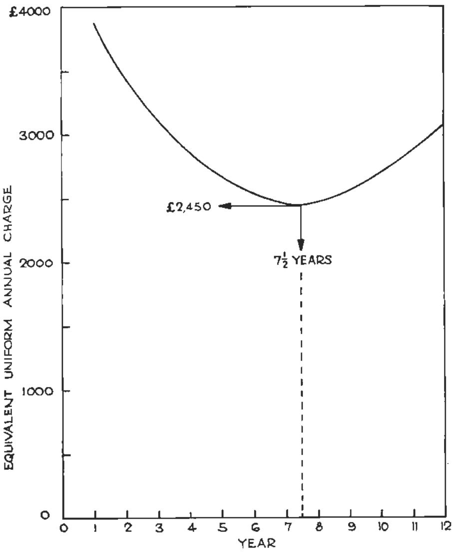

Figure 17.1 Optimal replacement age

The main point to be taken into account when considering the re-use of equipment or plant at another project situation is that the alternative which involves the replacement, bears the cost of:

(a) Recovery of the equipment or plant. The recovery cost is likely to be greater if re-use is contemplated and it is carefully taken out, instead of being ripped out for scrap.
(b) Transportation to workshops for overhaul or to the new site for re-installation.
(c) Overhaul.
(d) Installation and setting to work at the new site.
(e) Storage charges pending re-use.

At the same time the alternative scheme must be given credit for the materials being re-used. The credit is assessed as the cost of an installation which would be involved in providing the same service at the new site. This credit value minus the cost of recovery, transportation, overhaul, storage and re-installation is equivalent to the second hand value of the equipment or plant being replaced and is a net credit to the replacement scheme. It can also be considered as a debit to the retention scheme.

In an economic comparison study to determine whether to retain the existing installation or sell it at its second hand value, the procedure is the same as comparing whether or not to buy some similar equipment at its second hand price. Capital recovery charges are debited against the installation based on the second hand price and taken over a period equivalent to the remaining economic life. The difference, financially, will be the same whether the installation is retained and no new expenditure is incurred or is disposed of at its second hand price and cash is received or again, whether new equipment is not purchased, with no expenditure being incurred or the equipment is bought at its second hand price, when expenditure is incurred. In both cases either the installation is held or the cash, but not both. This is illustrated in an example of a study made to determine whether to replace or scrap part of an existing radio transmitting station installation.

EXAMPLE 17.2

The first scheme involved alteration to the existing installation to allow for remote control and monitoring at a cost of £5000, and the provision of additional power supply equipment to cater for increase in power output, at a cost of £10 000. The station equipment was to be completely overhauled concurrently with the upgrading and was expected to have an economic life of 20 years. Total annual maintenance and operating costs were estimated to be £9000, including mains power consumption costs.

The second scheme involved the recovery of the existing installation and replacement with a new type of equipment which would provide for all necessary requirements. The cost of the new equipment, installed and set to work was estimated at £45 000 and the annual maintenance and operating charges at £7500. The cost of recovery, transport and disposal of the old installation was estimated to just cover the value as scrap.

The annual charges of the two schemes at 5% interest rate were calculated as follows:

Retention Scheme

(a) Capital recovery cost (£5000 + £10 000) × 0.08024 = £ 1204
(b) Annual maintenance and operating costs of upgraded installation = £ 9000
Total annual cost = £10 204

Replacement Scheme

(a) Capital recovery cost (£45 000 × 0.08024) = £ 3611
(b) Annual maintenance and operating costs of new installation = £ 7500
Total annual cost = £11 111

From an economic point, the first scheme is the more attractive because the cost difference in annual charges is £907 less.

The existing installation was however of a type which could be economically used at another station which was being expanded at the time. When this aspect was taken into account the costs involved in the replacement schemes were shown to be:

(a) Careful recovery of the equipment to minimise damage = £ 300
(b) Crating and package of materials = £ 100

(c)	Transport to workshop for overhaul and later transport to the new site	= £ 100
(d)	Overhaul cost, including new components for frequency change etc.	= £1200
(e)	Installation costs at new site	= £2100
(f)	Incidental costs	= £ 200
	Total annual cost	= £4000

The inclusive capital cost for providing an identical new installation at the new site was estimated to be £18 000. The net residual value of the replaced equipment was therefore £18 000 – £4000 = £14 000. The study then showed:

Retention Scheme

(a)	Capital recovery on upgrading existing installation to meet new requirements (£5000 + £10 000) x 0.08024	= £ 1204
(b)	Capital recovery on the residual value of the equipment (£18 000 – £4000) x 0.08024	= £ 1123
(c)	Annual maintenance and operating costs of upgraded installation	= £ 9000
	Total annual cost	= £11 327

Replacement Scheme

(a)	Capital recovery cost (£45 000 x 0.08024)	= £ 3611
(b)	Annual maintenance and operating costs of new installation	= £ 7500
	Total annual cost	= £11 111

The replacement scheme was therefore the more economical by £216 per annum. The capital recovery charges on the residual value of the equipment in the retention scheme are considered an annual charge on the non-realisation of the second hand value.

In studies where the remaining life of the installation being considered for replacement is less than the life of the replacing installation, the study is generally carried out on a present worth basis over the remaining life of the installation being considered for replacement.

The possibility of re-use of equipment or plant for installation elsewhere depends not only on the physical and electrical condition of the installation, but also whether there will in fact be a use for it at the end of its period of requirement at its present location. The engineer must keep in mind in any study with re-use under consideration, that a more desirable alternative may become available by the time the re-installation has to take place.

FURTHER READING

CALABRO, S., *Reliability Principles and Practices*, McGraw-Hill, New York, 1962

STEINBERG, M. J. and GLENDINNING, W., *Engineering Economics and Practice*, W. Glendinning, New York, 1949

THUESEN, H. G., *Engineering Economy*, Prentice-Hall, Englewood Cliffs, N.J., 1957

Chapter 18

Depreciation

VALUE DEPRECIATION

The present value of equipment or plant is in general less than the original cost, and radio facilities are no exception. This decrease in value is due to a number of causes, among which are deterioration due to exposure, use, obsolescence or the introduction of more efficient types of equipment and plant to provide the same service. Technological development may be such that new equipment, a duplicate of the old, can be produced at a lower cost and operate at a higher efficiency. It is normal practice to counterbalance this depreciation in value by setting up a depreciation account. An adequate part of the total capital expiry must be assumed to have taken place each year of the useful life of the facility and this must be made good or paid for as an essential operation or overhead expense before the results of working can be declared. Prudence naturally demands that some yearly provision be made for depreciation but whether made or not the cost has been incurred and sooner or later must be reckoned with.

The initial capital cost of an item or facility can be considered as payment in advance for the service it provides. As an example, the purchase of a broadcast transmitter is part of the payment for so many hours of transmission. However, land and access roads required for the establishment of stations are assumed to be imperishable and no depreciation cost is incurred. The annual cost of using the capital involved consists of the interest payments only and no charge is made for replacing the capital.

The payments to the depreciation account are such that the cumulative total over a period equal to the average life of the installation, after due allowance has been made for its residual value, amount to the initial cost. This account plus the residual value would normally be used to pay for renewal of the installation, assuming on the average that materials, labour and incidental costs are constant. Depreciation provision is a component of operational costs, not an allocation of surplus. It cannot be taken away from profits, because until it has been provided no profits can be said to exist. This interpretation of depreciation is in line with that of the accountant who aims at returning the original capital outlay to the investor on withdrawal of the installation from operation or service.

In practice, the situation is usually complicated by the replacement consisting either of a different size or type, or else of an installation provided at a different price level. The former variation, if it can be foreseen, need not affect the depreciation provision made for the initial installation. If the replacement is bigger, its extra cost can legitimately be covered by an increased borrowing on capital, coupled with the institution of large depreciation provision on the new purchase. The variation due to price level, however, is a much more difficult problem and is discussed subsequently.

Generally, in engineering, depreciation is not calculated by endeavouring to determine a value of the installation at the end of each year and then deducting this amount from that determined at the end of the previous year. It can be calculated in several formalised ways, so that the procedure is one of allocation rather than valuation. The engineer in making an economic study deals with the same phenomena as the accountant in depreciation accounting, but whereas the accountant deals with broad average situations, peculiar to existing installations and to current periods, the engineer is concerned with more specific situations involving, in the main, future periods. The engineer is interested in those factors which are susceptible to future control, while the accountant is interested in total costs.

The rate at which deterioration takes place will vary with different installations and plant and can best be assessed in the light of experience. On account of this difference in the rate of deterioration, there have arisen several different methods of computing depreciation. Which method to use in any given instance or situation can best be determined by experience and is a matter for the engineer to decide.

STRAIGHT LINE DEPRECIATION

This method of depreciation which is the most popular method of unit accounting is sometimes alternatively known as the fixed instalment method.

The straight line formula, as its name implies, assumes that the depreciation each year is the same amount. The value falls in a straight line from its initial cost at the beginning of its economic life to the estimated salvage value at the end. The amount of depreciation in any one year can be expressed as follows:

$$\text{Straight Line Depreciation} = \frac{\text{initial cost} - \text{estimated salvage value}}{\text{estimated life (years)}}$$

The rate of depreciation is

$$\frac{100}{\text{estimated life (years)}} \text{ per cent per annum}$$

the rate in this case being expressed per cent of the wearing value.

An antenna switching matrix costing initially £200 000 to install and with a salvage value of £2000 after 25 years service would have a depreciation of

$$\frac{£200\,000 - £2000}{25} = £7\,920 \text{ per annum}$$

as calculated by the straight line depreciation method.

If the salvage value is estimated to be zero, the straight line depreciation would be £200 000/25 = £8000 per annum.

Instead of a time base, a service base may be used, so that the depreciation can be charged as so much per unit of service. As an example, if a transmitter is estimated to work for 150 000 hours during its useful life, after which it will be scrapped, and its service life is estimated to be 25 years, sufficient information is available to be able to calculate the depreciation in terms of transmitter hours.

The advantages of the straight line method of depreciation are:

(a) It is simple and calculations are straight forward.
(b) The depreciation instalments completely write off the initial capital cost over the estimated life period of the facility.

The disadvantages are:

(a) It makes no allowance for the interest on the depreciation fund.
(b) It does not balance the inequality of operating and maintenance charges which tend to increase with time.

FIXED PERCENTAGE DEPRECIATION

In this method, a fixed percentage of the remaining capital (book value) from the preceding year may be computed for each year. The percentage may be 10, 20 or other value, and always leaves a final value in the last year which may be considered as salvage value.

If the fixed percentage depreciation method is applied to the previous example at the rate of 10%, the depreciation in the first year amounts to: 10% × £200 000 = £20 000. In the second year the depreciation charge would be: 10% × (£200 000 − £20 000) = £18 000. In the third year the depreciation would be 10% × £162 000 = £16 200 and so on until the 25th year.

This method represents more accurately the actual value of many installations. Many types of radio plant, particularly mechanical aids, depreciate much more readily in their first years of life than later, and even after they have reached the end of their useful life they may, if adequately maintained, continue to give service for several years.

The main disadvantages of this method are:

(a) No allowance is made for interest on the depreciation fund.
(b) Because the charge varies from year to year, it introduces problems where price-fixing is involved.
(c) It cannot be used with an asset which has zero salvage value at the end of its estimated life.

Its main advantage is that it ensures that the depreciation which is written off in the early years of the life of the asset is at a high rate, thus offsetting the fact that it is most likely that the maintenance and operation charges will be at a low value during the early part of the life.

SINKING FUND DEPRECIATION

In this method equal annual instalments are assumed to be invested and to earn interest, so that at the time of retirement the paid-off principal plus accrued compound interest equals the value of the installation. The payments are assumed to be made into a special fund, called a sinking fund.

The amount which is charged to the depreciation reserve consists of this sinking fund payment together with the added interest on the accumulated sinking fund and the book value of the installation at any time is taken to be the initial capital installation value less the amount accumulated in the sinking fund. It is to be noted that the interest is on the sinking fund accumulation and not on the original capital.

The annual instalments are lower than the straight line method but when the effect of interest on capital is considered the overall result is the same. This is because, with the straight line method, the outstanding capital on which interest is payable is steadily reduced whereas with the sinking fund method the whole of the original capital is charged with interest until the installation is retired. Another point is that the sum of the annual charges which are the annual sinking fund deposits, plus interest on all previous deposits, together with the interest on the undepreciated value, is constant with the sinking fund method.

If the sinking fund depreciation method is applied to the antenna switching matrix example at an interest rate of 10%, then the uniform end-of-the-year payment into the sinking fund will, for a Sinking Fund Factor of 0.01017 be:

$$(£200\,000 - £2\,000) \times 0.01017 = £2\,013 \text{ per annum.}$$

The uniform end-of-year payment will be the payment into the sinking fund for the first year. In following years however the amount to be depreciated will increase because of the interest which is added. In the above example, the 10% interest will increase the payment in the second year to £2214.

The advantage of the sinking fund method of depreciation is that it is based on sound principles of compounding or discounting.

The disadvantages are:

(a) The depreciation fund does not grow rapidly enough in the first few years and consequently there could be a loss in the event of the installation being prematurely retired.

(b) The alleged intricasy and the need for accurate accounting.

ANNUITY METHOD

In this method, an equal amount is set aside each year for the service life of the installation and accumulated to the end of the period. If the present value of the sums set aside is equal to the cost of the installation, then the accumulated amount at the end of *n* years of the sums set aside is equal to the accumulated amount of the cost of the installation. Thus, at the end of the service life there is more than enough to replace the installation at the original cost. There is in addition, the compound interest on the original cost for *n* years. Thus, the annual payment is the same as that into a sinking fund which is to be used to extinguish the debt due at the end of the service life with interest.

The difference between the annual payments in the sinking fund method and the annuity method is simply the annual interest on the original cost. Whether the installation does or does not have a scrap value at the end of its service life, it can be shown that the difference in the annual payment is the annual interest on the original cost.

This method of depreciation rests upon the assumption that the cost of operation depends in part upon interest on the capital invested in the installation. On this assumption depreciation is a constant annual charge sufficient to cover both the decrease in value of the installation and interest on the declining value. For if the money was not invested in the installation it could be profitably invested in securities etc.

SUM-OF-THE-YEAR'S DIGITS METHOD

There is some similarity to the fixed percentage technique with this method but the principal reason for its retention is because the computations are more quickly made.

An illustration will suffice to make this method clear. From the matrix switch example at the beginning, the years of life of the switch are 25. At the end of the first year, the years of life are 24 and so on. Now

$$25 + 24 + 23 + 22 \ldots + 4 + 3 + 2 + 1 = 352$$

This number 352 is said to be the sum of the years of life and is the base number. The depreciation at the end of the first year is assumed to be 25/325 of the total depreciation of (£200 000 – £2 000). The depreciation at the end of the second year is assumed to be 24/325 of the total depreciation and so on.

Of the five methods of depreciation accounting discussed, the straight line method and the sinking fund method are the methods most frequently encountered in practice in computing depreciation for radio engineering installations. In neither case is interest on the original cost considered in building up a replacement fund. In the straight line method, no interest is computed on the annual payments into the replacement fund. In the sinking fund method, interest is computed on the annual payment into the replacement fund. Thus the constant annual payment by the sinking fund method is less than by the straight line method.

A factor frequently used and of special significance in engineering economic studies is the uniform series capital recovery factor. It consists of the sinking fund factor plus the interest rate on the capital. When the capital investment is multiplied by the factor, it gives the uniform annual payments over *n* periods of time which are required to recover the capital investment and the interest to be paid on it. The factor can be easily calculated from tables of single payment compound amount factors. When the residual value of the installation is zero the capital recovery factor which includes the interest payments can be applied directly. If the installation suffered no loss in value during its life, and its residual value was the same as the original cost, the annual cost of using the capital would consist of interest charges only. No charge would be made for replacement of the capital. This applies particularly to the land required for station installations.

TYPICAL DEPRECIATION EXAMPLES

The following examples are typical of the studies carried out in connection with depreciation of the various types of radio equipment and plant.

EXAMPLE 18.1

Two transmitters of different manufacture, efficiency and physical size, but providing the same type of service are to put into service on a point-to-point link on a continuous operating basis. They are to be installed in a rented building at a charge of £1.00 per square metre of floor area and because of a particularly severe environment are expected to have a life of only 10 years on site.

Details of the two units are as follows:

Transmitter No. 1

(a) Capital cost installed = £5000
(b) Area occupied, including area for stores = 200 m^2
(c) Operating and maintenance costs, including overhead and power = £5256 per annum
(d) Salvage value = £1600

Transmitter No. 2

(a) Capital cost installed = £3500
(b) Area occupied, including area for stores = 391 m^2
(c) Operating and maintenance costs, including overhead and power = £5100 per annum
(d) Salvage value = £600

On the basis of 5% interest rate and the straight line depreciation method it is desired to determine at what operating time per annum the two transmitters will cost the same amount.

Transmitter No. 1

(a) Annual interest charge £5000 × 0.05 = £250
(b) Annual depreciation, neglecting interest on deposit (£5000 – £1600)/10 = £340
(c) Annual rental for building space = £200
Total = £790

Transmitter No. 2

(a) Annual interest charge £35000 × 0.05 = £175
(b) Annual depreciation, neglecting interest on deposit (£3500 – £600)/10 = £290

(c) Annual rental for building space = £391
Total = £856

Annual difference in these costs is £856 – £790 = £66.

On the basis of continuous operation, (i.e. 365 × 24 = 8760 hours per year) the operating costs are:

Transmitter No. 2

$$\frac{5100 \times 100}{8760} \text{ p per hour} = 58.2 \text{ p per hour}$$

Transmitter No. 1

$$\frac{5256 \times 100}{8760} \text{ p per hour} \qquad = 60 \text{ p per hour}$$

The difference in operating costs is therefore:

$$(60 - 58.2) \text{ p} \qquad = 1.8 \text{ p per hour}$$

To cover the annual cost difference the required operating time is:

$$= \frac{66 \times 100}{1.8} \text{ hours}$$

$$= 3667 \text{ hours}$$
$$= 153 \text{ days}$$

EXAMPLE 18.2

For equipment such as a single channel v.h.f. radio telephone system which is often installed on a short term basis in more than one situation, to meet an immediate communication need pending major cable relief, it is necessary to consider the cost of more than one installation and recovery.

A v.h.f. single channel system comprising two terminals, is estimated to have an average life of six years in any one situation and an economic life of 18 years. This would mean installation and recovery three times during its economic life. The costs involved in each case are estimated to be:

(a) Equipment cost, including radio equipment, antennas and towers for two terminals = £7000
(b) Installations, including tower foundations and commissioning both terminals = £5000
(c) Transport costs = £ 150
(d) Administration and overhead charges = £1450
Total installation cost = £13600

(e) Recovery, including making good any damage = £ 400
(f) Installation at another site, including new foundations for towers = £5000
(g) Transport costs = £ 150
(h) Administration and overhead charges = £1450
Total installation cost = £7000

(i) Scrap value of materials after 18 years service = £ 350
(j) Charges associated with recovery, including administration, overhead and transport = £ 350
Residual value at end of economic life = Nil

With an average life of 6 years at each situation, three installations are involved.

First Installation

Residual value = Original cost – recovery and reinstallation costs
= £13 600 – £7000
= £ 6 600

$$\text{Percentage residual value} = \frac{6\,600}{13\,600} \times 100$$

$$= 48.53\%$$

Second Installation

Equipment and plant which during their complete service life are issued and returned to store are generally accounted for at their first cost until finally retired and scrapped.

Hence residual value and the percentage residual value for the second installation will be the same as the first, under normal conditions.

Third Installation

As the equipment and plant are scrapped after the third installation the residual value after recovery and disposal will be nil.

For depreciation purposes based on the life of one installation, it is necessary to assess an average residual value of one installation based on an assessed residual value at each recovery. As the residual value at the end of the final installation is nil:

$$\text{Average residual value} = \frac{48.53 + 48.53 + 0}{3}\%$$

$$= 32.35\%$$

If we assume a straight line method of depreciation the percentage depreciation rate is:

$$= \frac{(100 - 32.35)}{6}\%$$

In this case = 11.28 per cent of £13 600 = £1534.

It is a relatively simple matter to show that this method provides for ample payments to the depreciation reserve.

The total capital outlay during the 18 years of service by the system
= £13 600 + £7000 + £7000
= £27 600

and the payments to the depreciation reserve = 18 × £1534 = £27 612.

EXAMPLE 18.3

The following example illustrates the application of straight line and sinking fund methods of depreciation for a typical 50 kW medium frequency broadcast station with an anti-fading radiator.

The transmitting station cost £860 000 to establish. The transmitter building cost £400 000 and a combined standby power/workshop building £150 000. Radio equipment inside the buildings and including power plant cost £200 000 and external plant including the antenna cost £110 000.

The building was estimated to have an economic life of 60 years after which the salvage value would be nil, while the estimated life of the radio installation was 25 years with a salvage value of £12 000.

With an interest rate of 5%, it is desired to ascertain the total annual depreciation charges in the 7th year after commissioning of the station, and also the book values.

(a) *Straight line method*

(i) Transmitter building = £400 000
(ii) Power and workshop building = £150 000
Total = £550 000

(iii) Annual depreciation charge for buildings

$$= \frac{550\,000}{60} = £9166$$

(iv) Radio internal equipment = £200 000
(v) Radio external plant = £110 000
Total = £310 000

(vi) Annual depreciation charge for technical facilities

$$= \frac{(£310\,000 - £12\,000)}{25} = £11\,920$$

Total annual depreciation charge
£9166 + £11 920 = £21 086

The book value of the installation after a period of 7 years is £550 000 + £310 000 − 7(£21 086) = £712 398.

(b) *Sinking Fund Method*

(i) Buildings, 60 year life
Depreciation in first year = £550 000 × 0.00282 = £1551.
The amount to be charged to the fund in the 7th year
= £1551 (8.142 − 6.801) = £1551 × 1.341 = £2080.
(ii) Radio installation, 25 year life
Depreciation in 1st year = £298 000 × 0.02095 = £6243.
The amount to be charged to the fund in the 7th year
= £6243 (8.142 − 6.801) = £6243 × 1.341 = £8372.
(iii) Total depreciation in the 7th year = £2080 + £8372 = £10 452
(iv) The book value of the two station buildings after 7 years
= £550 000 − (£1551 × 8.142) = £550 000 − £12 628 = £537 372.

The book value of the radio installation after 7 years
= £310 000 – (£6243 × 8.142) = £310 000 – £50 830 = £259 170.
Hence the total book value of the installation after a period of 7 years is
= £537 372 + £259 170 = £796 542.

EXAMPLE 18.4

The following example illustrates the application of the fixed percentage depreciation method. It should be noted that this method cannot be used where an installation has zero salvage value at the end of its estimated life.

A h.f. transceiver was to be fitted to a trawler as part of a prawning venture at a total installed cost of £2200. Because of previous experience with radio equipment operating under similar environmental conditions, it was estimated that the unit would be scrapped after 5 years and realise £110.

Since the depreciation under this method is a fixed percentage k of the value at the beginning of the year.

$$\begin{aligned} k &= 1 - \sqrt[5]{\frac{110}{2200}} \\ &= 1 - \sqrt[5]{0.05} \\ &= 1 - 0.54928 \\ &= 0.4507 = 45.07\% \end{aligned}$$

The following lists for each year the depreciation and the value at the end of each year of the transceiver.

Year	*45.07% of* (£)	*Depreciation* (£)	*Value at end of year* (£)
0	–	–	2200
1	2200	991	1209
2	1209	545	664
3	664	229	365
4	365	165	200
5	200	90	110

An important point about this method of depreciation is the sudden drop in valuation during the first years of use of the transceiver.

Although the service life assessment is needed, an inaccurate value does not seriously affect the correctness of the accounting since the balance diminishes relatively slowly in the latter years, and the annual contribution is small.

EXAMPLE 18.5

Many radio installations consist of several different items of equipment and plant. These items often have different initial costs, different scrap values and have different service lives.

The vapour phase cooling system of a high power transmitter is a typical example as it consists of the following major items:

Item	*Cost* (£)	*Scrap Value* (£)	*Life (years)*
Heat exchanger and piping	12 000	0	25
Fan and motor	400	50	15
Deionizer unit	200	20	10

The engineer was required to determine the total annual depreciation and the composite life of this installation on a 5% basis.

Obviously, the total annual depreciation charge for such a unit is the sum of the annual depreciation charges for the several parts.

The total annual depreciation is equal to:

$$D = \frac{12\,000}{CAF(25)} + \frac{350}{CAF(15)} + \frac{180}{CAF(10)}$$

$$= \frac{12\,000}{47.727} + \frac{350}{21.579} + \frac{180}{12.578}$$

$$= £251.4 + £16.2 + £14.3$$

Hence total annual depreciation charge = £281.9
The wearing value is £12 000 + £350 + £180 = £12 530
and the composite life is

$$= \frac{\log\left(1 + \frac{12\,530}{281.9} \times 0.05\right)}{\log 1.05} \text{ years}$$

$$= \frac{\log 2.2}{\log 1.05} = \frac{0.3424}{0.0212}$$

$$= 16.1 \text{ years}$$

It is of interest in this particular example that a life of 25 years was assumed for the heat exchanger at the time that the study was conducted. However in the actual field installation where three units were installed all three were replaced after only 5 years service due to severe corrosion problems experienced with the copper cooling fins of the radiator elements. Fins on the heat exchanger of the station air conditioning system were similarly corroded.

FURTHER READING

MARSTON, A. R., WINFREY, R. and HEMSTEAD, J. C., *Engineering Valuation and Depreciation*, McGraw-Hill, New York, 1953

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Chapter 19

Cost Comparison Studies

The aim of cost comparison studies is to determine which of several alternatives, providing approximately the same facilities has the least cost expressed as the present worth of all associated expenditure and to show the difference between the alternatives.

There are many factors involved in a cost comparison and for the specific system all must be considered. In the case of a communication system between two points, for example, they may include:

(a) The first cost of the installation of all associated communication equipment required for the system, and not just the cost of the radio bearer.
(b) The first costs of all the support facilities including buildings, site, access roads, fencing, drainage, fuel storage, power etc.
(c) The various alternative types of systems which could provide the desired communication needs. These may include high frequency, line-of-sight microwave relay, tropospheric scatter, satellite, submarine or telephone cable systems.
(d) The annual maintenance and operation charges including wages and salaries for personnel, power, fuel, annual inspections, spare parts, transportation, administration, overhead expenses, taxes etc.
(e) The needs for ensuring the security of the system such as fire protection, vandalism, environmental conditions (high winds etc.), susceptibility to jamming or other forms of electrical interference etc.
(f) Traffic studies to assess circuit requirements for future years in order to determine capacity and the expected revenue from the installation.

It is necessary to compare the alternatives over a period sufficiently long to reveal the cost adequately, but not too long, because the reliability of forecasts decreases with the length of the period covered. The length of the period chosen will depend on the nature of the scheme, but normally for radio engineering purposes would seldom exceed 20 years.

The studies are concerned with relative costs and in the interests of simplicity costs common to all alternatives are ignored. The comparison therefore does not establish the total cost of any plan nor does it reveal the profitability or otherwise of a project. The costs take into account all the payments which must be made at various times over the study period in acquiring equipment and plant, in installing and maintaining it in service, and in obtaining the facilities which the plant is designed to supply.

In addition to comparing costs of alternative systems, cost studies allow the engineer to determine the relative cost of each major element of the project. Broadcast station estimates, for example, include the costs of transmitters, programme input equipment, test equipment, antenna, transmission lines, matching equipment, power supply, programme lines, maintenance spares and other equipment, and their installation. It also includes the cost of purchasing the site, construction of buildings, access roads and connection to the power mains. This sort of general perspective is valuable in focusing attention on the relative importance of the various parts of the project and showing where effort at reducing costs will be the most rewarding, if the project is successful.

The cost of a plan can be divided into four basic sections: Capital Cost; Maintenance Cost; Operating Cost; Retirement Cost.

Subject to some reservations, they constitute the cost of a plan and form the basic material on which present worth studies are based. Payments which took place before the beginning of the study period are not considered as part of the cost of a plan. They are sunk costs and remain unaffected by any later decision.

The following selected examples are typical of economic comparison studies carried out in radio engineering practice. Costs used are not necessarily in line with present day values but are used simply to illustrate the method of working the problem.

EXAMPLE 19.1

Broadband Radio Relay System and Coaxial Cable

A communication system was to be provided between two centres to give initially 1200 channels for telephony plus a television circuit. The centres were 1600 km apart with two intermediate major stations. Commercial power was available only at the terminals and the two intermediate stations. An economic comparison was to be made between a broadband system and a 2 tube coaxial cable system. A 4 tube coaxial cable was also to be taken into reckoning in consideration of possible heavy future demand.

The following points are relevant:

(a) Multiplex equipment was regarded as being approximately equivalent for each solution and was not taken into consideration. Similarly, signalling equipment was taken as common to both systems.

(b) Although survey work for the two systems takes different forms, experience has shown that the estimates would both be about the same cost and this charge also was deleted from the comparison study.

(c) In the assessment of building costs, no account was taken of proposed new buildings at the two intermediate stations as these buildings were common to all studies. Existing buildings were available for the terminal equipment.

(d) All costs were based on same-date prices. It was assumed that escalation would be approximately the same for all solutions and was not taken into account.

(e) It was difficult to provide an assessment of equipment obsolescence. It was considered likely that economic obsolescence would antedate any significant degradation in equipment performance.

Capital cost of radio equipment including installation costs was as follows:

Item	*Cost (£M)*
(a) Radio equipment, including feeders and antennas	2.6
(b) Towers, including foundations	1.0
(c) Power supply, including fuel storage facilities	1.3

(d)	Equipment shelters	0.65
(e)	Spare parts for radio equipment and power plant	0.25
(f)	Test equipment for four stations	0.22
(g)	Workshop and repair facilities	0.03
(h)	Sites, including access roads, fencing and site works	0.72
(i)	Freight charges	0.07
(j)	Engineering administration and overhead, documentation, vehicles, training, supervision and commissioning	0.86
		7.7

Capital cost of a coaxial cable system, including installation costs was:

	Item	*2 Tube (£M)*	*4 Tube (£M)*
(a)	Cable, nylon jacketed, lead sheath and polythene lightning protection sheath	4.0	5.0
(b)	Cable installation, laid solid mole plough and rock excavation	1.3	1.4
(c)	Contingencies, 25%	0.32	0.35
(d)	Freight of cable to pegs	0.51	0.63
(e)	Carrier equipment, 12 MHz system installed	0.8	0.8
(f)	Test equipment for main stations	0.15	0.15
(g)	Power plant	0.12	0.12
(h)	Spare parts, including spare cable section	0.05	0.06
(i)	Freight of material other than cable	0.07	0.07
(j)	Sites including access tracks to buried manholes, property gates, right-of-way etc.	0.04	0.04
(k)	Engineering administration and overhead, documentation, mechanical aids, vehicles, training, supervision, camps and commissioning	0.84	0.98
	Total installed cost	8.2	9.6

An economic comparison study gave the following costs:

	Radio relay system (£M)		*2 Tube coaxial cable system (£M)*		*4 Tube coaxial cable system (£M)*	
Capital Cost		7.7		8.2		9.6
Obsolescence	Towers Shelters Site Works	40 yrs	Cable Site Works	40 yrs	Cable Site Works	40 yrs
	Equipment	25 yrs	Equipment	25 yrs	Equipment	25 yrs
Annual charges 5%						
Capital recovery		0.511		0.495		0.576
Maintenance charges		0.085		0.065		0.065
Present worth of annual charges (20 y period)		7.43		6.98		7.99

The figures do not include any duty or sales tax or other form of taxation, rates or rentals which may be applicable. The economic life of the cable was taken as 40 years as experience had shown this to be a reasonable period in an ideal situation. However, in the particular example the route was along a path which had a particularly aggressive environment. Lightning was severe, isoceraunic levels up to 90, and termites were of major concern to existing underground construction. Although a nylon sheath was proposed to combat termites and a 50 mil polythene sleeve for lightning protection, the technique had not been fully field proven at the time.

If it is assumed that the life of the cable should be reduced from 40 to 25 years, the same as the carrier equipment, because of the environmental conditions, it is interesting to note the effect on the study. The life of the radio plant has been assumed to remain the same as lightning and termites are considered to have negligible effect on a properly engineered system. Special earthing provision for the towers has already been included in the tower costs.

	Radio relay system (£*M*)	*2 Tube coaxial cable system* (£*M*)	*4 Tube coaxial cable system* (£*M*)
Capital Cost	7.7	8.2	9.6
Obsolescence . Towers Shelters Site Works	40 yrs	Cable 25 yrs	Cable 25 yrs
Annual charges 5%			
Capital recovery	0.511	0.581	0.680
Maintenance charges	0.085	0.065	0.065
Present worth of annual charges (20 y period)	7.43	9.1	10.5

For a plant life of 40 years for the coaxial cable, the 2 tube system is the most economical arrangement based on the present worth of annual charges. However, for a plant life of 25 years for cables, the radio system is the most economical arrangement. This highlights the need not to conclude too hastily from figures presented from an economic comparison study without proper examination of all the facts and the assumptions made. In the first place, any economic comparison of this type is an attempt to reduce constant conditions, a situation which involves time and is thus subject to variations with time.

A major factor in this particular problem is the expected life of the cable, an estimate of probable condition 25 years hence and this poses two questions:

Are the environmental conditions such that the useful life of the cable will be reduced to 25 years?
How effective will the nylon jacket be against termites and the polythene sleeve for lightning protection?

Another factor which must be kept in mind is the influence of world copper and lead prices on cable. Experience in recent years has shown that the market is subject to unexpected price rises, which add sharply to the price of cable.

In making a decision, other factors which cannot be evaluated in money terms must also be considered. For example, it may be possible to secure radio equipment in sufficient time to meet the target date whereas to produce 1600 km of coaxial cable may be a long term operation. Also, specialist radio staff may not be readily available to maintain the radio system, whereas staff may be already stationed along the route to maintain cable type equipment.

A further aspect which is important in an examination of main line communication circuits is the question of reliability. In the example, the reliability of the radio system was based on 5 hours total outage per year. Experience with typical modern systems indicates, however, that 2 hours total outage per year or 99.98% can be achieved. This does not take into consideration any planned outages. The reliability estimate for the cable route was based on statistical data taken from other installed broadband cable systems and modified according to estimates of improved reliability arising from experience with:

(a) Ploughed cables which are free from early year faults caused by backfill, after trenching.
(b) The remote location of the route which would pass through only a small percentage of built-up areas which have been shown to be the areas of greatest likelihood of mechanical damage to buried cables.
(c) Modern buried transistorised cable systems which have a small incidence of component failure.

On this basis one cable fault and one carrier equipment fault per annum for the 1600 km route was estimated with a mean outage time of 7 hours and 1.5 hours respectively in the case of the 2 tube cable, or 99.90% reliability, and 6 hours and 1.5 hours respectively in the case of 4 tube cable or 99.91% reliability. The 4 tube cable if fitted with repeaters on the spare tubes would offer slightly greater reliability than the 2 tube cable, but with the likely staff dispersal along the long route, travelling time would probably constitute the greater part of the outage time.

It is often necessary to meet a requirement for wayside traffic on a route as long as in this example, and in this regard radio could provide sub-baseband channel circuits. Some needs may require the addition of v.h.f. or u.h.f. short haul radio systems at additional cost. Alternatively, drop and insert facilities could be provided. Both 2 tube and 4 tube cable systems provide a flexibility to serve circuit requirements to small offices along the route, and can readily cater for greater developments if necessary, by supergroup dropout, should some point become an area of substantial development.

Cost considerations are, of course, of major importance but in planning a main line system, geographical and technical consideration must be taken into account. The type of terrain over which the system has to be installed, accessibility of selected sites for installation of intermediate repeater stations and the availability of power may well be predominating factors governing the choice of a system.

Even where the geographic features do not clearly indicate the advantage of, say, a radio system, the calculation of the relative costs may be no easy exercise. At large city terminal or intermediate stations, road and footpath excavation work for coaxial cable laying is generally a very expensive operation. Where congestion exists, other utility services may have to be shifted, manholes may have to be rebuilt and in some cases these problems and difficulties may well override the more costly items of the equivalent radio system. Economic comparison studies should therefore be made only after full knowledge has been gained of the proposed route and the problems involved, in order to make such a cost comparison realistic.

EXAMPLE 19.2

Parallel and Standby Transmitters

A medium frequency broadcast station was to be established on the outskirts of a large town with an authorised output power of 10 kW. In examining the tenders for the transmitters, the engineer was faced with the problem of deciding between two schemes offered. One comprised two 5 kW transmitters normally operated in parallel to give the desired 10 kW to line, but with the capacity for providing a 5 kW standby transmission on one transmitter, should the other unit be faulty or be down for maintenance. The second offer comprised a 10 kW transmitter and a 2 kW separate unit. The 2 kW unit was to act as standby for the 10 kW unit.

The following points were relevant:

(a) The programme input equipment, transmission lines, antenna system and emergency power were common for both systems and were not taken into consideration.

(b) The floor space requirements for two 5 kW units plus combining unit was almost identical with that required for the 10 kW plus 2 kW unit.

(c) Because of proximity of the site to the built-up area, management expected to vacate the site after 18 years and to install a new installation on another site.

The estimated salvage value of the transmitters after this period was:

(i) twin 5 kW units, including spares held	= £2000
(ii) 10 kW unit, including spares held	= £1700
(iii) 2 kW unit including spares held	= £ 500

Although the 2 kW transmitter would have had relatively little use by the end of the period, there would probably be small demand on the market because of rapid changes in the state-of-the-art and improved efficiency which usually takes place with transmitting equipment over such a long period.

(d) The station was to be fitted with a recovered power plant considerably in excess of requirements and it was assumed that no extra capital costs would be incurred to cater for periods when the 10 kW and 2 kW units were run-up together, prior to changeover.

(e) The capital cost of the two 5 kW units plus combining unit, installed, and commissioned was £50 000. Spare parts amounted to £5000.

(f) The capital cost of the 10 kW unit installed and commissioned was £35 000. Spare parts amounted to £6000.

(g) The capital cost of the 2 kW unit installed and commissioned was £12 000. Spare parts amounted to £2200.

(h) The 10 kW/2 kW combination required a transmission line switching system estimated to cost £1500.

(i) The annual operating and maintenance charges including labour, parts and power for the twin 5 kW units were estimated to be £17 800 while the 10 kW/2 kW combination were estimated to be £17 450.

(j) Interest rate of 10% was applicable for the economic study.

(i) *Twin 5 kW Units*
Capital recovery
(£55 000 –£2000) × 0.12193 = £ 6462
Interest on salvage value of
recovered transmitter (£2000 × 0.1) = £ 200
Annual operating and maintenance charges = £17 800
Total = £24 462

(ii) *10 kW/2 kW Units*
Capital recovery 10 kW trans.
(£41 000 –£1700) × 0.12193 = £ 4792
Capital recovery 2 kW trans.
(£14 200 –£500) × 0.12193 = £ 1670
Capital recovery line switch
(£1500 × 0.12193) = £ 183
Interest on salvage value of recovered
transmitters (£2200 × 0.1) = £ 220
Annual operating and maintenance charges = £17 450
Total = £24 315

The economic comparison study shows that the 10 kW/2 kW combination is the more economical solution to the extent of £147 per annum. However, the advantages of a twin 5 kW unit are as follows:

(a) During daily maintenance periods and during failure of one 5 kW transmitter, transmission would be retained at 5 kW level. When the 10 kW is down for maintenance of fault attention, transmission would be carried on with the 2 kW transmitter. This would give reduced field strength and may cause loss of listeners particularly in the fringe area.
(b) Less capital is tied up in spare parts. Because of common components the two 5 kW units involve a spare holding of £5000 compared with £8200 for the 10 kW/2 kW combination.
(c) Two similar type models are likely to result in greater efficiency in fault finding by staff than two separate items of equipment each with its own peculiar circuit characteristics.

EXAMPLE 19.3

Staffed and Unstaffed Transmitter

A medium frequency broadcast station consisted of two 50 kW transmitters on different frequencies operating into a dual frequency radiating system. The station was continuously staffed for the full 18 hours per day of transmission from a staff team which included one property labourer. An economic comparison was required to determine the relative economics of making the station unattended compared with the staffed arrangement.

Each 50 kW transmitter had an associated 10 kW standby unit which was capable of operation into either the main 183 m dual frequency radiator or into an individual small 37 m standby radiator. Programme monitoring of the station transmissions was already being carried out from the studios some 20 km away. An auto start diesel engine generating set was installed, but load switching was manually controlled.

The following points were relevant to the study:

(a) The installation of remote control equipment would not affect the equipment or plant maintenance charges (excluding labour) already being incurred.
(b) The property labourer would be retained full time for property upkeep and to assist visiting technical staff as necessary.
(c) The station installation was relatively new and no major technical difficulties would be involved in the introduction of the remote control facilities.
(d) It was estimated from past records that 45 manhours per week, plus travelling time from the studios, would be required for routine maintenance and fault attention.

Manual Operation Charges

(a)	Labour, including penalty rates for weekends and holidays, 9500 manhours at £4.50 excluding administration and overhead	= £42 750
(b)	Transport allowance to staff	= £ 850
	Total annual charge	= £43 600

Remote Operation Charges

Capital cost of interface equipment for:

(a) Transmitters 2 × 50 kW and 2 × 10 kW
(b) Programme input equipment
(c) Antenna switching
(d) Power plant
(e) Remote control equipment

Cost includes all charges associated with purchase of equipment, installation and modifications to equipment at the transmitting station and estimated to be £100 000.

(a)	Capital recovery of capital charge assuming 25 year life at 5% (£100 000 × 0.07095)	= £ 7095
(b)	Additional power and maintenance costs associated with remote control equipment	= £ 1600
(c)	Station labour costs, including travelling time 2800 manhours at £4.50 excluding administration and overhead	= £12 600
(d)	Transport allowance to staff	= £ 230
(e)	Annual rental for two control circuits between studio and transmitting station	= £ 1000
	Total annual charge	= £22 525

It is seen that there is an annual saving of £21 075 by operating the station remotely from the studios.

Significant savings in staff labour costs can be achieved by the unattended operation of transmitting stations. Against this saving in operational expenditure, the conversion to unattended operation involves some capital expenditure on additional control and supervisory equipment. Experience has indicated that problems associated with remote control of transmitters are not exclusively those of circuit design. Care has to be taken to ensure that the building facilities such as fire protection are adequate, and that proper documentation and adequate test facilities are provided to assist in routine maintenance, plant performance measurements and fault clearance.

Point-to-point radiocommunication systems introduce particular unattended problems as it is no simple matter to determine the accuracy of a transmission system on a continuous basis. Both the transmitted and received signals should be available at a single point to enable comparisons to be made but even then the situation is not completely satisfactory because the fault could be in either the transmit or receive path. For some types of point-to-point circuits, error correcting systems can be provided, and in these cases the signal received contains practically the same intelligence as the original message. However, this is not applicable to all communication situations and some compromise solution must be sought. The compromise usually consists in selecting a critical portion of a transmission system and considering this portion independently. For example, the output signal of a transmitter can be compared with the input to determine whether exact correlation exists. The same procedure cannot, however, be applied to an overall situation because the signal at the input to the receiving terminal has impressed on it noise etc. due to the transmitting terminal and to the propagation medium.

A major problem associated with remote operation of transmitters associated with broadcasting is that of qualitative programme monitoring. If the transmitter is located reasonably close to the studios this generally presents little difficulty. Either direct off-air pickup or a return programme line will provide adequate supervision. For stations in a remote locality the problem is a difficult one. One system in use comprises an automatic monitor which simply compares the incoming programme with that from a reference source which may be an off-air pickup. It compares a programme of unknown technical quality dubbed, 'compared programme', with a programme that is known to be satisfactory, called 'reference programme'. If the quality of the compared programme falls below a certain standard the equipment may either give an alarm or initiate executive action to deal with the trouble. Another system uses an absolute monitor which transmits information on the content of the signal on two low level tones in the upper end of the audio band. However, because of the restricted frequency response of some long open wire or cable programme lines this method may not always be practicable.

Control and supervisory circuits extended to the remote station should be kept to a minimum because of the high rental of circuits, particularly if long distances are involved. Control facilities are required for switching the programme channels, the transmitters and antennas. Supervisory facilities are required for these conditions, plus fire, programme fail, and other station alarms.

The introduction of unattended operation of broadcast and television transmitters can in the majority of cases be justified on the basis of savings in labour cost. The resulting problem is two fold. Firstly, how to provide the means to accomplish this, and secondly how to improve the reliability of the equipment if necessary, to ensure that these economies in staffing are in fact realised. This is a trade-off between design for reliability and cost of maintaining the equipment. In the past, reliability has been measured in terms of the outage time which has resulted mostly from power failures, and only marginal gain could be foreseen by an improvement in reliability of station equipment itself.

However, interest is now generally directed to the reduction in those outages which require an unscheduled visit by a technician. This eliminates power failures and implies faults, rather than progressive, and thus predictable, loss of performance. They occur more commonly in quiescent paths such as control equipment and thus bring the need for a new approach to the design of component parts and units.

EXAMPLE 19.4

Power Supplies for a Radio Relay Station

An economic comparison study was to be made of various methods of providing power to a remote microwave radio relay solid state repeater requiring 200 W at 24 V d.c. on a continuous basis. Four propositions were to be studied on 5% interest basis. These were:

(a) Extension of a single wire earth return power line for 20 km with a tariff of 11 pence per kWh. A single bank of 200 Ah batteries was to operate on float.
(b) Provision of two 1.5 kW diesel engine generating units feeding two sets of 500 Ah batteries operating on a charge/discharge basis.
(c) Provision of one 2 kW brushless type wind generating unit feeding two sets of 500 Ah batteries operating on a charge/discharge basis.
(d) Provision of 240 W thermo-electric generator floating a set of 200 Ah batteries.

Scheme 1

(a)	Cost of extending power line 20 km as per Authority quote = £30 000. Assuming life of line 35 years, capital recovery (£30 000 × 0.06107)	= £1832
(b)	Annual power charges at 11 pence per kWh at 85% efficiency, trickle charge	= £ 227
(c)	Installed cost of 24 V, 200 Ah battery system including batteries, charges, regulator, freight and installation charges = £1000. Assuming life 12 years, capital recovery (£1000 × 0.11283)	= £ 113
(d)	Annual battery maintenance including labour, travelling costs, averaged over 10 years from station 60 km distant	= £ 100
(e)	Capital cost of building space for charger and batteries £2000. Assuming building life 35 years, capital recovery (£2000 × 0.06107)	= £ 122
(f)	Miscellaneous, including building maintenance costs etc.	= £ 61
	Total annual charge	= £2455

$$\text{Actual cost per kWh} = \frac{2455 \times 1000}{24 \times 365 \times 200}$$

$$= £1.40$$

Scheme 2

(a)	Cost of two 1.5 kW diesel engine generating sets, including control units, fuel supply system, foundations, freight to site and installation charges = £8000. Assuming life of 20 years, capital recovery (£8000 × 0.08024)	= £ 642
(b)	Engine maintenance parts including greases and lubricating oils based on 10 year period	= £ 150
(c)	Fuel delivered to site	= £ 140
(d)	Labour charges associated with regular bi-monthly inspections at £4.50 per hour excluding administration but including travelling time from head station 60 km, averaged over 10 year period.	= £ 250
(e)	Vehicle costs	= £ 100
(f)	Two banks 500 Ah batteries including charge/discharge panel, battery cupboards, freight to site and installation charges = £1800. Assuming life 12 years, capital recovery (£1800 × 0.11283)	= £ 203
(g)	Bi-monthly battery maintenance carried out in conjunction with engine visits, averaged over 10 year period and includes one cell replacement per bank and travelling time from head station 60 km	= £ 150
(h)	Capital cost of building accommodation for batteries and engine sets = £10 000. Assuming life 35 years, capital recovery (£10 000 × 0.06107)	= £ 611
(i)	Miscellaneous, including building and site maintenance charges	= £ 312
	Total annual charge	= £2558

$$\text{Actual cost per kWh} = \frac{2558 \times 1000}{24 \times 365 \times 200}$$

$$= £1.46$$

Scheme 3

(a)	Cost of 2 kW brushless wind generator including freight, voltage regulator and installation, £5000. Charger designed for high wind loading conditions. Assuming life 12 years, capital recovery (£5000 × 0.11283)	= £ 564
(b)	Tower for wind generator, 160 km/h wind loading, including foundations, freight and erection costs. Tower medium duty self supporting type 30 m height = £13 000. Assuming 40 year life, capital recovery (£13 000 × 0.05828)	= £ 758
(c)	Maintenance charges including regular 3 monthly inspections averaged over 10 years from previous installations and including travelling time from head station 60 km	= £ 135
(d)	Vehicle costs	= £ 64

(e)	Two banks 500 Ah batteries including charge/discharge panel, battery cupboard, freight to site and installation charges = £1800. Assuming life 12 years, capital recovery (£1800 x 0.11283	= £ 203
(f)	Bi-monthly battery maintenance, averaged over 10 year period and includes one cell replacement per bank and travelling time from head station 60 km	= £ 150
(g)	Bi-monthly booster charge for batteries by portable engine-generating set carried by maintenance staff, including annual charges and operating expenses of the unit shared with other stations	= £ 158
(h)	Capital cost of building accommodation for batteries = £3500. Assuming life 35 years, capital recovery (£3500 x 0.06107)	= £ 214
(i)	Miscellaneous including building maintenance charges	= £ 110
	It was assumed that the wind generator could be accommodated on site without additional site costs	
	Total annual charge	= £2356

$$\text{Annual cost per kWh} = \frac{2356 \times 1000}{24 \times 365 \times 200}$$

$$= \pounds 1.34$$

Scheme 4

(a)	Cost of 24 V 240 W thermo-electric generator, including regulator, piping system, freight to site installation charges and spare burner, £8000. Assuming life 25 years for system, capital recovery (£8000 x 0.07095)	= £ 568
(b)	Cost of shelter for plant and gas tanks, concrete base, and iron stand for tanks, including cartage materials to site and labour = £350. Assuming life 35 years, capital recovery (£350 x 0.06107)	= £ 21
(c)	Generator maintenance including burner replacement, averaged over 10 years	= £ 30
(d)	Vehicle cost, maintenance staff 60 km from head station	= £ 90
(e)	Gas cylinders delivered to site 60 km from depot, including labour 2 men and travelling time	= £1100
(f)	Installed cost of 24 V, 200 Ah battery system including batteries, charger, freight and installation charges = £900. Assuming life 12 years, capital recovery (900 x 0.11283)	= £ 102
(g)	Labour charges associated with regular 3 monthly inspections of generator, battery maintenance at £4.50 manhour excluding administration but including travelling time from station 60 km averaged over 10 years and battery booster charge as necessary	= £ 145

(h)	Capital cost of building space for batteries etc. £2000. Assuming life 35 years, capital recovery (£2000 x 0.06107)	= £ 122
(i)	Miscellaneous including building maintenance	= £ 65
	Total annual charge	= £2243

$$\text{Annual cost per kWh} = \frac{2243 \times 1000}{24 \times 365 \times 200}$$

$$= £1.28$$

Summarising, the cost of supplying 200 W on the assumptions made are:

(a)	Extension of mains	£1.40 per kWh
(b)	Twin diesel generating sets	£1.46 per kWh
(c)	2 kW brushless wind generator	£1.34 per kWh
(d)	Thermo-electric generator	£1.28 per kWh

Improved technology and reduced manufacturing costs have brought another power source, solar cells, into reckoning for remote radiocommunication stations. Elimination of diesel generators or the regular replenishment of bottled gas supplies is an important contribution to reducing overall maintenance costs although some tropical areas may still require diesel or thermo-electric back-ups during monsoon periods when there may be long periods of cloud cover. The cost of solar cells which comprise about a third of the basic cost of the power system has decreased considerably in the last few years and further reductions appear likely.

One solar system developed for a 500 km broadband microwave relay route with 13 repeaters has an output of 132 W and is used in conjunction with a 1500 Ah battery system. The installed cost of the system was approximately £150 per watt.

EXAMPLE 19.5

Transmission Lines

A balanced four wire transmission line 360 m in length was to be provided between a high frequency transmitter of 500 kW carrier output power and a curtain antenna. The conductors to be used were to have an effective diameter of 15 mm and a comparison was to be made between lines constructed of copper and aluminium conductors.

The following points were relevant in the study:

(a) All construction costs including labour, poles, insulators, foundations etc. but excluding the line conductors and fittings were of equal value in the two schemes.

(b) Attenuation of a sample line of copper conductors was measured at 0.17 dB per 300 m at the operating frequency.

(c) Attenuation of a sample line of aluminium conductors was measured at 0.2 dB per 300 m at the operating frequency.

For the line to be constructed of copper conductors:

(a) Total line attenuation $= \dfrac{360}{300} \times 0.17$ dB

$= 0.204$ dB

(b) Power loss at (say) 600 kW average = 27.5 kW

(c) For a basic onsite operating and maintenance cost of 40 pence per radio frequency watt output from transmitter, then the cost of the transmission line losses

$$= \frac{27.5 \times 1000 \times 40}{100}$$

= £11 000 per annum.

This loss however is incurred only if the line is in use for the full period of transmission throughout the year. The usual situation is that some antennas are in use for only a few hours per day. If, however, the subject line forms part of a common circuit between transmitter and the line matrix switch then an equivalent 33% usage would be an average figure at a typical large station.

On this basis the line loss

$$= \frac{£11\,000 \times 33}{100}$$

= £3630 per annum.

For the line to be constructed of aluminium conductors:

(a) Total line attenuation $= \dfrac{360}{300} \times 0.2$ dB

$= 0.24$ dB

(b) Power loss at (say) 600 kW average = 32.4 kW

(c) Annual cost of transmission line losses

$$= \frac{32.4 \times 1000 \times 40 \times 33}{100 \times 100}$$

= £4276 per annum.

Net saving by using copper conductors

= £4276 –£3630

= £646 per annum.

Material costs associated with the two lines including conductors, terminations, equipotential clamps etc. were approx.:

Copper = £4000
Aluminium = £1400.

The increased capital cost of a copper line was £2600, but it would result in a saving of line loss of £646 per annum. Hence from a financial aspect, the copper line additional costs would be recouped in four years.

Because of the high cost of copper and inferior tensile strength of copper and aluminium for low sag conditions, many lines are constructed of copperweld or alumoweld. Some also use tubing for the bottom conductor to reduce the overall weight. Since the reduced amount of high conductivity material used in copperweld and alumoweld conductors results in lower overall cost, the cost differential of the two types of lines would be much smaller. Preference would then probably be decided on other issues, such as environment.

Transmission lines are a major cost item in the establishment of a station. The cost of some lines exceed £60 per metre and close attention to site layout plans is essential to minimise capital expenditure. Also losses in the line mean less power radiated by the antenna. Because line losses increase with frequency, antennas operating at the high frequencies are connected to the lines of shortest length, where practicable.

At one large international broadcast station with 19 transmitters of aggregate power nearly 2000 kW, the total length of transmission lines is more than 36 600 m with the longest single line being about 1300 m.

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Section 3

Safety Practice

Introduction

This Section has been prepared as a guide for staff to safe working in radio and radar installations and in particular in broadcast and television stations and to assist management faced with the need to draft or update rules and regulations applying to their technical facilities and staff. It outlines rules and recommended safe practices in current use which will help engineers, technicians and other staff to perform their work safely and to avoid accidents and injuries.

Most Governments now have legislation and controls to create and maintain a safe overall environment. The legislation is administered under various names but *Health and Safety at Work Act, Occupational Safety and Health Act* etc. are typical. Most of the Acts require the employer to provide and maintain plant and systems that are safe and without risk to health, to provide such information, instruction, training and supervision to ensure the safety and health of his employees, to provide a working environment that is safe, to maintain the place of work in a condition that is safe and without risk to health, and to provide and maintain a means of access and egress from the workplace that is safe and without risk. The employee, on his part, is required to take reasonable care for the safety and health of himself and of other people who may be affected by his acts or omissions at work. Also, the employee is required to co-operate with his employer in relation to any duty or requirement imposed on his employer by statutory provisions to enable that duty to be complied with or be performed.

Although safety is the responsibility of everyone—the individual worker, the supervisors, the engineers and management—it is management's responsibility to set down guidelines and rules and to give the leadership and drive necessary to instill in the staff a safe working attitude. It must set an example by showing a continued interest in safety by ensuring that the employees can work in an environment free from hazard with equipment that has been designed for safe construction, operation and maintenance.

Every station management should have a safety policy with local safety rules always being made with this policy in mind. The primary object of the rules must be to ensure the personal safety of the station staff and of third parties. All staff should be required to observe them with breaches being treated seriously, even if no accident occurs. Station supervisors should play a major role in safety training, counselling, checking and by setting a good example.

Safety includes both the safety of staff who work on technical facilities and the safety of the equipment or plant. Equipment or plant malfunction, failure or damage may in turn result in personal injury to the staff working on the facility so the interactions between safety to staff and safety of equipment or plant are significant.

All technical staff must read station safety rules carefully, ask questions about their work and train themselves to form the habit of carrying out their work safely. It is important that they develop an appreciation of the potential dangers which exist on their station. An unsafe worker is a danger to himself, his fellow workers and the equipment with which he works. Safety comes first in any operation, and time and thought must be given to doing the job in a safe way.

Most accidents at radio stations are due to human fallibility such as the failure to use safety equipment and safe methods. Not many are due to imperfections in the radio equipment or plant. Elimination of all unsafe conditions and unsafe acts is the only sure way to eliminate accidents.

Part 1

Philosophy and Responsibility

Chapter 20

Philosophy and Plans

SAFETY ENGINEERING PHILOSOPHY

Such basic factors as adequate training, supervision by properly qualified personnel, correctly installed equipment, safe access to all equipment for maintenance purposes, the availability of the correct instruments, apparatus and tools and the knowledge of how to use them are all important safety practices in most fields of engineering. A full and proper appreciation of the various hazards involved in performing work is vital.

There are, however, additional hazards in the field of radio engineering. These include high voltages used with high power transmitters, the radio frequency voltages encountered on transmission lines and antenna systems, electrically charged components, burns from hot water and vapour phase cooling systems of transmitting tubes, the biologically hazardous situation created by intense electromagnetic fields, the risks of high winds, rain and ice associated with work on tall masts and towers and the danger of working on compressed air operated switches in transmitters and transmission line matrix systems. Wherever possible work on unsafe apparatus and live circuits should be avoided but where there is no alternative then the work should be recognised as constituting an especially dangerous situation for which special safety precautions are necessary.

Adequate maintenance programmes, frequent inspections and, above all, the education of workmen must be recognised as essential prerequisites for safe work. These are the responsibility of the organisation at all management levels. Supervisors must exercise constant vigilance to ensure that rules are obeyed and best practices followed. Printed rules cannot provide for every contingency, and situations can arise where additional safety devices or new precautions are necessary. Here the role of the supervisor is of prime importance and he should be encouraged to suggest new safeguards wherever necessary. It is recognised that cost must always be taken into account when expenditure on equipment and working procedures are under consideration, but the safety of workmen must remain a prime objective.

Those persons directly associated with the management of the organisation are, however, not the only ones who have responsibility for accident prevention. In the final analysis, every person in the organisation must carry a share of the responsibility. Even those engaged in work not associated with the technical equipment, such as labourers, cleaners and office workers, should carry out safety instructions and see to it that neither they nor any fellow workers are injured through an unsafe act that may be attributed to their own inattention, negligence or thoughtlessness.

The basic philosophy should be to concentrate on the detection of hazards and then to eliminate them as far as possible. This applies to all phases of the work from planning, to design, construction, installation, testing, operations and maintenance. Thus, engineers engaged on developing methods and establishing standard practices should endeavour to apply the eliminate-the-hazard-first approach, where possible. However, it is recognised that there are times when certain constraints, such as funds, exist and the engineer is expected to produce the most practical and the safest design within these limitations. If an engineer has processed a job, and has left an avoidable hazard in it, he has not fully met his responsibility. In many instances, accidents occurred on a job because the work had not been adequately studied or engineered.

Accident possibilities, if they seem remote, are apt to be discounted. While this point of view has some practical merit, it may also be destructively disarming. Unless all possibilities have been determined by thorough analysis, it is likely that false conclusions will be drawn and severe hazards will exist without provision for adequate control. All plant and equipment on a radio station should be safe, regardless of the calibre of the workmen assigned to its operation and maintenance. The transmitter hall and high voltage vault areas should be just as safe as the programme input room. In planning installation works and operational activities, the engineer should make sure that supervisors in charge of the work know the specific hazards involved in each operation and know how best to eliminate or control them.

Safety programmes are aimed at preventing workmen injuring themselves and others. It is generally accomplished through the use of safeguards, e.g. mechanical, electrical etc., supplemented by instruction at regular intervals. The continuing educational programme is necessary because, unfortunately, the absence of accidents lulls personnel working in hazardous areas or they may be so used to the presence of danger that they are no longer conscious of it. Ironically, the more a person knows about the hazards of his work, the more complacent his attitude sometimes becomes. Commenting on 1800 serious electrical injuries over a two year period in California, Allison[1] says,

"Don't assume that these victims knew nothing about electricity. The list of injured and killed includes a large number of electrical engineers, superintendents, managers, service and maintenance men and electricians. So it should come as no surprise that experience has proved that one cannot expect everyone to understand all the hazards and to exercise due care all the time."

For these reasons the designers of station equipment should ensure that the preliminary designs are carefully examined to determine where injury might occur to installation, operations, and maintenance workmen. The final design should provide inherent protection against breakdown, damage to insulation, erroneous operation and the risks associated with electrical or mechanical failures. It has often been a point of discussion as to why technological progress and mechanisation have not led to any marked improvement in the safety of radio station staff. The fact is that over the past fifteen years or so, there has been a veritable revolution in methods, particularly in the maintenance and operation of radio engineering equipment.

The use of a comparatively large maintenance and operations staff was an essential characteristic of earlier stations but this has been superseded by processes requiring fewer staff and making use of increasingly complex equipment of higher power. As the equipment has become more complex, fewer but more skilled operators have been required. The absence, or errors, of even one such workman can, as a result, threaten a significant proportion of the station's maintenance schedules. An effective accident control programme therefore is an increasingly important factor. Moreover, a more responsive safety effort is required of the skilled maintenance expert than the relatively unskilled workman. The probability that they will encounter a varying risk pattern is a challenge to the designer's ingenuity, if he is to assist effectively in the control of equipment and personnel accidents.

A reduction in the total number of accidents on a particular radio engineering project does not necessarily involve a proportionate reduction in the hazards for each individual workman. Sometimes there is an increase, since high powers and automation make the mistakes of the workman more serious. In fact, the nature of the hazard has altered. The deterioration that has occurred in some areas can be attributed to the following factors:

(a) Inadequate vocational qualifications of staff to cope with the complexity of modern radio and electronic equipment. Ignorance of the presence of dangerous potentials on components may lead to a serious shock. For instance, many electric shocks and also other injuries from equipment have occurred when operators were unaware of the manner and sequence by which circuits were energised. Adjustment and maintenance of equipment should be carried out by properly trained and adequately qualified workmen.

(b) Careless installation, operation and maintenance practices, particularly in relation to protection facilities. Standards of safety require that all intrinsically dangerous components or parts should be so protected, wherever situated in the equipment or plant, that no operator can perform an unsafe act in relation to them. This of course is setting a high objective, but examinations of some modern broadcast transmitters, made by safety conscious manufacturers having the foregoing principles in mind, show that such a standard is not unobtainable.

    There is unfortunately a tendency on the part of some designers to pay more attention to safety features when the equipment is intended for use by unskilled persons, or to minimise safety features on relatively low voltage equipment. Therefore, there may be increased possibility that an accident will happen to a skilled but careless workman. This is a matter which the workman must keep in mind all the time. He must realise that no safety device can be counted on for 100% reliability.

    There is also the problem of failure of some components during normal testing and fault finding procedures. For example, staff should be aware that small electrolytic capacitors can explode violently if inadvertently connected in the reverse direction. The contents include shredded metal and caustic electrolyte, and are very dangerous as they are ejected from the capacitor at high velocity. A particular danger can occur when newly fabricated circuit boards are being bench tested at near to eye level.

The explosion phenomenon is not only confined to polarity reversal during testing. Many cases of explosion have occurred in working equipment. *Figure 20.1* shows one electrolytic capacitor which exploded resulting in catastrophic failure of the system. The noise from the explosion was heard by staff in an adjacent room even through the unit was fully enclosed and situated in a room with a high noise level. The capacitor was a 500 μF unit rated at 20 V and formed part of the power supply unit of a city paging transmitter. Considerable damage occurred to the power amplifier and driver stages. The capacitor was 10 mm in

Figure 20.1 Exploded electrolytic capacitor

diameter and 40 mm in length and the enclosed internal material was ejected out of the case some 65 mm.

(c) The violent action of high power switchgear, pneumatic transmission line switches, pneumatic tank circuit drives, high pressure water cooling systems, high speed air scavenger fans and escaping steam of vapour phase cooling systems. Records of accidents at high power broadcasting stations show that a large percentage of personal injuries were caused by the violent action of some plant, arcs, explosions and burns.

(d) Insufficient appreciation of the hazards involved. The workman operating, testing or maintaining high voltage and high power equipment must be extremely cautious at all times. Violation of a basic rule may result in immediate death or serious injury. He cannot expect the designer or constructor to provide him with all conceivable safeguards necessary to protect him. Constant attention and observation of the safety rules is the most effective procedure when working on high voltage and high power equipment.

Many large organisations and particularly Government instrumentalities operating broadcast and television services have a code of general principles which lays down the measures necessary to safeguard the safety and health of its employees while they are at work and wherever they may be working.

Typical management provisions[2] include the following:

(a) The issue of a statement of safety policy and responsibilities.
(b) The adoption of arrangements for joint consultation with employees on safety matters.
(c) The appointment of safety co-ordinators.
(d) The provision of safe work places and a safe working environment.
(e) The provision of safe plant, machinery and equipment.
(f) The adoption of safe work methods and appropriate training and placement of employees.
(g) The adoption of occupational hygiene principles and control of harmful chemicals and physical agents.
(h) The adoption of measures to minimise the risk of and harmful effects of fire and explosion.
(i) The provision of appropriate personal protective equipment and the adoption of measures to ensure its proper use.
(j) The establishment of medical, health and first aid services.
(k) The maintenance of injury and accident records and arrangements for accident investigation.

The employee also has an obligation under the code. This is briefly summarised as follows:

(a) Each employee shall have responsibility for safe working consistent with the extent of his control over or influence on working conditions and methods.
(b) Each employee shall take such action as is within his competence and responsibility or report or make such recommendation to a higher level as he deems necessary to avoid, eliminate or minimise hazards of which he is aware in regard to working conditions or methods.
(c) Each employee shall observe all instructions issued to protect his safety or the safety of others.
(d) Each employee shall make proper use, or to the extent of his responsibility ensure that proper use is made, of all safeguards, safety devices, personal protective equipment and other appliances provided for safety purposes.
(e) No employee shall, or shall cause another employee to, interfere with, remove, displace or render ineffective any safeguard, safety device, personal protective equipment or other appliance provided for safety purposes, except where necessary as part of an approved maintenance or repair procedure.

INTERPRETATION OF SAFETY RULES

Safety practices may vary considerably in detail from one station to another, and yet both stations may have good safety records. The heart of the matter is that safe and consistent working procedures for the particular location must be set up, and the workforce should be thoroughly familiar with, and willing to abide by, these procedures. However, knowledge of the procedures is not enough—there must be keen interest in safety on the part of both worker and management, and hence ways and means of creating and maintaining interest in safety are required to develop and maintain the vigilance necessary to prevent accidents.

Supervisors should ensure that no job is done more easily or quickly at the expense of safety, and that no man is ever urged to greater output if there is any question of a seriously decreased safety factor. In planning every job, safety for personnel is a major consideration and often the principal one, particularly when working on high voltage equipment or on masts and towers.

Supervisors must be constantly on the alert for problems resulting from the transfer of employees who have been working on low power equipment and antenna systems to jobs involving high powers. Where such transitions occur, supervisors must ensure specific job safety instructions are issued and followed through.

A careless workman is a potential hazard not only to himself, but also to his fellow workmen. The majority of accidents, including electric shock, occur because someone was careless. Carelessness by supervisors and qualified technical workmen cannot be excused, because on a large radio station complex, many unskilled workers may be employed and in many situations they depend greatly upon the knowledge and skill of technical people, for their safety.

After an accident has occurred, the hazard causing it usually stands out unmistakeably. Accident prevention calls for the identification, recognition and location of hazards in advance of the work operations, and this requires continual vigilance and care on the part of all people involved in planning and performing the work. By the proper design of tools and equipment, and by wise selection of material used on the job, many hazards can be removed from the work scene.

It is recognised that hazards cannot be entirely eliminated in all cases, and the big problem in formulating rules is to decide how far it is practicable or necessary to go in reducing hazards. It is not sufficient to provide against possible hazards in installation and new construction only. Deterioration in materials and performance makes it essential that a check be kept on conditions and performance, and that adequate safety be preserved by inspection, checking, testing and maintenance. Some rules may specify quantitatively the amount of deterioration permissible before replacement, but in general this must depend upon the good judgment of engineers and supervisors.

All new employees should be carefully instructed as to the hazards of the work and be issued with a copy of station safety rules. The workman's immediate supervisor should ensure that the rules have been read and understood correctly, and the workman should be called upon at any time to show his knowledge of the rules. Workmen should not only comply with the rules but also use all safety devices provided, work carefully, and co-operate in activities having as their object the prevention of accidents.

Supervisors should warn staff of the hazards involved in the wearing of personal accessories such as metal rings and wrist watches. The accessories have been responsible for many electric shocks and burns, and some organisations make it a mandatory rule that they not be worn by staff working on radio and electrical equipment. Wrist watches, particularly those with metal bands, and rings, besides being excellent electrical conductors create conditions ideal for the flow of electric current. The area of contact on the skin is considerable, pressure is usually firm and the skin beneath the accessor is usually moist and offers good conductivity because of acids and salts in solution.

One survey conducted among electronic workers revealed that 20% had been the victims of shock or severe burns resulting directly from the wearing of metal accessories. Some workers also revealed experience of expanding type metal watch bands being caught on live high voltage terminals.

CLASSIFICATION OF ACCIDENTS

Accident statistics point to a certain number of hazards than can be identified in the installation, operation and maintenance of radio equipment and plant. An examination of several hundred accidents of all degrees of seriousness, including fatal accidents at broadcasting and television stations, has enabled the classification shown in *Table 20.1* to be made. More than 85% of the accidents were due to the human element such as failure to use safety devices and safe methods.

Table 20.1 CLASSIFICATION OF ACCIDENTS

Accident cause	*Percentage*
Handling equipment and materials on ground	25.2
Tripping over objects or slipping on floor	12.6
Contacting sharp objects or bumping into objects	9.6
Contact with live conductors and components	9.0
Falls from structures, platforms and ladders	7.5
Falling or moving objects	6.7
Hand tool operations	4.4
Mechanical aids and machinery operations	4.2
Erection of structures and antennas	3.4
Test equipment operations	3.2
Working on tube hot water systems	2.2
Use of welding equipment	2.0
Operation of explosive powered tools and explosives	1.5
Handling harmful substances	0.8
Compressed air operations	0.7
Other causes	7.0

For the purpose of the Table, accidents are defined as those in which it was found necessary to use first aid facilities on the victim either at the workface or in hospital. Of fatal accidents included in the statistics, three contacted transmitter e.h.t. supplies, eight were killed during mast erection operations and one was crushed by a mechanical aid.

By comparison with the number of accidents in factories, homes or on the roads, the number of accidents at radio stations is relatively small. However, some lives are lost and there must be continual effort to reduce this loss.

LESSONS TO BE LEARNED

From an examination of many of the reports associated with the accidents in the Table some lessons which can be learned are:

(a) It is important to detect and eliminate hazards before they cause accidents.
(b) The cause of each accident should be ascertained and steps taken to eliminate the hazard and prevent a recurrence.
(c) The prevention of accidents is not only good ethics but also a wise economic investment.
(d) In the majority of cases, accidents can be prevented.
(e) The majority of accidents are due to similar causes, irrespective of the size of the organisation.
(f) There is one or more causes for every accident, they do not just happen.

Important lessons can also be learned from the design, installation, operation or maintenance of the equipment or plant involved in some of the accidents. These may be summarised as follows:

(a) All equipment must be properly earthed. In the case of high power transmitting equipment, an earth system of low impedance at the operating frequency is essential.
(b) Appropriate interlocking of control circuits and equipment must be provided.
(c) Equipment should have adequate built-in short circuit capability and be provided also with protective devices such as fuses, relays, vacuum switches and the like.
(d) High voltage equipment must be enclosed in earthed metal or insulated type enclosures, where practicable.
(e) No equipment or plant should be operated without authority or warning. Typical unsafe acts include closing switches without authority, failure to place warning signs or signalmen where needed and failure to block or guard equipment against unexpected movement.
(f) Protective equipment must be used. Failure to use rubber gloves, insulating mats or sleeves around energised equipment, failure to use protective equipment for eyes, ears, head, feet and body where necessary contributed to many of the accidents.
(g) The components comprising the equipment should be of high quality to recognised standards, and correctly installed in the equipment.
(h) Equipment and plant must be adequately and effectively maintained.
(i) Correct operating, installation or erection practices must be followed.

EMERGENCY ORGANISATION PLANS

No radio station can be made completely immune from disaster. Fire, explosion, mast collapse, flood or cyclone may strike even the most carefully protected station. When the emergency comes, proper action can make the difference between a minor incident and a major catastrophe. If a serious loss does occur, a restoration plan prepared in advance may mean, especially in the case of a large commercially operated establishment, the difference between returning to normal operation with a minimum of delay or going out of business.

Catastrophic fires, in particular, occur all too frequently, even at establishments that are physically well protected, and no form or amount of insurance can replace some of the consequences of a disaster—lost time, effort and lives. The importance of having a complete plan to enable a station to cope with sudden emergencies is well appreciated by the management of most organisations. Periodic revisions and continual improvement to the plan will ensure that it will be the best plan to implement should an emergency occur.

While fire is one of the best known, and most often studied, emergency situation, there are other natural disasters which can cause havoc at a radio station. These include hurricanes, cyclones, electric storms, floods, explosions, and earthquakes. Bomb threats, vandalism and civil disturbances have also become a problem in recent years.

Many large radio stations, particularly those involved in high power international broadcasting activities, involve very large investments and station complexes exceeding £14 million are in existence. It is essential, therefore, that management be properly prepared to cater for emergency situations. It must decide in a general way how existing facilities fit into the organisation's long range objectives, so that if an important antenna system, switching matrix, transmitter, power house or even the entire station is lost, it will be in a good position to decide quickly what action can and should be implemented immediately to restore operation on site or to re-establish elsewhere.

Management must also see that responsibilities are clearly defined, that good communications are maintained, and that all staff on the station periodically receive proper training, to cope with possible emergency situations. The more decentralised and diversified the operations of an organisation, the better its ability to recover from a disaster. It is essential that far more authority and responsibility be delegated to certain station staff during time of disaster than is normally given. Management has to determine which members of the staff are to take over in these circumstances and must ensure that they receive all necessary help and support to prepare them for this work. Because most large station establishments are operated on a shift basis the station manager and other key personnel may not be immediately available on site. The disaster organisation plan should therefore include a succession list of persons to take over the responsibilities.

Because most staff will have had little experience in emergency situations on the station, it is understandable that at some levels there could be a degree of disinterest, even ranging on scepticism, about the risk of say a large fire, the threat to life and the problems of re-establishment. Management has to supply the leadership, direction and support necessary for a good emergency plan. It must show the way and by precept and example establish the interest and co-operation of the station staff.

DEVELOPMENT OF EMERGENCY PLANS

In the development of an emergency organisation plan, some of the important actions which management must take, may be summarised as follows:

(a) Train and periodically check all station personnel in emergency procedures, including station shut-down, raising the alarm, fire fighting, first aid and also salvage including the use of waterproof covers to protect equipment from water.
(b) Assign and periodically check specific responsibilities.
(c) Post emergency instructions in appropriate locations throughout the station.
(d) Establish close liaison with local fire department, first aid services and civil defence organisation.
(e) Prepare a written detailed plan covering the use of alternative facilities, including the necessary arrangements and procedures for transportation of replacement equipment or spare parts, and support personnel.
(f) Familiarise personnel who would carry out the emergency plan with the alternative facilities, and test all details of the plan in advance.

Whether the station is staffed or not, emergencies can happen at any time. It is essential therefore that there always be some person nominated to take charge. Where the station is continuously staffed, an officer should be appointed on each of the shifts to take charge. In practice, this generally becomes the responsibility of the shift leader. In any case he should be:

(a) Trained in the proper operation of all fire fighting plant and appliances on the station.
(b) Familiar with every part of the station equipment and plant, and with existing and potential hazards.
(c) Trained in first aid.
(d) Capable of effectively taking complete charge of all staff, irrespective of trade groupings, should the need arise. He should have the complete authority of management to take whatever steps he considers necessary at the time to deal with the situation, particularly where the safety of the staff is involved.

When disaster strikes, management is often faced in many situations with the problem of restoring order out of chaos. To minimise the effect of disaster consideration should be given to the following:

(a) Where staff are in attendance, an evacuation plan, which is known and fully understood by everybody, will help minimise accidents and may save lives.

All doors of buildings, transmitter and vault enclosures should be easily opened from the inside, even though they may be locked from the outside. Padlocks or similar devices which require a key should not be provided on any door or gate which may require opening in the event of emergency exit by a workman, unless a key is located permanently near the lock. Bells associated with fire alarms or panic alarms should be so placed that they can be heard in every room which may be frequented by staff.

A case is on record where a building in which the studio of the local broadcasting station was located, caught fire, and the announcer unaware of the fire continued his duties. The sound-proofing of the studio had prevented him hearing the fire bells outside.

(b) The very nature of the work at some large stations involving work on high power equipment and tall structures, operation of mechanical aids, operation of high voltage generating plant, etc., makes it essential that any emergency organisation should include a first aid rescue crew. This rescue crew is needed particularly during the periods of work when large scale construction and rearrangements are in progress. Nevertheless, the nucleus should even be part of every shift where large numbers of people are on duty.

The importance of this need is emphasised by the case of a rigging crew erecting an antenna on a television tower. A sudden gust of wind swung the antenna and it knocked one of the riggers unconscious and caused a bad cut in an artery of one arm. His fellow worker could do no more than hold his thumb on the artery because of the situation of himself and the victim. The winch man on the ground who saw the accident immediately raised a panic alarm and the station first aid rescue crew were quickly on the scene.

(c) Vital circuit and equipment records should be safeguarded, as the loss of circuits, diagrams and other drawings of station equipment and plant could have an effect more crippling than the physical destruction. Duplicate copies should be held at a location remote from the station.

At one m.f. broadcasting station, a fire occurred inside a modulator control cubicle extensively damaging wiring and terminal blocks. The only wiring diagram of the transmitter had been mounted in a frame on the wall of the cubicle and was badly charred by the fire. It took staff two days to restore service, owing to the lack of wiring information.

(d) The great benefit of standby power plant, transmitters, antennas and other critical plant and equipment, in minimising the effects of disaster should be considered during the planning of a station or at times of upgrading of facilities. Standby facilities also provide for greater service reliability and flexibility during normal conditions.

(e) Alternative means of communication should be provided so that in an emergency some form of communication can be established. At many large stations, public address systems are common, radiocommunication is maintained with certain vehicles including the fire tender, and portable compressed air operated panic alarms stategically located are provided to summon aid in an emergency.

Where programmes are provided to the station by microwave radio links, the order wires on this system can be used as an alternative means of outside communications should the normal telephone cable network be out of service.

(f) In order to restore facilities as quickly as possible, a pre-arranged plan should be developed. Key men of the various trades groups should know what could be done if the normal facilities were lost.

Several failures of sectionalising insulators and inductors have been reported from m.f. stations using antifading radiators and it is wise practice with these structures to design the base matching network to provide for matching with the radiator normal, and also for the case should the sectionalising insulator or coil become faulty.

At some stations, a knife switch is provided at the sectionalising point to electrically bridge the mast sections and further switches are provided in the matching hut to allow immediate predetermined change to the network to meet the changed mast condition. At one 50 kW station where this facility had been provided, a most unusual situation arose. A guy insulator near the top of the structure had failed and during the operation of replacing the insulator, the top part of the mast crashed to the ground and damaged the standby radiator. Fortunately, there was sufficient inductance and capacitance available in the matching network to allow a rematch on the shorter mast and the station resumed transmission after a short break.

Another case of emergency action occurred when the power amplifier stage of a 10 kW m.f. transmitter was severely damaged when lightning struck the 230 m radiator and entered the transmitter tank circuit via the transmission line. The transmitter was of the low level modulation type and the operator isolated the power amplifier stage and coupled the 500 W penultimate stage to the transmission line and resumed transmission.

In an organisation controlling several stations, it would be expected that mobile generating plant, a self-contained transmitter, link system and the like, would be held at a central point for immediate transport to any of the stations.

(g) The prompt restoration of service after an emergency is often desired, and this aspect should be fully covered in the emergency plan. By commencing immediate salvage operations much equipment can be reused or damage minimised. For example, the quick removal of water from equipment cubicles, cable ducts, chases etc., can do much to hold damage to a minimum after a fire, particularly if the fire had been reasonably contained.

(h) Management is often primarily concerned with the safety of its own station staff, the security of its property and the uninterrupted flow of its services, whether they be broadcasting, television, or other form of activity. There is however another important consideration. There is the responsibility to co-operate with other authorities for general community protection. This involves working closely with various local and national authorities such as police and civil defence organisations.

(i) One aspect which is of importance to management is public relations in the event of a disaster. The public, and especially families of the staff working on the station, are entitled to prompt information.

An officer who has direct access to top management should be authorised to deal with reporters, local authorities, civil defence organisation and others who quickly descend on any scene of disaster.

STORM EMERGENCIES

Storm warnings are usually issued in sufficient time by meteorological authorities to permit emergency precautions to be implemented. Many large radio stations, particularly those operating in tropical areas where hurricanes, cyclones, and the like are prevalent, have pre-arranged plans to deal with these situations. Often the operating staff is supplemented by other shift operators and maintenance workmen, by recalling people for duty.

On receipt of advice of the approach of a cyclone etc., it is practice at several stations located in tropical areas to put many of the following measures into operation:

(a) Board up all large glass windows with shutters provided for the purpose. Particular attention to be given to those windows in transmitter halls and control rooms.
(b) Fit special hoods over transmitting air inlets to prevent water being sucked into the air duct cooling system.
(c) Fit additional temporary bracing to transmitter air outlet ducts, where these project on the roof.
(d) Start up emergency power plant, and where this plant is capable of providing full power for the station, switch all station plant to this service and isolate incoming mains at the switchboard.
(e) Check that station emergency battery lighting system is operating.
(f) Check fire alarm system is functioning by operating special test facility provided on the unit.
(g) Check with all staff present that they know the fire drill.
(h) Check with all staff present that they know the first aid rescue drill.
(i) Check that tarpaulins and plastic covering held for emergency situations are readily available.
(j) Cut off power to all buildings and areas not essentially requiring power.
(k) Check that automatic manhole drainage pumps are operational.
(l) Remove any chemicals that will heat or produce flammable gases in contact with water to a safe area.
(m) Check that mast lighting is operating when conditions warrant, and if out of order immediately advise the airport authorities.
(n) Check that antenna counterweight systems are free to operate and any normal travel limit stops have been removed. Where automatic winches are provided they should be fully operational.

(o) Where the station is subject to flooding:
  (i) Provide bulkheads and sandbagging to keep water out of ducts and chases, and check sealing of all ducts and pipes leading into building manholes and pits.
  (ii) Ensure drums of fuel and other flammable liquids are located above expected water level.

Figure 20.2 Damage to antenna system resulting from cyclone

At some stations, standing orders require that tall radiators be taken out of service and earthed during electric storms and that standby radiators be used, whilst others require that transmissions cease completely, during bad storms.

Figure 20.2 illustrates the extent of damage to one antenna system of a high power international broadcasting station located in the tropics following the onslaught of a cyclone.

BOMB THREAT

Explosives and incendiary devices have recently become powerful weapons in the hands of terrorists and others. Injury to staff and damage to equipment have been extensive. It is an escalating threat to radio stations, particularly studios, and procedures for dealing with a bomb threat must be included in emergency plans. Station personnel should be appropriately trained to deal with the problem, there should be tight security and good liaison should be established with outside authorities such as the Police, Ambulance and Fire Brigade.

Critical bomb locations in buildings used for studio purposes include:

Air conditioning ducts
Underfloor cable ducts and chases

Announcers console
Network switching centre
Cable distribution frame
Tape and record libraries
Film processing room
False ceilings over studios
Power switch room
Tape recording and replay rooms
Orchestral studios

Considerable damage has been caused at some transmitting stations as a result of the detonation of explosives. Masts and towers have been popular targets. Areas where explosives and incendiary devices have been placed include:

(a) Inside the transmitter cubicle by lowering the device through the air exhaust duct.
(b) Inside the power substation enclosure by using a long stick and string to place the device at a vulnerable point.
(c) On the base insulator of a tall radiator by strapping with cord or tape.
(d) On the anchor block of a mast guy by binding the device to the tightening screw.
(e) Near the antenna matching hut at the base of the mast.
(f) Inside the manhole carrying the programme circuits to the transmitter.
(g) At the base of the transmission line anchor frame near the transmitter building.

Bomb threat warning may be received in a number of ways, viz:

(a) Telephone call to a person within the organisation,
(b) Telephone call to Police, or some other outside organisation,
(c) Written threat.

In the event of a bomb threat being received by telephone, the person taking the call should endeavour to obtain as much information as possible from the caller. Some organisations who have had experience in dealing with these situations have a Bomb Threat Call Checklist Card placed near the telephone to facilitate assembly of data on receipt of a bomb threat call.

Staff should be suitably instructed in the bomb threat situation so that they may be fully prepared to meet it. Training programmes should be seen to possess certain qualities if they are to be successful. For instance, they should be recognised as having official support and backing and should offer high standards of realism and interest.

An Emergency Control Officer should be nominated to provide co-ordination and decision making for all emergency situations where large numbers of staff are employed, such as at studios. The Emergency Control Officer's primary responsibility should be to effectively control and direct all phases of activity relating to a bomb threat and subsequent search, evaluation and decision on the course of action in consultation with organisations or experts as considered appropriate to the circumstances.

As soon as is practicable after completion of an exercise dealing with a bomb threat, a full de-briefing should be held. Only in this way can the operation be evaluated so that lessons learned may be translated into planning for future operations.

SHUT-DOWN PROCEDURES

As part of the normal preparation for emergencies, plans should be drawn up for emergency shut-down procedures at the station. To bring about the shut-down of a large radio complex, it is often not just a simple operation of pushing a button, throwing a switch or directing an individual. At many stations, particularly where power is generated continuously on site, there may be complicated procedures which must be followed.

Plans should be established for standard or routine shut-down procedure when advance warning time of impending disaster is sufficient to accomplish this in an orderly way without danger to personnel or damage to equipment and plant. However, there must also be an established alternative plan for a crash station shut-down to meet this situation, should it arise. Emergency mains isolations or switches should be located in a prominent, easily accessible position and clearly identified as such so that all station staff are able to disconnect equipment in case of emergency. Particular emergency shut-down operations, which may involve safety of workmen or damage to plant, should be thoroughly examined in order to produce automatic built-in safety measures or fail safe devices.

In emergency shut-down procedures, consideration must be given to the special requirements of some form of lighting, means of ensuring that fire alarm facilities including alarms and pumps are on standby, and to communications aspects. Emergency situations can arise at any time of day or night. When they occur in the day time it is likely that there will be sufficient staff on duty at the station to deal with many situations which may arise. However, during night shifts, only minimum operating staff would be available and this aspect should be considered in drawing up plans to deal with particular emergency situations.

COUNTERMEASURES AGAINST FAILURE IN COMMUNICATION NETWORKS

Breakdown in national telecommunication networks occurs in unexpected places or in unexpected situations as a result of many causes. These causes can be man made in the form of vandalism, major cable rupture by earth moving machinery, and explosion as a result of gas leakage into ducts, collision by aircraft with tower, or they can result from natural disasters such as flooding, fire, lightning stroke, cyclonic or typhonic wind, heavy snowfall, earthquake and landslide.

Although many public telecommunication networks including broadcasting and television networks have inbuilt flexibility and equipment redundancy it is not possible to cater for every situation and in the event of disaster well planned provisions against disaster in the form of mobile type radiocommunication, broadcasting or television systems of various capacities and frequencies will do much to ensure the speedy restoration of the network. In the case of natural disasters when the public are also directly affected because of loss of life, damage to buildings, loss of transport and other essential services social reliance on the telecommunications network is very intense and speedy restoration, even if only by temporary facilities, will do much to ease peoples' minds at a time when they anxiously await information on plans for assistance or other vital news.

Fixed radiocommunication, broadcasting and television facilities now form part of most permanent public telecommunication services and much can be done during the design and installation stages to ensure that they are physically strengthened particularly against high wind, lightning stroke, earthquake, flood, landslide and heavy snowfall. Measures which should be taken into account include strengthening of the tower and antennas and support brackets to withstand violent earthquake shock, or high wind loading, reinforcement of equipment building, improved lightning protection facilities, automatic fire extinguishing system, installation of fire shutters, fire protection doors and the use of non-combustible building materials, security measures to prevent unauthorised entry to buildings and the tower, protection against long duration failure of commercial power by the installation of fixed emergency generating equipment or a mobile unit or increased battery capacity, protection of antenna systems from build-up of snow by the provision of shrouds or inbuilt electrical heating devices, design of buildings near the tower to take into account falling snow and blocks of ice dislodged from the tower and the decentralisation of radio terminals to improve network reliability so that all major broadband systems do not pass through a single station.

It is often impractical to provide the measure of security at every repeater or translator to the same degree as at major city terminals and stations but improvement in network reliability can be obtained by ensuring switching facilities are provided to allow the dispersion of broadband traffic or programmes through other paths should one particular route fail. In the case of the transmission of a television or sound broadcast programme to a network of transmitters it is practice in some countries to put the programme into a loop circuit configuration. By this means if one section of the bearer system fails as a result of disaster or catastrophic equipment failure at one or more stations, it is possible to change over quickly either automatically or manually to another back-up route.

When telecommunication facilities are put out of service for any number of reasons, early re-establishment of communication between isolated points or areas should be ensured by having available a range of radiocommunication facilities which will allow the disaster situation to be handled quickly and effectively. The aim should be to restore normal operation as quickly as possible. The extent of the back-up equipment will depend on many factors including organisational policy, the geographical size of the network, density of traffic in various parts of the network, the relative importance of traffic carried, the degree of redundancy of equipment in the network, the extent of multi-routing of transmission circuits and the physical security of station buildings, towers and equipment.

The time taken to restore service is influenced by many factors. These include site accessibility, the extent of damage, the age of the equipment, the availability of spare parts, the arrangement of the spare parts i.e. whether component parts, modules, units etc. the availability of manpower resources and the experience and competency of the technical staff sent to the scene. When damage is too extensive to allow on site repair it may be necessary to transfer temporary replacement facilities to the site or a suitable nearby site.

Experience with many real and trial exercises on restoration of communications following a disaster emphasises the importance of radio links for the control and direction of restoration activities. This involves the use of u.h.f. links to adjacent repeaters coupled to normal order wire facilities or where the disaster is in a remote area the use of a high frequency link to a base station either in a major city control point or country centre where it can be patched into a working communication circuit. In addition to the establishment of emergency facilities for the technical staff and engineers carrying out the restoration of communication services, facilities may be required by police, hospital, government and local public bodies concerned with recovery activity. Single channel systems operating in the v.h.f. connected to a switchboard at the nearest telephone office or up to 24 channels in the u.h.f. band could be established.

In the case of total or major damage to a microwave broadband repeater or terminal station transportable radio equipment is available. Some of the units available are very versatile. They can also be used to bridge failed junction circuits between major telephone exchanges, to interconnect a transportable telephone exchange into a network or to bridge a ruptured or damaged coaxial cable. Units are available with rotary antennas and operating in broad frequency spectrum segments between 1.7 GHz and 15.25 GHz with simplex, or duplex or stacked channel operation. The units are lightweight and if site access roads are impassable they can be easily transported together with any necessary zip-up mast and antennas to the site by helicopter. The overall versatility of the equipment in physical configuration offers use in equipment rack installation, tripod mounting, antenna tower location, table top or numerous combinations of these. Standard system capacity is 1200 channels or a colour television transmission circuit.

The complete restoration of a service following breakdown requires several stages of action which might be spread over a considerable period of time. The time required for initial restoration of service has to be kept to an absolute minimum but the period of restoration to normal is as a general rule not of great consequence. Some types of failures such as collapse of a mast or tower may require a long time for manufacture and construction of a replacement but initial service restoration may be restored relatively quickly by using a zip-up structure.

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Chapter 21

Staff Responsibilities

THE ENGINEER

It is the practice with many organisations employing large numbers of technical staff to have a co-ordinating committee to handle all major matters relating to safety. Engineers play an important role on the committees and one or more may be appointed as part-time 'safety engineers' with the task of establishment and application of an efficacious system of accident prevention.

The safety engineer is a specialist appointed by management to deal on the material and psychological planes with matters concerning the prevention of accidents. The measures he may use may be technical, psychological or organisational in nature. Good safety performance, however, will only be accomplished when the workmen themselves are impressed with the necessity of working safely. Most technicians, riggers, radio linesmen, mechanics and all other trade and group members, will willingly assume responsibility for the safety of themselves, their colleagues and equipment when management provides them with a well designed installation, is sincerely interested in, and backs solidly, a good safety programme and the men are equipped with the best safety tools and facilities available to do their jobs.

Some of the specific responsibilities of the safety engineer may be listed as follows:

(a) The regular audit of equipment and plant installation, maintenance and operating procedures, specialised tools and testing facilities to ensure facilities are working properly and staff are using them correctly and that in using them they are not exposed to hazards.
(b) By instruction, counsel and advice, assist line management to fulfill its responsibility for safety by the development, promotion, and maintenance of a continuing safety education programme. This involves the training and encouragement of staff to act safely and to do the job the right way.
(c) The direction or supervision of precautions for such catastrophies as fire, storm damage, collapse of structures, explosions, staff transport accidents and the organisation of the rescue service, in so far as there do not already exist other special services.
(d) The maintenance, analysis and interpretation of accident and injury statistics, accident cost data and follow up investigations into accidents.
(e) The maintenance of liaison with National Safety Councils and other such bodies in so far as they concern the radio organisation.
(f) The dissemination of fundamental safety knowledge by the preparation of safety booklets, manuals, bulletins, etc., for use by first line supervisors.
(g) Recommendations on procedures for the introduction into service of new

installations, plant and apparatus in so far as operational safety is concerned.

(h) Inspection and clearance of new safety devices.

(i) Checking of designs of temporary facilities such as anchorages, guys, scaffolds, structures, equipment re-arrangement and power feeds for safety.

(j) Liaison with design engineers to ensure that facilities are free from inbuilt hazards or operating difficulties.
Facilities should be made to fit the people who operate and maintain it and not as so often happens, people having to fit the facility. In some installations valves associated with water return equipment of vapour phase cooling systems have been installed in inaccessible points underneath major components.

THE STATION MANAGER

A properly qualified and experienced officer should be in charge of the operation and maintenance of the station plant and directly responsible for its safe operation. For the purpose of this exercise, the local officer-in-charge has been designated as station manager, regardless of his local title.

In a large station complex involving more than one site and several different trade group disciplines, the duties of the station manager may be delegated for any particular section of the station work to a foreman, supervisor (or otherwise designated senior staff member) who should report to the station manager as required on all aspects of safety.

When the station is under normal operational control the officer-in-charge of the shift should be responsible for ensuring that the directions of the station manager are carried out, and that in all other respects, the safety rules are observed.

When any of the station equipment or plant is undergoing test by installation or specialist staff not normally under the control of the officer-in-charge of the shift, the senior specialist officer should be responsible for the safety of the equipment and staff working on it, and for any nonstandard conditions that may be caused by other operational equipment.

The duties of the station manager in so far as his safety responsibilities are concerned may be summarised as follows:

(a) To create and issue local safety instructions.

(b) To hold safety meetings with foremen, supervisors and other key personnel, and to instruct them in safety procedures.

(c) To make safety inspection tours of work areas at frequent and regular intervals.
The station manager should have a definite system of regular inspection to cover all equipment and plant on the station. Not only may hazards have been overlooked in the planning and installation of newly installed facilities, but more important, the daily wear and tear and changes made may cause hazards to develop which are likely, in the absence of adequate and regular inspection, to come to light only when they result in an accident.

(d) To arrange for the issue of hard hat and protective clothing.

(e) To take charge of the storage of flammable liquids and explosives.

(f) To arrange for ambulance, doctor or hospital services as required.

(g) To investigate all accidents and prepare report for submission to the responsible engineer.

(h) To ensure that no workman is permitted to operate, adjust or maintain any equipment unless he is suitably qualified to do so, has the necessary consent and that adequate safety precautions are being observed.

Staff required to work on high voltage equipment must be trained by competent and experienced instructors. Only after the station manager is satisfied that the workman has the knowledge and ability to handle high voltage equipment and is thoroughly familiar with the safety rules and procedures, should the workman be permitted to operate, adjust or maintain the equipment. The operation and maintenance of some high power radio equipment calls for highly skilled staff. *Figure 21.1* shows part of the control console of a 2 MW transmitter and indicates the extent of metering and control facilities provided for a transmitter of this power.

Figure 21.1 Control console of 2 MW transmitter (Courtesy US Navy)

(i) To ensure that all staff working on the station, and including those employed by contractors, are fully aware of such matters as the location of fire extinguishing plant, safety equipment, first aid equipment, building emergency exits and the presence of live conductors in the vicinity of the work.

(j) To keep a station log book showing all changes in plant or equipment conditions. He should read and sign the log book when assuming duty and sign again on ceasing duty.

(k) To ensure fire extinguishing equipment and services are adequately maintained, readily available at all times and that every operational shift includes at least one person instructed in the use of that equipment.

(l) To ensure first aid equipment and safety aids are properly maintained and readily available at all times.

(m) To keep in safe custody any key or device forming part of any safety facility, where this is required by the rules.

(n) The station manager should not accept responsibility for the action of staff of contractors working on the station equipment or plant which has not been accepted. Nevertheless, he should ensure that nothing is done that might endanger the safety of these workmen.

Equipment or plant which has been taken over from a contractor should be subject immediately to the normal control and restrictions. The contractor's staff should not be permitted to again work on the plant unless they have the approval of the station manager and unless all work is carried out strictly in accordance with the safety rules and procedures applicable at the station.

(o) To promote good housekeeping.
There should be a proper place for all materials, tools and equipment and they should be in their place when not in use. Waste materials from installation or maintenance work should be removed from the area of operations immediately. When workmen must climb over or go around discarded materials, equipment, tools or piles of rubbish, the danger of accidents is increased unnecessarily. The station manager should be on the alert to ensure that this danger is eliminated. Good housekeeping is a continuous condition which must be given proper attention and thought.

Accidents which have occurred on radio stations due to poor housekeeping include:

(i) Slipping on concrete floor as a result of oil leakage from a transformer tap. A drip tray should have been provided.
(ii) Tripping over transmitting tube placed on floor during tube replacement operation. The tube should have been placed in a socket position provided on the tube trolley.
(iii) Tools dropped from a mast during erection. The workman should have used a bag to hold his tools.
(iv) Injury to hand while handling transmitter packing crate lid. Nails should have been removed before discarding the crate.

(p) To ensure that complete and up-to-date circuits of all equipment on the station, together with all necessary operating instructions, are available at all times to staff who may require them in the course of their work.

(q) To ensure that all staff concerned are advised immediately of any change in critical circuit setting or adjustment, and are given all corresponding operating instructions.

(r) To impart to every workman on the station the understanding that the violation of established safety rules will not be tolerated.

SUPERVISORY STAFF

Supervisors at all levels are responsible for the completion of work efficiently, economically and safely, through their own efforts and those of the staff they control. As maximum efficiency, economy, and safety cannot be secured without the earnest support and co-operation of all staff, the role of the supervisor is a most responsible one. Supervisors are in a key position to help in achieving these objectives. They know the work and are familiar with the risks and hazards involved. They are constantly at the workface and have a degree of intimacy with it unequalled by anyone else in the organisation. Furthermore, they are in a position to know the individual workmen so well, their abilities, sense of co-operation, safety habits and reaction to authority.

In many work situations it may be impracticable to eliminate the hazard completely and steps must be taken to control its effects. In most cases the two necessary ingredients for an accident—hazards and men—are present, and both must be controlled to prevent accidents. Hazards are controlled by the provision of interlocks, guards and other appropriate devices, while the workmen are controlled by the supervisor who sees that the men follow prescribed safety procedures. Quite obviously the effectiveness of these methods of accident prevention depends heavily on the supervisor and his ability to accurately locate the hazards in the work environment, to effectively control them and the action of his subordinates.

The main responsibilities with respect to safety, of the supervisor of each trade group may be summarised as follows:

(a) To adopt such precautions as are within his power to prevent accidents and to see that the safety rules are observed by workmen under his control.
    Before commencing work in which potential hazards exist the supervisor should hold a short safety session with the workmen involved to discuss the hazards, and the safety practices to be adopted. It is important that the workmen be encouraged to participate in these discussions.

(b) To ensure that all new employees are carefully instructed as to the hazards of the work and how to avoid them, are issued with a copy of the station safety rules, have read the rules and correctly understand them.
    Failure of a supervisor to warn workmen who have very little or no knowledge of potential dangers of work on which they may be engaged can be considered as negligence.

(c) To take steps to prevent unauthorised persons from approaching places where work of a hazardous nature is being carried out.

(d) To prohibit the use of any machine, tool, test equipment or other device unsuited to the work in hand or which has not been properly tested by competent people.

(e) To encourage the wearing of safety apparel, such as safety glasses and hard hats, in areas where their use is recommended or is mandatory.

(f) To ensure that workmen when working in isolated places, such as aloft on a mast or tower and where a foreseeable event could result in serious injury, are provided with a means of communication with other workmen.
    Portable two-way radio equipment is provided on many stations for this purpose. Also, many structures where staff may be required to carry out adjustment work on antenna systems and sectionalising coils are fitted with a telephone jack point.

(g) To first obtain the permission and clearance of the station manager before permitting any member of his staff to work on equipment which is operational or undergoing test.

(h) When equipment or plant has failed in service and staff are engaged on location and repair of the fault, he must see that under no circumstances is life endangered in order to reduce the duration of the breakdown.

(i) To ensure that safe handling and lifting methods are practised by workmen under his control.
Whilst workmen are expected to carry a reasonable load, the supervisor should see that where awkward or heavy material is being handled, adequate staff or mechanical aids are used to do the work safely.
(j) To give full support to all safety activities, procedures and programmes.

If more than one person is engaged on work on or about transmitters, transmission lines, antennas, masts or towers which are energised or could be expected to be energised or in any other hazardous area, then in the temporary absence of the supervisor, one of the persons should be designated as officer locally in charge of the work. The employee instructing the workmen would be considered to be in charge of the work.

THE PROBLEM OF THE SMALL STATION

One of the major problems confronting the safety movement is the failure of small organisations engaged in radio engineering activities to prevent accidents to staff. The importance of this is emphasised by the fact that small stations, such as those employing say ten or less technical staff, employ a large percentage of the total technical radio workforce.

Certainly the advantages of preventing accidents are just as important to the small station management as to the very large station management but it is surprising how many attempts to improve the safety performance of small organisations, in general, have been far from fruitful. Some of the reasons why many small groups have failed to achieve a high standard of safety have been due to the following:

(a) Management of many small organisations has often been reluctant to make funds available for works which would not show a definite and prompt profit on the investment.
(b) Even a high accident rate in a small workforce produces accidents so infrequently that management has not been impressed by the seriousness of the problem.
(c) The responsibility for safety throughout the organisation has not generally been vested in any one particular officer.
(d) Where responsibility has been invested in one officer, such as the Chief Engineer, management has not given him sufficient authority to ensure implementation of an effective safety programme.
(e) Very few small stations maintain a record of accident statistics.
(f) Only a few of the organisations have shown interest in the activities of national safety groups.

ORGANISATION CHART

An organisation chart, or written statement, clearly showing the division of responsibility between officers and employees down to and including all supervisors on the station should be posted conspicuously in offices, workshops, depots and in other places where the number of employees and the nature of the work warrant it. It should also be included as part of the book of safety rules.

SAFETY RULES

A safety rule should not be established unless there is a need for a rule, the rule can be followed, and the intention is to enforce it.

Enforcement of rules is necessary to ensure the complete success of any safety programme. Disciplinary action should be avoided until management has thoroughly discharged its safety obligations, and every effort has been exhausted in securing voluntary co-operation. However, in the final anlaysis, disciplinary action for failure to follow a rule must be taken or the rule will essentially cease to exist. Management action must indicate beyond any doubt that certain safety violations cannot be tolerated. Firmness in securing conformity with such safety rules would be consistent with the wishes of the majority of staff on the station.

Safety rule books should be furnished to every workman by the station manager. Suggestions to management for changes in, and additions to the book, would normally originate with the supervisors, but subordinate staff should be encouraged to submit suggestions.

The main considerations in the establishment and maintenance of safety rules are that:

(a) They be few in number, easily understood and practical.
(b) They be carefully explained to each workman when he receives the book containing the rules.
(c) Supervisory officers always set a good example by following the safety rules themselves.
(d) Safety rules have equal application in all sections of the station work.
(e) No rule be published which cannot be enforced.
(f) Prompt corrective action be taken for failure to comply with safety rules, the emphasis being on education of the group, rather than punishment of the individual.
(g) Each published rule be covered by a general instruction issued by the engineer or station manager.
(h) Each hazard covered by a safety rule be definitely demonstrable as unsafe.
(i) Safety operating practices not be called safety rules.

General safety rules which have been issued by one organisation for staff at its radio stations are shown in the following Example.

EXAMPLE 21.1

RADIO STATION
GENERAL SAFETY RULES

The Safety Rules which are listed below have been formulated, not as restrictive measures, but as guides to workmen and supervisors in their co-operative efforts to prevent accidents.

One of the important points to keep in mind about your job is the necessity for working safely and following the safety regulations which apply for each operation.

Certain safety rules have a substantial impact on the safety of an individual or the entire workforce. A single violation might place the safety of many workmen in jeopardy. For these reasons, an intentional violation of the following Safety Rules will result in immediate disciplinary action.

No Smoking

Smoking in Flammable Liquid Store Rooms, Battery Rooms, Control Rooms, Tape Recorder Rooms, Power Generating Rooms, Filter Cleaning Rooms, near Petrol Bowsers and other areas so designated on the station is strictly forbidden.

This rule is necessary because some materials in these rooms or areas are highly flammable.

A match or cigarette carelessly thrown away could start a fire that would endanger many lives.

In those areas where smoking is allowed, take care to use the ash trays provided and avoid doing anything that might start a fire.

Observe All Safety Keys, Locks and Tag Rules

Safety keys, locks and tags are used throughout station equipment to protect personnel and equipment.

Unauthorised removal or replacement of locks, keys or tags, misuse of such locks, keys or tags or operation of a control that has a tag attached is a very serious offence.

Use Safety Devices

Workmen are paid to use the safety devices provided or installed on the equipment and plant they operate. Use of such devices makes each job a lot safer and in most cases easier.

For his personal protection, a workman is not permitted to make a safety device inoperative or to remove it. Also, equipment must not be operated if the safety device is not functioning properly.

Wear Personal Protective Devices

Personal protective devices such as safety glasses, hard hats, gloves and safety belts are provided on certain jobs because of an indicated need.

It is emphasised that personal protective devices do not eliminate hazards. They are a second line of defence which protects the workman from injury provided that they are used.

Refusal to wear such devices may lead to disciplinary action.

Wear Proper Clothing

Staff working near machines or on masts and towers should not wear loose fitting clothing.

Where heavy material is being handled, safety shoes should be worn. Staff working near or on high voltage equipment, machines or on masts and towers should wear appropriate footwear. Open toe or loose footwear will not be permitted.

Metal finger rings must not be worn by staff who are required to work on radio or electrical equipment.

Do Not Operate Unless Authorised

No equipment or plant is to be operated by any workman unless he is properly qualified to operate the equipment or plant, and has the authority of his supervisor to do so.

To operate most equipment and plant on a radio station in a safe manner, specific training and skill are required. Failure to observe this rule could be dangerous to you and your fellow workmen.

Horseplay Prohibited

Horseplay is dangerous and a poor excuse for fun. Horseplay includes any act which may startle or distract a person from his work. Horseplay has resulted in serious injury, and even death, and will not be tolerated on station property.

Seek First Aid Promptly

Prompt first aid should be obtained for any injury, even though of a minor nature.

The treatment may prevent complications and will enable your supervisor to take steps to prevent a similar accident. The investigation by your supervisor might reveal a hazardous condition that could lead to a more serious injury if not promptly corrected.

Fire

Make yourself familiar with the local arrangements for giving an alarm and the procedure to be followed in the event of fire outbreak. Notices giving details of these arrangements are displayed prominently throughout the station.

Good Housekeeping

Tidy and systematic working methods should be employed in your work to ensure that jobs are carried out safely and efficiently. In particular, do not leave materials and tools lying on the floor where others may trip over them.

Remember that no job is finished unless left in a neat and tidy arrangement.

FIRST AID RULES

The safety rules book should contain or be accompanied by the following:

(a) A list of names, addresses and telephone numbers of doctors, ambulances, fire brigade, civil defence units and members of the organisation who are to be called in emergencies.

(b) A copy of rules of first aid, methods of resuscitation and fire extinguishment.

These first aid rules should be issued to every employee and also posted in conspicuous locations throughout the station and in work vehicles.

When the nature of the accidents that occur on radio construction sites and the conditions in which they occur are considered, it will be realised that the availability of first aid facilities and the presence of personnel trained in first aid are of major importance.

Radio stations are as a general rule in a remote or isolated location and immediate assistance of medical aid may not be available. Certain accidents such as electric shock or those accidents occurring aloft on structures need immediate attention, and the chances of survival mainly depend on the promptness with which such attention is given. In cases of electric shock where asphyxiation is caused by muscular contraction or paralysis of the respiratory system there is an excellent chance that the victim can be revived if artificial respiration is promptly applied. There is a 95% chance of saving the injured person within the first minute, but only 25% chance from the fifth minute onwards.

In addition, there are certain mistakes to be avoided in the minutes immediately succeeding the accident; such mistakes can reduce the chances of successful medical treatment. It is as important to know what should not be done in the event of an accident, as it is to know what should be done. This shows how desirable it is to have staff qualified in first aid on all operational shifts of the station. Workmen or supervisors who have received practical training and who are in charge of first aid boxes can save lives or reduce the extent of injuries. The names of all qualified station first aiders should be posted near each first aid box.

INSTRUCTING WORKMEN

Every new workman on the station should be told immediatly on taking up duty that he will be required to observe safety rules. He should be informed of the hazards of his work and advised how he can reduce the danger of accidents to himself and fellow workmen. A procedure alone does not of itself bring safety into an activity. There must be complete adherence to the procedure established and this must be accomplished through education of the workmen and enforcement of the rules.

With safety procedures involving such vital matters as lock-out, flag and/or tag rules, education of any workman must begin the very first day he commences work on the station. There can be no ignorance concerning this rule.

Every organisation should have a definite programme for training of personnel along safety lines. Sufficient time and effort must be given to training the men in the safe way to do their jobs. The men should be trained to select the safe as well as proper tool, taught to get into the safest position and to make the proper use of safety equipment. All of the safety procedures should be in writing and readily available to every workman.

Special courses should be conducted by qualified instructors. These courses may well include such things as emergency resuscitation, fire extinguishment, basics of first aid, the use of safety equipment and mast top resuscitation techniques for those staff required to work on masts and towers.

QUALIFICATIONS AND FITNESS OF EMPLOYEES

The organisation should use every reasonable means and precaution to assure itself that each employee, particularly those holding positions of responsibility, is technically qualified and is mentally and physically capable of performing his work in accordance with the safety rules and any other applicable rules, codes or regulations.

For radio lines staff and riggers required to work on masts and towers, the organisation should ensure that only those workmen certified medically fit for this type of work are employed. To ensure the continued fitness for this employment, workmen should undergo periodical medical examinations.

VISITORS TO RADIO STATIONS

Visitors should be prohibited from approaching any live radio or electrical equipment or other hazardous equipment or plant unless accompanied by a qualified member of the station staff who would warn the visitors of the danger attendant upon such approach. He must take all necessary steps with regard to safeguards, to ensure the safety of the visitors and ensure that safety rules applicable to visitors, are observed. For instance, some authorities require all visitors to construction sites to wear safety helmets, and some also specifically prohibit private vehicles being driven on access roads near antenna systems.

No visitor is to be permitted to operate any equipment or plant on the station without proper authority.

Visitors must be kept away from where high density electromagnetic fields may exist, because of the possibility that some persons may have metal or plastic implants or may depend on cardiac pacemakers.

It is the practice at some stations, particularly those operating on high power, to issue a card or brochure to all visitors on Safety Information for Visitors. The brochure generally contains the following:

> Brief description and purpose of the station. Powers and peak voltages that may occur during transmission. Plan of the area, showing those considered dangerous from the point of view of voltage, power density, line clearance etc. Instructions regarding movement of pedestrians. Instructions regarding movement of vehicles on the site. Reasons for insisting on an escort.

Safety precautions for staff and visitors at some of the early high power wireless telegraphy spark stations left much to be desired and many serious accidents resulted. *Figure 21.2* shows the extent of protection at one station. These practices are not acceptable today.

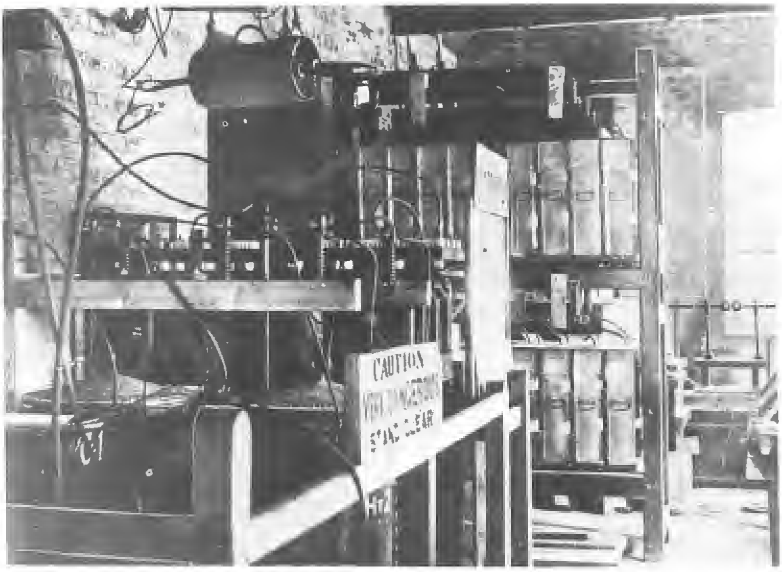

Figure 21.2 Early wireless telegraphy transmitter (Courtesy The Marconi Co.)

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Chapter 22

Aids and Facilities

SAFETY AIDS

A supply of first aid equipment, protective clothing, safety aids, fire extinguishing plant and equipment sufficient to enable employees to meet the requirements of the safety rules should be provided on every station. First aid and fire extinguishing equipment, in particular, should be provided in conspicuous and suitable places throughout the station buildings, near line matrix switching equipment, coupling huts, power house, line material storage depots and also in vehicles used for construction work or the transport of staff.

The nature and extent of medical attention provided, and the first aid facilities, must be sufficient for the needs of the employees, having regard to the hazardous nature of the work at the station, and the distance from hospital or other medical assistance.

Many minor injuries can be treated satisfactorily at the job site if adequate first aid facilities are maintained. All staff on the station should be encouraged to receive training in first aid, and supervisors must ensure that every workman has been instructed as to how to secure first aid, when needed.

The kinds and quantities of safety aids, facilities, devices and equipment which are required will depend on many factors. The following list is typical of aids and facilities provided for a large staffed station:

(a) First aid outfits including stretchers.
(b) Insulating wearing apparel such as insulating gloves, insulating appliances such as rods, and tongs for any necessary handling or testing of live equipment or lines as well as insulating shields, covers, mats and platforms.
(c) Protective goggles and helmets of suitable materials and appropriate construction.
(d) Portable signs such as 'Men at Work', 'Danger', and the like.
(e) Fire extinguishing devices either designed for safe use on live parts or plainly marked that they must not be so used.
(f) Earthing devices for making protective earths.
(g) Fixed or portable lighting equipment.
(h) Test equipment and probes.
(i) Safety belts, ropes and ladders.
(j) Panic alarm and communication systems.
(k) Ear muffs and ear plugs.

High power transmitting stations, because of the large physical size of the equipment, plant and facilities, make it possible for a workman to be trapped inside a transmitter, antenna switching enclosure or room, vault room or electric substation. In areas where this is possible, panic alarms with conspicuously marked buttons or pull cords should be installed in easily accessible locations to permit a workman inadvertently trapped or enclosed in the area to make his predicament known to other workmen in the vicinity.

Safety helmets must be worn by staff engaged in operations where there is a risk of injury from falling objects. All helmets worn on radio station premises should be made from first class insulating material and should be properly cared for to ensure that they are always in good condition. There are many things that can affect the life of plastic type helmets found on many stations. Solvents and hydrocarbons in particular can seriously affect their life. Materials and conditions which may reduce the strength of plastic type helmets include:

Excessive exposure to the sun and heat.
Solvents from certain glues used with stick-on type labels.
Certain solvents, oils and chemicals used in cleaning and construction activities.
Solvents from paints, thinners and varnishes.
Mechanical abrasion resulting from improper storage with tools etc.

All protective devices, tools and equipment on which the safety of workmen depend, should be inspected and/or tested at intervals of not more than six months. The inspection should apply to all devices, tools and equipment, whether actually in use or not at the time of inspection. Any devices, tools or equipment found unfit should be withdrawn from service to be discarded or repaired, and should be replaced by sound equipment. On completion of the inspection the inspecting officer should enter the date of the inspection in a register kept specifically for the purpose and certify that all such tools, devices and equipment held are in good condition, where such is the case.

Protective devices such as guards over belts of blower motors, shrouds and other forms of cover, must always be in position when the machines are running.

Figure 22.1 Danger notice near dissipative line

Such protective devices and also electrical protective devices should not be removed or rendered inoperative, unless the machine is stationary and has been deliberately immobilised to prevent its operation while the protective devices are out of action.

Permanent 'Warning' signs forbidding entrance to unauthorised persons should be displayed in conspicuous places at all unattended and unlocked entrances to equipment rooms, transmission line switching areas, antenna matching huts and power rooms containing hazardous exposed current carrying conductors moving parts. Suitable 'Danger' signs should be placed on or near equipment or plant having exposed high voltage conductors. *Figure 22.1* shows an application of this philosophy to a 500 kW water cooled dissipative line at a high frequency broadcast station. The message has been spelt out in three languages.

The control room at a transmitting complex is often located in an area remote from the equipment it controls, and an operator who takes local control of a transmitter for test purposes may not be able to observe equipment in the vault or water cooling and steam condensing areas. In these cases, fixed intercommunication systems should be provided to allow communication between workmen. A well designed system would allow for communication between all main isolated sections of transmitters and between the control room and all high voltage areas, antenna switching matrix, antenna matching huts, power house, programme input rooms, and other critical areas.

Communication devices, which may be a telephone connected directly to the control room or other continuously staffed point, are also desirable at locations near antenna systems, particularly where the systems cover a large area and involve tall structures or operate at high powers.

NOISE

The noise level of high velocity air blowers in some transmitter equipment, and engine generating units in power rooms, may cause hearing damage, but significant reduction of sound levels in many cases can often be both extremely difficult and expensive. Measures to house noisy units and machinery in noise insulating enclosures can be effective but in many cases create a host of other problems. Where it is not practicable to eliminate high noise levels, suitable reduction in level to operating staff may be achieved by the use of ear muffs or ear plugs.

If operators are exposed to high noise levels for only a few times a month, such as for regular testing of emergency generating plant and earplugs give acceptable protection from that noise, then the provision of earplugs would be more economical than ear muffs. Also, there will be environments such as exist at stations in the tropics where the earplugs may be preferred to earmuffs from a comfort point. However, ear muffs give greater attenuation to noise than ear plugs. An external ear muff gives an attenuation of 25 to 40 decibels whereas a waxed cotton wool ear plug gives about 20 decibels attenuation. Rubber plugs have a range of attenuation of 18 to 25 decibels and a silicone rubber plug individually moulded varies from 18 to 28 decibels depending on tightness of fitting.

Figure 22.2 shows a typical ear muff provided for operators at one television station comprising four transmitters with high velocity air blowers.

Figure 22.2 Ear muffs for protection against noise

It is the responsibility of management to ensure that operators are protected against any noise of sufficient level and duration which is capable of causing damage to hearing. However, unless safety rules relating to the use of ear protectors are made and enforced, experience has shown that many operators will cease using them either from discomfort, inborn carelessness or other reasons.

EMERGENCY EXITS

The laying out, marking out and recognition of exits and thoroughfares is most important. All exits and thoroughfares should be instantly recognisable not only by those personnel working on the station but by visitors to the station and others, who may be called in to deal with an emergency situation, such as fire brigade officers. The path of escape must be unmistakable.

Each room or area and each working space about equipment and plant should have suitable means of exit which is kept clear of obstructions. No emergency exit should be fastened or obstructed against egress during periods of occupancy. All exits, especially emergency exits, must open freely and there must be no doubt that locks or other fixing devices function properly in a limited time period. As they are emergency exits, the correct key must be kept next to the lock. One arrangement is to house the key in a thinly glassed box adjacent to the door. However, devices which do not require keys are strongly recommended.

If the plan of the room or area and the character and arrangement of equipment and plant are such that an accident would be liable to close or make inaccessible a single exit, as in the case of long narrow equipment rooms, spaces behind transmitters and high voltage units, a second exit should be provided where practicable. As a basic rule, particularly where high power equipment is concerned, a workman should have at least two safe exits to freedom. If possible, the exits should lie in opposite directions. The provision of two exits so located as to render the cutting off of both at one time extremely improbable is fundamental to safety.

The layout of equipment and plant, particularly in high power transmitter areas, matching huts for antenna systems, antenna switch buildings and enclosures and other high voltage areas should be such as to provide access and egress in a safe manner. A workman entering the room, building or enclosure should enter a safe area and not one with exposed live equipment and conductors. A workman leaving the same area should enter a safe area. All doors and gates should open in the direction of egress with the exception of sliding doors, which are permissible in exits through fire walls between such areas as the transmitter and the transformer vault.

WORKING ALONE

No person should work alone on a transmitter or any other radio or electrical equipment, or carry out testing or experimental work on such equipment where the voltage, whether d.c., power frequency or radio frequency exceeds 350 V peak between conductors, or between a conductor and earth, except in routine operation or testing where live parts are properly guarded.

With some large organisations it is practice to have at least three operators on every shift where high power transmitters are involved, particularly where installed in an isolated location. The main consideration being safety rather than equipment requirements. In the event of an operator being hurt, one would be on hand to give immediate first aid to the victim while another would be free to raise the alarm and seek medical assistance.

The continual observation of a workman engaged on the testing, adjustment or maintenance of high voltage equipment must be mandatory because in the event of a person being the victim of a severe electric shock or paralysed and cannot let go, he is in either case virtually helpless to summon aid. Immediate help can be given by those who recognise the problem, and then only if they can see the victim and know what to do.

The importance of these rules is shown by the case of a workman carrying out alterations to a transmission line switch located inside a wire enclosure at the rear of a 10 kW broadcast transmitter. All equipment within the enclosure was protected with the exception of a 10 kV busbar supplying e.h.t. to the transmitter. The busbar was mounted about 2.4 m above floor level. A flashing red light system was installed to operate when the enclosure door was opened with the transmitter operational, but no gate switch interlock was fitted. The workman disabled the flashing red lights, apparently because they were too close to his work, mounted a small step ladder, and while working on the earthed switch his head contacted the bare 10 kV conductor. He was killed instantly. Although the presence of the live conductor was known the workman was allowed to work alone in the hazardous situation without action being taken to properly guard the conductor, and to locate an observer near the transmitter.

The practice of allowing workmen to remain inside an enclosure with live high voltage equipment should not be permitted, other than under exceptional circumstances and then only after a senior officer, preferably the engineer or station manager, is completely satisfied that the workman is in a safe position, clear of all hazardous electrical and mechanical plant, and that he is under constant observation by another workman who is outside the enclosure and who can shut down the plant if necessary. The dangers of this practice should be realised by all concerned, as several accidents have resulted from workmen staying within high voltage enclosures while tests were being conducted. Every possible avenue should be explored to obtain the necessary information or to carry out the operation without a workman being placed in such a hazardous area.

FIRE EXTINGUISHING FACILITIES

Adequate approved fire extinguishing equipment should be conveniently located throughout the station and clearly marked. Any appliance which has not been approved for use on energised equipment should be plainly and conspicuously marked with a warning to that effect.

All fire extinguishing equipment should be inspected at regular intervals by competent people, be easily identifiable and always be readily available. Care must be taken to ensure units are not so close to the equipment they are designed to protect that they might become inaccessible if the equipment catches fire. Also, extinguishers must be placed outside small equipment buildings as well as inside.

Workmen trained in the proper use of fire extinguishing equipment should be on duty for every operational shift of the station. When work is performed outside normally staffed hours, the station manager should ensure that at least one member of the staff working, additional to the shift supervisor, knows the action to be taken should an emergency arise. All staff occupying supervisory positions, whether on a permanent or temporary basis, should be instructed in the proper use of all fire extinguishing equipment and services.

Equipment and rooms fitted with automatic CO_2 or similar systems should be fitted with an interlock system to protect staff when they are working on the equipment or in the room so fitted. The dangers of carbon dioxide when used for fire extinguishing purposes are those of suffocation and of reduced visibility. The officer making the system inoperative should hang a sign on the doors leading to the area to indicate that the fire extinguishing equipment has been disabled. Where the equipment is remotely controlled a notice should also be displayed on the panel containing the remote control facilities. The restoration of the system to its correct mode should be the responsibility of the officer who disabled it.

Action to be taken when fire starts should be along the following lines:

(a) Isolate power from the equipment involved.
(b) Raise the alarm in accordance with local instructions.
(c) Shut down all forced air cooling devices.
(d) Attack the fire with facilities available.
(e) Report the occurrence in accordance with local instructions.

FURTHER READING

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Part 2

Operations and Maintenance

Chapter 23

Electrical and Radio Equipment

WORKING NEAR HIGH VOLTAGE EQUIPMENT

The electrostatic discharges experienced by staff working near unshielded high voltage equipment, such as transmitter tank circuits and high power antenna matching networks, do not as a general rule constitute a direct hazard but they may lead to accidents of a secondary nature. Currents even slightly in excess of an individual's threshold of perception might produce apprehension, fear or other adverse reaction. A surprise might be associated with an involuntary movement resulting in loss of balance, a fall, or contact with a high voltage conductor or a dangerous mechanism, with serious injury as an after effect.

If a workman stands on a good earth, for example the copper floor of an antenna matching hut, near a large high voltage inductor, and he has footwear of zero resistance, then he will be at zero potential with respect to earth. A capacitive current will flow from the high voltage inductor to his body and from his body to the copper earth sheet. This capacitive current results from the distributed capacitance between the high voltage inductor and his body. If, however, his shoes are not of zero resistance, as is the normal case, or he is standing on a wooden box, and he touches an earthed metal panel, then the current will flow through his arm.

When the workman is insulated from earth, an arc will jump from his body to an earthed metal object as soon as the distance between his body and the object becomes sufficiently small enough. The charge between his body and earth will be suddenly discharged and the workman's potential immediately drops to zero. The discharge occurs in the form of a damped oscillation which has an extremely small duration but is associated with a relatively high current since the charge is removed in a very short time. This high current of short duration causes a shock, and unintentional reaction of the muscles, especially if the individual is not prepared for the shock.

During the testing of one dual frequency 50 kW matching network an engineer received burns to the toes of a foot as he passed one of the high voltage rejector coils of the network. The floor of the building was covered with copper sheet. The charge between his body and earth discharged through the metal brads on his leather soled shoes and resulted in small but annoying burns to the toes.

A similar experience was cited by maintenance riggers during the early days of the high power v.l.f. station at Rugby. When the workmen were transported by lift to the top of any of the 270 m masts, no electrical effects were noticed because of the shielding properties of the lattice steel mast. However, on the open platform at the top near the antenna termination points, the field was so intense that a workman could easily draw sparks from the brads of his shoes. Some workmen related how they could read the Morse keying of the

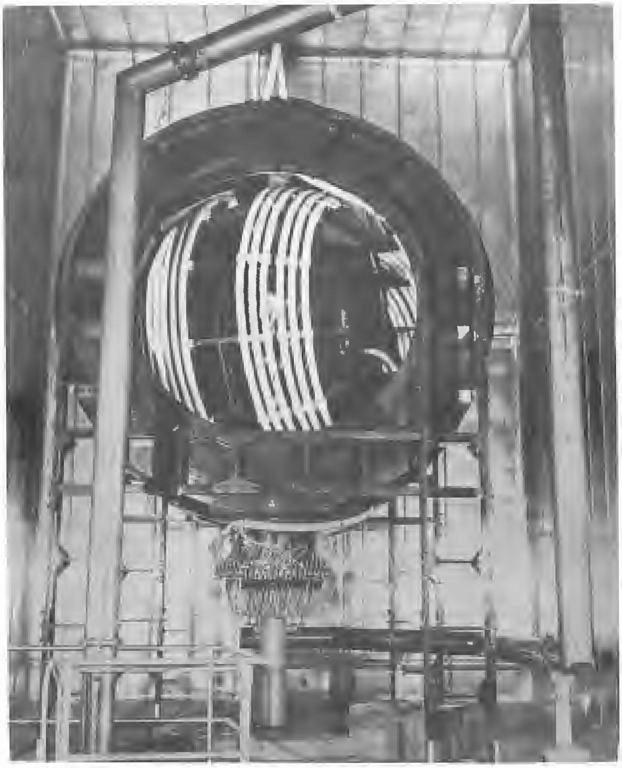

Figure 23.1 High power variometer (Courtesy US Navy)

transmitter by this means.

Figure 23.1 shows a large variometer associated with a 2 MW v.l.f. installation. The field produced by this inductor would be hazardous to a workman should he be allowed near it when it is energised. Some inductors associated with high power v.l.f. systems are about 7 m high and 4 m in diameter and formed from two Litzendraht conductors, 5 cm thick run in parallel to reduce copper losses and potential gradient. They are mounted in rooms completely shielded.

If it is necessary for a workman to be inside a normally enclosed area, such as a matrix switching hut, combining hut or antenna matching hut in connection with observation, adjustment or checking purposes when power is applied, approval should only be given subject to:

(a) Direct communication facilities being set up between the workman in the enclosed area and the officer controlling the transmitter.
(b) Power to the equipment being applied only when requested by the workman in the enclosure.
(c) The workman in the enclosure taking up a position which is considered to be safe from contact with high voltage.
(d) The doors of the enclosure being kept unlocked and where possible in an open position.
(e) A second workman standing by to keep the workman in the enclosure under constant observation during the test period.

Although it is not usual to permit workmen to work on live medium frequency radiators it is nevertheless still practised at a few stations, mainly to allow staff to replace mast lighting lamps during the normal daylight hours of transmission. In these situations the same capacitive discharge problem exists. Wooden ladders without wire reinforcement in the stiles or fibreglass types are used to give the necessary insulation, but during contact with the steel mast, and again on breaking contact, the arc can be of some concern. The usual practice is to carry a metal tool, and to contact the structure quickly and firmly. Once in contact with the steel, the workman will not feel any arcing. On breaking away from the structure, the tool is removed off the steel as the last act, when the body is on the ladder and clear of the structure. Ladders must be long enough and placed so as to make simultaneous touching of earth and any live part absolutely impossible.

EARTHING PROCEDURE

Proper earthing of radio and electrical equipment is extremely important particularly when working with high voltages. Conductors and equipment properly earthed can be a life saver, but when earthed through the body of a workman can be fatal.

When an enclosure contains equipment or conductors which may be subject to peak voltages in excess of 1000 V and which are accessible when the enclosure is opened without the use of a tool, earthing switches should be provided to earth those high voltage parts, before access is possible.

When making temporary protective earths on a normally live circuit of radio equipment, the following precautionary measures should be observed, with the earth being made to all conductors which are to be considered as earthed. However, no connection of the conductor to earth should be made until it has been positively verified that the part of the system concerned is completely isolated from all power supplies:

(a) The workman making a protective earth on equipment or lines should first connect one end of the earthing device to an effective earth connection supplied or made for the purpose.

Although insulated stranded wire, similar to the one shown in *Figure 23.2*, is widely used for earthing devices, some organisations require that only sash chain be used owing to the danger of wire breakage inside the insulation. Another arrangement is to use a flexible stranded copper wire covered with transparent insulated sleeving to allow visual inspection of the condition of the conductor.

(b) The normally live parts which are to be earthed should next be tested for any indication of voltage, by means of probes or other appropriate test equipment, the workman carefully keeping all portions of his body at the distance required from such parts when alive, by the use of suitable insulating rods or handles of proper length, or other suitable devices.

Only approved type voltage detecting test equipment should be used for this verification. The detecting device should preferably have self checking facilities to enable it to be tested before and after the verification. Great care must be exercised in dealing with high voltage equipment. A circuit should not be assumed to be dead even when the switch is turned

Figure 23.2 Typical transmitter earthing wand

off and, in particular, when the switch is under remote control. Relays and switches may be inoperative, fusing may be incorrectly wired and a fault may have rendered the switch ineffective. Also a fellow workman may fail to hear the instructions to operate a switch or he may inadvertently operate the wrong switch.

(c) If the test shows no voltage, or the local operating rules so direct, the free end of the earthing device can then be brought into contact with the normally live part and securely clamped or otherwise secured thereto before the workman proceeds to work upon the parts.

(d) In working with high voltage equipment, all earth connections must be carefully checked by using a test instrument such as a voltmeter in the first instance, and then when no voltage is detected, an ohmmeter. Visual inspections can be dangerous and should not be relied upon. Clear synthetic lacquers and chemical finishes may prevent an effective earth being obtained. Many lacquer and anodising treatments are transparent to the eye but make good electrical insulators. Paint, lacquers and rust should be mechanically removed before attaching an earth connector.

(e) On transmission lines and antenna elements, portable earthing devices handled directly by means of insulated handles, rods or ropes may be employed.

The use of portable earths for the protection of radio linesmen working on transmission lines, including lines used for slewing purposes and antennas carrying high voltages at radio frequencies, deserves more attention than is frequently given. It has been practice at many stations for linesmen to work between short circuits or bridges and earths placed on either side of the transmission line section to be worked on, in addition to isolating the line ends, closing earth switches and the application of hold keys or tags. However, such practice does not always ensure adequate protection at high power transmitting stations where transmissions continue on other circuits, because of high energy pick up from radiations or coupling from adjacent lines. Nor does it give protection from violation of line clearance due to human error. Experience has shown two and sometimes three low impedance earths may be necessary in the field at high frequency stations. One should be installed directly at the work location, a second at a quarter wavelength distance at the transmitting frequency towards the transmitter and the third at a similar distance towards the antenna. Where several high power transmissions are taking place, more earths may be required, and test instruments should be attached to the line to ensure that the voltage has been reduced to a safe level.

The same basic principle should be adopted when working on a high frequency curtain antenna system with multiple feeders and dipoles. As high induced voltages are likely to exist on feeders, dipoles, reflector elements, guy ropes etc. care should be taken during the stage of gaining access to the work area. Appropriate clothing, headgear, footwear and gloves should be worn to minimise contact between skin and metal parts of the antenna system and structural elements. In addition to disconnecting the transmission line all vertical feeder lines should be bridged and earthed at their lowest ground point. If work is to be carried out on the feeder, bridges or short circuits should be placed on both sides of the work point and within one metre of the work point. Whether or not gloves are required to carry out the repair work after completion of safety arrangements will depend on the level of any voltage which may exist. Since dipoles on the antenna system are resonant elements considerable care is necessary in working in this area. Detuning of dipoles may be necessary by placing bridges at appropriate positions on the feeder away from the element feed point.

At some radio stations, remotely controlled switches are employed to connect antennas and transmission lines to earth. These are mainly for equipment protection from lightning, and workman should not rely on them as a prime safety device.

(f) The protecting earth, should not be removed from the earth connection until the device has been disconnected from all normally live current carrying parts.

At high power transmitting stations care must also be exercised to ensure proper and effective earthing of metalwork of vehicles prior to refuelling operations. An arc produced near exposed fuel, although not an electric shock hazard, can have serious consequences. A low impedance earth system should be installed in the refuelling area, and all bowser metalwork properly connected and bonded thereto, and a flexible lead provided for connection to vehicle bodywork. The use of rubber conducting tyres has proved satisfactory for the discharge of static charges from vehicles but not completely satisfactory for earthing of radio frequency voltages induced by the high radiation field, because of the difficulty in providing a sufficiently low impedance path to earth.

EARTHING HIGH VOLTAGE CAPACITORS

The earthing wand or stick attached to transmitters and other equipment using capacitors connected to high voltages should preferably be fitted with an auxiliary testing probe wired in series with a suitable current limiting resistor. First contact with the capacitor is made with the probe. If a capacitor is holding a charge, it will be safely discharged to earth, and the normal earth connector can then be placed on the capacitor terminal. Attempts to discharge high voltage capacitors without the current limiting resistor frequently result in a loud report from the arc, and may cause physical reaction by the workman, and subsequent damage to tubes and other nearby components.

Capacitors should normally have a discharge path between live terminals to ensure they are discharged to a safe potential before access can be gained by personnel. The discharge path may be through a permanent bleed circuit or a temporary mechanical device automatically applied after disconnection of power or on opening an access door. Care should however be exercised where bleeder resistors are used. Firstly, because of the time constant, discharge is not instantaneous, and some circuits have a time constant of about one minute. Secondly, bleeder resistors may become open circuit due to burn out, poor contact etc., and become useless as a protective device. Thirdly, with the modern approach to modular construction, even with high power equipment, the bleeder resistor network may be installed in another module and will give no protection against capacitor charges if modules are isolated during fault finding activities.

Special care is necessary in earthing where high voltage capacitors are connected in series, as it is not sufficient to earth just one terminal of the capacitor bank, nor is it sufficient to momentarily earth the terminals one at a time. The capacitors will still retain some charge. The safe practice is to short circuit and earth all terminals. In some transmitter installations a device is mounted on each capacitor and is so arranged that movement of a control mechanism short circuits each capacitor.

High voltage capacitors which have been removed from circuit should be discharged and the terminals short circuited with a copper strap which should remain in position until the capacitor is put back in service. The same requirement holds for high voltage capacitors held as spares in store. This safety requirement prevents the capacitor from recharging. It is a phenomenon of a large capacity, high voltage capacitor that it will partially charge itself when stored in certain environments even though entirely disconnected from any d.c. source.

Where it is necessary to test or measure a voltage across a capacitor normally operating at 1000 V or more, the test probe should not be handled while the circuit or component being tested is energised. The following precautions will assist in safely performing measurements:

(a) The power source must be disconnected.
(b) The busbar supplying the capacitor must be discharged with a suitable

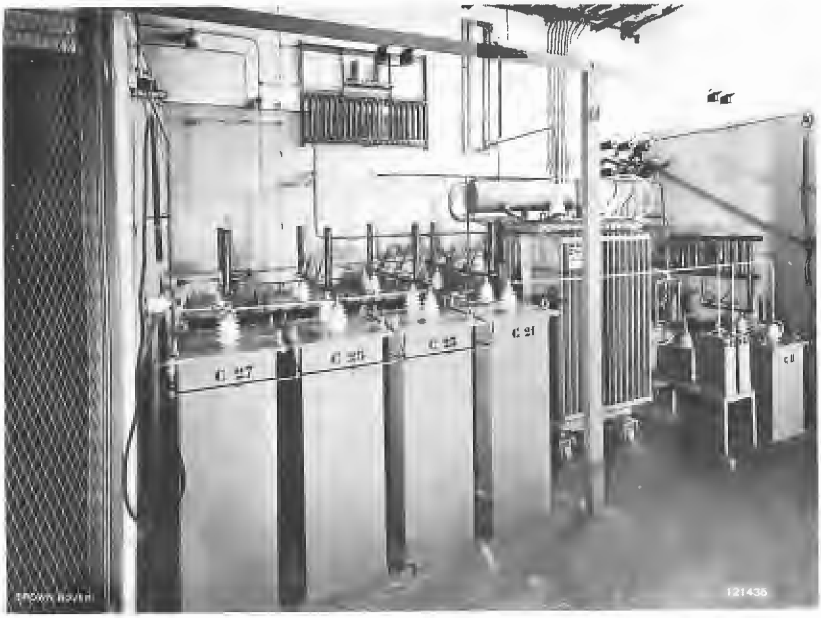

Figure 23.3 Filter cell capacitors (Courtesy Brown, Boveri & Co.)

earthing wand or stick. The operation should be repeated several times to ensure complete discharge.

(c) The controls of the test equipment must be set correctly for testing the voltage. Test leads capable of safely carrying the voltage should be attached to the desired test points.
(d) Staff must withdraw to a safe position from the component under test and the test leads.
(e) Only after completion of these precautions should the protective shorting and earth connections be removed and the circuit re-energised.
(f) After completion of the measurement or reading, the power source must be disconnected and made free from voltages as indicated in item (b) above, before removing the test leads.

Figure 23.3 shows the capacitor units associated with one high power medium frequency transmitter installed mid 1950s. The eight capacitors are each 10 μF and rated for 12.5 kV d.c. The earthing wand can be seen on the left wall of the cubicle.

ISOLATING TRANSMISSION LINES AND ANTENNAS

Before any work is done on an antenna, transmission line or antenna switching matrix, the r.f. supply must be disconnected. After the transmitter has been closed down, the system should be solidly earthed (or short circuited as appropriate) and any associated apparatus, such as matching circuits, must then be disconnected if other antenna systems on site are still active.

Particular care must be exercised when working on tall antennas and associated transmission lines during periods of thunderstorm activity. To protect riggers and other staff against lightning discharges, it is the practice at many stations to prohibit work on structures, transmission lines and antenna matching equipment when a thunderstorm is active in the area.

A system of keys or tags (or both) should be used to ensure that the external plant cannot be powered while work is in progress. Where motor or pneumatically driven antenna or line switches are used, the system of keys and tags must be so devised as to ensure that no antenna or transmission line can be energised while work is being done on it and also that the switches cannot operate while work is being done on or near the switching equipment itself. If more than one maintenance party is engaged, a separate tag may be required for each party.

The system of keys or tags should be such as to ensure not only that the antenna or transmission line cannot be powered while work is in progress, but also that there is no danger from neighbouring radio frequency circuits (either through direct contact or through coupled voltages) or from any power supplies, such as mast lighting, that may be carried by the conductors.

A check must be made at a number of points by means of a suitable probe or meter to ensure that no radio frequency voltage, or any other voltage, exists on an antenna, switch or transmission line before it is touched.

Similar safety rules should apply to buildings and rooms containing equipment for switching, tuning, combining or matching of antennas or transmission lines. Such buildings or rooms should normally be kept locked to prevent the entry of unauthorised persons.

If it is necessary to apply power to the equipment for the purpose of carrying out tests or making adjustment, the safety rules must be fully observed and these should include the establishment of direct communication either by telephone or radio link between the point where the tests or adjustments are being carried out, and the transmitter control point. Great care should be exercised during any work on radio frequency circuits to ensure that conductors carrying high r.f. voltages are not opened.

Pawley[1] makes the following comments where staff must work near energised radiators:

'In the case of v.h.f. and u.h.f. aerials, it is necessary to insist that any screens that are provided should be in place while the work is being done. A minimum distance should be specified at which staff may work in the neighbourhood of live aerials and the tally system should be such as to ensure that no aerial can be powered that would create danger for staff working on the mast.'

If workmen must depend on others for operating switches to isolate equipment on which they are to work or must secure special authorisation from a superior officer before themselves operating such switches, the responsibilities of both parties must be clearly defined and understood by each.

The officer authorising the work, usually the station manager or his delegated officer, should be responsible for the following:

(a) Thoroughly familiarising himself with the work to be done and understanding the extent and nature of the protection required.
(b) Arranging and directing the application of necessary protection measures.
(c) Clearly conveying an explanation of the protection provided to the workman carrying out the work.

The party leader who is to perform the work should be responsible for:

(a) Making certain that sufficient and adequate protection has been provided, and for conveying to the men working under his control an exact knowledge of the boundaries of the protection and the equipment upon which it is safe to work.
(b) Establishing a means of communication with the officer authorising the work.
(c) Being at the location of the work when the authority-to-work is cleared.
(d) Estimating and reporting the expected time of normal clearance and emergency clearance, when requested.

The following precautionary measures should be taken, in the order given, before work is begun on or about the equipment or lines concerned, as a means for preventing misunderstanding or accident:

(a) The workman in charge of the work to apply to the station manager (or his delegated officer) to have the particular transmitter or other equipment, transmission lines or antennas isolated, identifying them by position, number, letter, colour or other means.
(b) The station manager at his discretion, to direct the proper person to operate all switches and isolators through which electric power may be supplied to the particular transmitter or other equipment, transmission lines or antennas to be isolated, and to direct that such switches, isolators and the like, be locked and/or tagged with a tag of a distinctive character, indicating that men are at work on the equipment.
(c) All remotely controlled switches, such as those associated with transmitters, antennas or transmission line switches, to also be blocked or locked out where necessary to avoid operational errors.
(d) A record to be made when placing the tag, indicating the time of disconnection, shut-down or isolation, the name of the man making the disconnection, shut-down or isolation, the name of the workman who requested the disconnection and the name of the officer who directed the action.
(e) Where the transmitter or other equipment, transmission lines or antenna systems can be made alive from two or more sources, all such sources to be disconnected. This rule to also apply to transmitter vault equipment which may provide a common power source for two or more transmitters, parallel transmitter installations using combiners or paralleling equipment, and antenna systems energised by more than one transmitter.
(f) When all the switches and isolators have been opened, blocked and tagged the station manager to require that protective earths be made upon equipment and lines which have been made dead, and that they be reported to him when so placed.
(g) Upon receipt of information from all persons operating or fixing earthing devices that protective earths are in place, the station manager to inform the workman who requested the isolation of the equipment or line, that the specified equipment or line has been isolated and earthed, and that he may proceed to work.
(h) The workman in charge to then confirm that no voltage is present on the equipment or line by checking with a suitable apparatus. This may be done by the use of voltage indicators, measuring instruments, glow discharge

lamps for indicating radio frequency voltages or other suitable means.

(i) The workman in charge to next immediately proceed to make his own protective earths on the equipment or lines on which he and his staff are about to work. Such earths to be made between the particular point at which work is to be done and every energy source. For example, when working on a transmission line connected to a dual frequency radiator, energy could come directly from the transmitter, down the line, or indirectly from a second transmitter via the coupling equipment, up the line. The earthing connections should be very short compared with the wave length.

(j) The workman in charge, upon completion of his work and after assuring himself that all men under his direction are in safe positions, to remove his protective earths and report to the station manager that all tags and keys protecting him may be removed and indicating his location at the time of reporting.

(k) The station manager to then direct the removal of tags and keys for that workman. Upon the removal of any tag or key there should be added to the record, the name of the workman who requested the removal, the time of removal, and the signature of the person removing the tag.

The actual key control system will depend upon local instructions and situations. In many modern installations, keys form part of the interlocking arrangements for transmitters and line matrix switches, and as long as these keys are removed, the equipment cannot be energised or operated. At some stations the interlocking keys are handed to the workman who will work on the equipment or the line, while at others the keys are not removed from the building. Instead, the keys are placed in a locked case in the transmitter control room and the key of the case is handed to the workman.

Before re-energising a transmitter, transmission line or antenna the station manager must satisfy himself that there is nobody at work on the equipment or plant, that any work which may have been in progress has been sufficiently completed to permit safe operation, that no apparatus or tools are left in or on the equipment or plant and that all testing or auxiliary apparatus connected for the purposes of testing has been removed.

BATTERY SYSTEMS

Batteries systems at large radio station complexes may be extensive. The voltage is normally 50 V and four banks each of 200 Ah capacity would be typical for a high power broadcasting station with processor control equipment.

Battery rooms should be provided with adequate ventilation, particularly during charging, to exhaust gases and to minimise explosions. Over 20% hydrogen in air has been measured in some battery rooms with large banks and inadequate ventilation. Although it is common knowledge that hydrogen is released from lead acid cells and that a hydrogen-air mixture is explosive, batteries are disarmingly familiar and the hazard is not always recognised. The enclosed type is particularly innocent looking but it is more dangerous than the open type if ignition occurs, because the gas is confined and will explode with greater violence. All naked lights must be kept away from battery rooms and smoking should be prohibited near these rooms.

Many explosions with batteries have been set off by sparks caused by staff working on the batteries, but ignition of the explosive mixture could be caused by any of the following:

(a) Loose battery connections.
(b) Connection or disconnection of battery leads.
(c) Shorting of cells or busbars by metal tools, wire -and other conducting materials.
(d) Naked flames from matches and lead burning torches.
(e) Sparks from testing instruments.
(f) Static discharges from insulation materials.

To safeguard against explosions, all enclosed cells should be fitted with anti-explosion devices to prevent flash-back into the cell from any gas ignited outside the cell.

Protective goggles should be worn during installation and maintenance activities on enclosed type cells under all conditions where any risk of ignition exists.

Where electric fans are used to improve ventilation they should be of the sparkless type, i.e. an induction type without brushes or starting switches.

Whenever it is necessary for staff to carry out work in a battery room, the doors and windows should be kept open or if the room is totally enclosed the ventilation fans must be kept running for the period of the work.

Racks used to support batteries should be substantial, and be made of either wood or metal so treated as to be resistant to deteriorating action by the electrolyte, and provided with non-conducting members supporting the cells or with suitable insulating material on conducting members.

Floors of battery rooms should preferably be of acid resisting material or be painted with acid resistive paint or otherwise suitably protected where acid is likely to drop or accumulate.

Storage battery rooms should preferably be lighted by incandescent lamps in keyless sockets controlled from outside the room, if practicable.

Where battery rooms are air conditioned, return air should not be taken from the room back into the air circulation system.

PORTABLE ELECTRICAL TOOLS

The continuing safe use of portable and semi-portable electrical equipment is basically dependent upon a properly engineered product, a system of routine maintenance attention, and the checking of all appliances before use. Accidents from the use of these tools are much too frequent. Many of these result from failure to earth the metal frame of the tool properly. Insulation which is defective may allow the frame of the tool to be energised, thus exposing the workman to shock. In many cases the direct injury from the shock is minor compared with the injury resulting from a fall from a mast, a ladder, scaffolding etc. because of the shock.

Environmental hazards experienced on radio stations are of major concern to the safety engineer. Typical hazards are:

(a) Performing work in restricted or confined areas such as inside transmitter cubicles, in floor ducts and chases, in ceilings etc.

(b) Performing work in wet or damp situations such as are often encountered when working on external plant.
(c) Performing work on masts, towers, scaffolding and similar types of structures where a slight shock from a faulty portable tool may result in a fall by the operator.
(d) Improper storage of the tools. Frequently they are thrown into tool boxes containing sharp objects such as chisels, hacksaws etc.
(e) Improper handling, such as hauling an electric drill aloft by using the lead as the hauling line.
(f) Physical damage to leads, particularly extension leads, by dragging them over installation materials, debris etc.
(g) Performing work in areas containing flammable liquids, leaky gas cylinders and explosive dusts.
(h) Performing work in an area where welding work is being carried out. Flames and hot metals can damage leads.
(i) Carrying out work, such as drilling, which requires penetration into an area containing live conductors.
(j) The absence of proper earthing on equipment or plant required to be earthed.

Supervisors should ensure that all portable electrical tools are equipped with three conductor flexible leads and that they are connected to the supply by properly fitted three pin plugs and sockets. The construction and the wiring of the tool should be such that all exposed metal parts are securely connected to the earth pin.

All workmen should be instructed in the safe use of portable electrical equipment. Such practices as disconnecting plugs from supply outlets or cord extension sockets by pulling on the flexible cord, carrying or lifting portable appliances by the cord and similar practices should be regarded as breaches of safe working procedures.

Workmen should be instructed to report all cases of overheating of the plug or flexible cord and evidence of arcing of the pins or contacts. In the event of any unusual occurrence, for example a blown fuse, failure of the tool to operate, or excessive sparking, workmen should immediately switch off the supply and return the tool and any extension lead in use with the tool to their supervisor, for inspection and checking.

The following additional points are relevant in the use of portable electrical tools:

(a) Locate extension leads in a position where they are not subject to damage. In radio station work, special attention should be paid to the danger of extension leads coming in contact with live conductors or other high voltage equipment.

    The use of makeshift arrangements to extend flexible cords are to be avoided at all times. If it is necessary to place leads across an area used by traffic, including pedestrians, and it is not practicable to suspend them overhead, a heavy board on each side will help to protect the leads.

(b) For areas and situations considered especially hazardous as regards electric shock, it may be preferable to use extra low voltage equipment. In this regard it is to be noted that in hazardous situations some electrical codes require the use of extra low voltage for hand lamps. Extra low voltage refers to a voltage normally not exceeding 32 V a.c. or 115 V d.c.

(c) To overcome possible hazards in the external plant environment, all portable power tools should be used with an earth leakage core balance relay unit.

(d) The generation of sparks at the interface of power tools brushes and commutator can create a potentially hazardous situation should the equipment be used in a combustible atmosphere.

(e) Protective goggles should be worn when using power tools that create sparks, flying chips or dust at the work interface.

(f) Care should be exercised in drilling into a wall, floor or ceiling which may contain live equipment or power cables.

(g) Where double insulation type tools are used they should not be earthed. Double insulation provides a suitable alternative to a single insulation combined with earthing of external metal.

(h) Where advance or preliminary radio installation work is necessary in a building under construction care should be taken when tools and/or extension outlets are plugged into the building constructors temporary power supply. The resistance of the earth and rating of fused may not provide adequate protection under all fault conditions. Special arrangements should be made for a check of the earthing and the fusing before tools are used in such cases.

(i) Flexible leads should be three core p.v.c. plastic cords of adequate current carrying capacity and should not exceed 35 m in length. Building type cables should not be used as flexible cords.

(j) Where long flexible leads are in use for long periods, the lead should not be allowed to remain in a coiled condition on a spool. Overheating has occurred in some cases damaging the cable to such an extent that the earth conductor came in contact with the active conductor.

(k) Dual or two way plug-in type of adaptors should not be used. For dual tool operation remote from the outlet, a three core insulated extension cord should be used to service the centre of activity. This extension cord set should be socket connected to a special double pole switched, dual outlet. Multiple outlets having more than dual operation should not be used unless protected by a double pole circuit breaker that will adequately protect the flexible lead.

(l) In a large radio station where many portable electrical tools may be held, one person should be held responsible for the storage and issue of these tools. Qualified electricians will generally be employed on such an establishment and could handle the control of these tools. However, it is not essential that the person responsible for storage possess electrical qualifications, but he should have some knowledge of the electrical features of the equipment. Each item of equipment, including extension leads, should be checked regularly. One means of ensuring this is to institute a routine test on each occasion the equipment is issued from the store. Suitable test sets are available for this purpose which will check for leakage current and continuity of the earthing conductor, and check the operation of the equipment.

All portable and semi-portable equipment and any safety devices in use must be subjected to inspection and test using equipment of an approved type by a qualified person at intervals not exceeding six months. Under conditions of heavy usage or rough treatment in the field, it may be preferable to carry out such inspection at more frequent intervals.

Depending on the type and size of the equipment, the frequency of its use, and the results of the regular inspections and tests, each piece of equipment may require to be completely dismantled and examined at regular intervals of about two years.

At the completion of the regular examination and testing, the workman responsible for this work would attach to each item of portable equipment and each extension lead, a durable label showing the date of inspection, or the date on which the next inspection should be carried out. A register of all portable electrical tools and extension leads is desirable to include details of the examination and tests and any repair work carried out.

Each portable electrical tool should be examined for:

(a) Damage to or loosening of the electrical connections.
(b) Damage to the flexible lead and plug.
(c) Damage to sheathing of flexible lead at point of entry.
(d) Firm termination of conductors with conductor strands being firmly held under terminal posts.
(e) Damage to the casing of the tool.
(f) Any other features which may give rise to hazards.

CARE OF GLASS ENVELOPE COMPONENTS

(a) Handling.

Experience has shown that transmitting tubes, cathode ray tubes and vacuum capacitors with glass envelopes are often damaged by small, almost imperceptible scratches in ordinary handling, resulting in later collapse. A glass envelope in a scratched condition often cannot withstand the great atmospheric pressure.

Any glassware whether transmitting tube, cathode ray tube, vacuum capacitor etc will suffer damage when knocked. The damage is often invisible, but nevertheless the glass surface may have been ‘bruised’. A tiny crack or flaw may open up and residual strains and/or steady atmospheric pressure will in time bring about failure.

It is a well known fact that even thick heavy panels of plate glass are cut to size by making a fine scratch on the surface with a sharp object and afterwards applying slight pressure to the sheet causing the glass to break where the scratch is made. Therefore, it is quite conceivable that the glass bulb of a transmitting tube, cathode ray tube or a vacuum capacitor will fracture as a result of a slight score on a critical section. The atmosphere exerts a pressure of over 1000 g/cm^2 on the outside surface of the tube and there will consequently be considerable pressure on a large surface. For example, there will be a pressure of about one tonne on the viewing surface of a 35 cm diameter cathode ray tube.

If the glass envelope of any component contacts a surface or is wiped by a cloth that is not quite clean due to the presence of sand, dirt or metal filings, there is every possibility that the envelope will sustain some damage. Only a soft dry cloth should be used to clean the glass envelope. Wetting of the glass surface is not recommended by manufacturers, but if the surface of the glass is excessively dirty, aerosol may be used to clean it. The surface of the glass should be cold before the liquid is applied. A lint-free moistened cloth is generally used for cleaning purposes. In the event that a tube or capacitor is placed on its side, it should always be placed on material which will not scratch the glass surface. Corrugated paper box liner or a rubber pad is often used for this purpose.

Glass envelope components are carefully inspected at the factory to ensure freedom from surface damage, and there is little chance that a tube or vacuum capacitor which has a damage-free surface will implode. Components may however incur shipping damage that is not reflected in the condition of the shipping container. They are usually well packaged and shipped in a manner to assure safe delivery, but extreme shock could damage the elements and metal-to-glass seals.

Glass jacketed components are subject to damage if placed side by side and allowed to knock together. Every precaution should be taken to eliminate the possibility of bruising the glass surface as a result of bumping components together, or accidentally striking them with tools or fittings during installation and servicing. During installation, care should be taken to avoid twisting or bending strains that could cause physical damage. Heavy rigid straps or connections such as filament busbars that result in strain, either mechanical or from thermal expansion, should be avoided. Also they must not be used as stand-off insulators to support heavy assemblies. Some operators have used silicone base greases wiped over glass enevelopes to prevent an accumulation of dust but experience has shown that the disadvantages exceed the advantages and it is now seldom practised. If excessive grease is placed on the glass it results in faster dust collection and during the wiping operations or cleaning process, the abrasive dust results in scratching of the glass. The dust problem is aggravated by components subject to stress in high voltage d.c. fields, because of the rapid accumulation of dust particles by electrostatic attraction.

(b) Cathode Ray Tube Implosions.

The viewing screens of cathode ray tubes should be carefully covered by an implosion guard of suitable materials. The nature and thickness of the guard and the method of fixing should be such as to safeguard viewers fully against flying glass, and any other part of the tube which might be projected if it should implode.

Modern large cathode ray tubes used for television purposes have a moulded glass implosion cap cemented to the front of the tube proper. Not only does this do away with the necessity for the safety glass window in the equipment but renders the tube much safer in the event of catastrophic failure. Tests have shown that even when the tube is forcibly destroyed, the implosion plate remains intact, and the cement holds the shattered faceplate, preventing it from flying. It will be obvious however that whether the tube is with or without the integral implosion cap the same degree of care must be exercised in handling the tube. Many organisations insist that staff wear safety goggles and gloves when handling and installing these tubes. Residual electrostatic charges on cathode ray tubes may result in shock. Where a tube is provided with both external and internal conductive coatings, the coatings should be connected together before the tube is separated from its equipment socket.

(c) Transmitting Tubes

Transmitting tubes should be handled with the greatest of care as internal structure, glass-to-metal seals, ceramic-to-metal seals and envelopes are liable to damage if subjected to shock, acceleration or vibration. Safety goggles are to be used to protect the eyes from flying glass or ceramic particles when handling large tubes. The goggles should provide side and front protection and have clear lenses which will withstand a rigid impact test.

Tubes must never be lifted by the bulb, as the weight of the structure, particularly in the case of large forced air cooled and high power vapour phase cooled types, is sufficient to cause damage to seals. *Figure 23.4* shows the lifting arrangement developed for handling a vapour phase cooled tube in a 250 kW transmitter being fitted and adjusted during assembly of the transmitter. Long tubes like high power klystrons are susceptible to bending near

Figure 23.4 Rockwell-Collins Tubelifting Device (Courtesy Rockwell International)

the centre and they should be supported at two or more points when picked up. The ceramic-to-metal seals at the collectors can be easily broken by rough handling or lack of proper support.

When long bodied tubes such as water cooled and klystrons are dropped, set down quickly or roughly handled, forces exerted on the body and elements as a result of sudden accelerations can be destructively great. Shock mounted lightweight crates or special moulded rubberised hair packs are provided for transport purposes and tubes should be kept in these containers when not in service.

In the case of tubes having flexible leads, care should be taken to prevent the leads from striking the glass with the resultant possibility of breakage. The glass bulb should be shielded from direct sunlight which would otherwise cause unnecessary temperature cycling as well as having an undesirable weathering effect upon the glass. It is particularly important to avoid scratching the glass during handling and cleaning, as a small scratch will weaken the glass envelope materially and may possibly cause a crack during subsequent heating or cooling cycles. The metal-to-glass seal is probably the most critical part of the tube manufacturing process as it is difficult to make a completely stress free seal. The bond between the metal and glass is a layer of oxide of the metal which adheres very strongly to the metal, and part of which dissolves in the glass. As a general rule the bond is satisfactory and provided that the bond area is not subjected to excessive temperature, rough handling or attack by active agents, it will last the life of the tube.

All tube terminals and connectors must be kept bright and clean to provide good electrical contact. Tubes when packed for shipment are generally protected from atmospheric moisture and may be stored at temperatures ranging from about –35 °C to +55 °C. If the inner barrier bag is not sealed before storing, the tube should be protected from moisture and extreme temperatures by some other means. Before placing water cooled tubes in storage, water should be completely drained from any integral water jacket, where this is provided, to prevent corrosion in the passages. The ports should then be covered with a suitable material, such as pliofilm, to prevent the entry of foreign matter.

Tubes should be mounted in their housing before any straps or connections are made, and in such a way that they are not subject to any mechanical strains. The glass envelope should not be permitted to come in contact with any metallic body or flammable material nor should it be subject to drops or spray of any liquid. Connecting leads, sufficiently flexible to permit some movement without imparting stress to the terminal seals, are essential and there should be sufficient clearance between the connecting leads and the glass bulb to avoid possibility of a corona discharge, which could result in a puncture of the glass. When making connections, care should be taken to exert the least possible bending movement at the terminals, and the leads should always be disconnected before any attempt is made to unclamp the tube and remove it from its mounting.

The glass envelope of transmitting tubes become quite hot during normal operation. If it is necessary to remove a tube from its socket or housing before it has had time to cool, care should be taken that it is not put down on any cold or heat conducting surface, otherwise the sudden temperature change may strain the glass and cause it to crack.

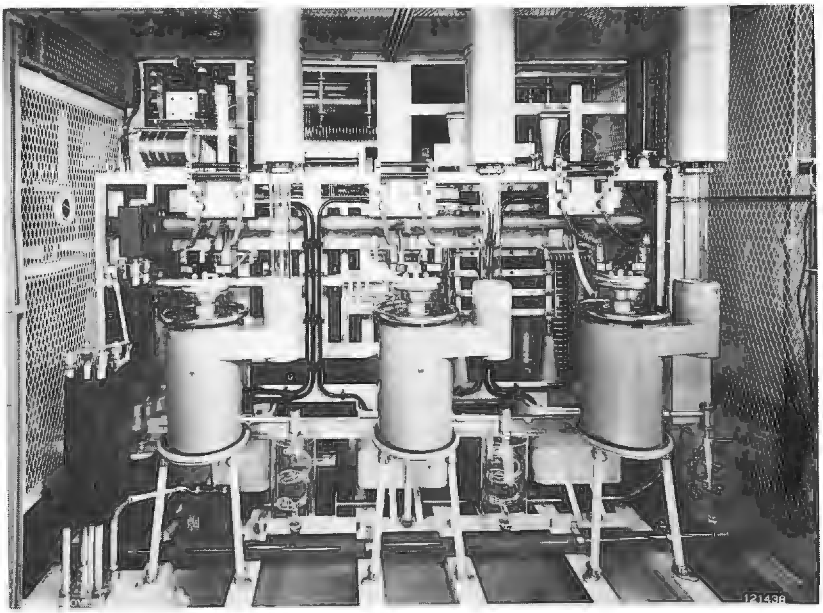

Figure 23.5 Final stage of 300 kW medium frequency broadcast transmitter (Courtesy Brown, Boveri & Co.)

Other glass components used in transmitters and which require care in handling include the insulated glass sections of the vapour cooling system. *Figure 23.5* shows the radio frequency final stage of a 300 kW medium frequency broadcast transmitter installed in 1970 with the three glass envelope tubes and the incoming and outgoing glass pipes associated with the vapour cooling system of each tube.

REFERENCE

1. PAWLEY, E. L. E. "Safety Regulations for the Staffs of Broadcasting Organisations", EBU Technical Monograph No. 3105, 2 ed., 1967

FURTHER READING

FORDHAM-COOPER, W., *Electrical Safety Engineering*, Newnes-Butterworths, London, 1978

Chapter 24

Mechanical Plant

TYPES OF MECHANICAL PLANT

The mechanical plant required for the installation, operation and maintenance of a large radio station complex will often be extensive. On the installation activities there may be such plant items as cranes, winches, tractors, pole hole borers, excavators, pneumatic drilling units, concrete mixers etc. On the maintenance activities some of the above may be required, and there may also be plant such as compressors, water pumps, air blowers, refrigeration and heating units, workshop plant, emergency engine generators etc., forming part of the radio system.

One of the important points to be kept in mind, not only in the planning and design of radio engineering work, but in carrying out this work, is the provision of proper safeguards for the workmen. Unsafe practices with mechanical plant can no more be tolerated than unsafe practices with electrical equipment.

The assembly, installation or erection of the mechanical plant associated with the radio station facilities is a major part of most large project activities, and adequate time must be provided on the works programme to allow for proper running-in periods during which adjustments may be required to ensure that the whole of the installation is co-ordinated into a trouble free and safely installed work. It has to be appreciated that each unit of plant is, as a general rule, but a link in a chain where one breakdown may delay the entire project. On the maintenance side, badly maintained plant will cause poor reliability in station operations, and unsafe plant may have a bad psychological effect on the staff.

COMPRESSED AIR PLANT

Compressed air and other gases are used extensively on high power stations. Typical applications of compressed air include transmission line matrix switches, transmitter shorting plane mechanisms, tuning drives, contact clamps for high r.f. current circuits, cooling of tuning elements and in the workshop of the station. Also dry air, sulphur hexaflouride and nitrogen under pressure are used in coaxial transmission lines, waveguides and high voltage capacitors.

In one modern 250 kW high frequency broadcast transmitter, compressed air is used to supply pressure on the r.f. contacts around the periphery of the tank circuit inductors, the balun and two cavity shorting planes. When the shorting planes are repositioned for a new frequency, the air pressure is first removed so the contacts do not slide. After they are in their new position the air pressure is again applied. Compressed air is carried to the moving shorting plane by plastic tubing loosely wound around the unused end of one of the inductor tubes. Compressed air also applies pressure to the contacts of the loading coil. Limited pressure is applied while the inductor is automatically tuned under reduced r.f. power and when in the correct position, full contact pressure is applied. Controlling the contact pressure minimises wear during tuning and yet provides adequate pressure to reduce contact heating. The requirement for compressed air per transmitter at 690 kPa is about 0.08 m^3 per minute continuously, for cooling one of the tuning elements, plus 0.03 m^3 per r.f. frequency change tune sequence. *Figure 24.1* shows part of the compressed air fittings, flexible supply tubing and the shorting plane peripheral contact system employed with this transmitter.

When improperly used, compressed air and other gases can cause serious injury which may result in death. It must not be assumed that a high pressure is necessary to cause injury. Serious injury has been caused by compressed air with a pressure as low as 69 kPa. If compressed air enters even a tiny puncture of the skin the affected part and sometimes the whole limb may swell alarmingly, with intense pain. Worse still is the hazard if the jet forces its way into the bloodstream, for

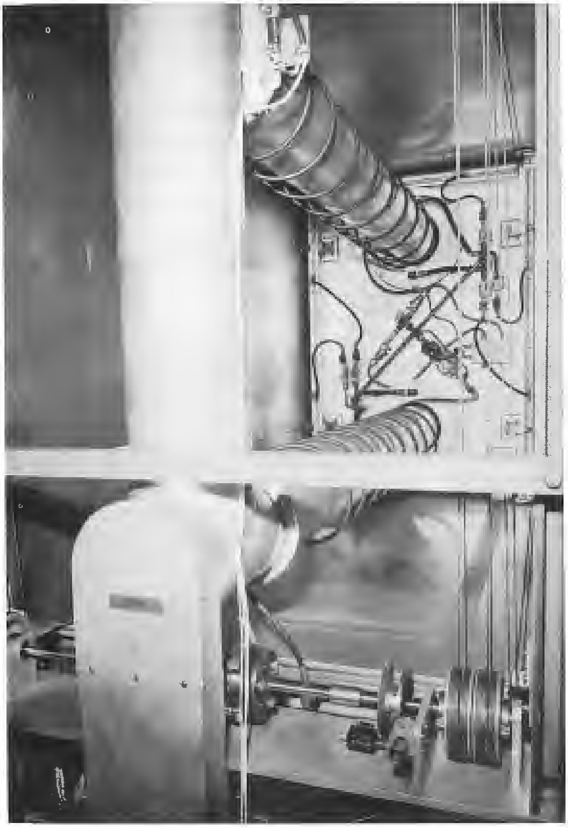

Figure 24.1 Compressed air fittings in transmitter cavity

it can travel until it reaches the small blood vessels in the brain, bursting the vessels to cause death.

When compressed air is used to clean out equipment and cubicles after work, care is necessary as there is a possibility of metal particles such as solder, wire cuttings, and also dust and grit being driven into the eyes and skin of the operator, his assistants or bystanders.

The following safety practices have been recommended at one large station when maintaining pneumatically operated equipment:

(a) All hose couplings to be in good condition and tightened up to the correct tension with the proper tool.
If the tailpiece or nut fractures with high pressure air in the line, serious injury could occur to personnel, or damage to equipment. A whipping hose in a transmitter cubicle may cause considerable damage to equipment.

(b) Flexible devices required for moving contacts to have regular maintenance carried out on the hoses to check for wear and possible damage from hot spots of the r.f. equipment. Air hoses in any way faulty should be removed immediately.

(c) The air receivers of the compressor to be drained and maintained at intervals as recommended by the equipment manufacturer.
In a large installation, one compressor system may feed one receiver tank at each transmitter, the matrix switch and other areas where compressed air is required.

(d) Safety valves to be tested at intervals recommended by the manufacturer to ensure they are in proper working condition. Seals on safety valves should not be broken or adjustments made, except by authorised inspectors.

(e) Should it be necessary to blow out a line or hose it is important to ensure that the end of the pipe or hose is so directed that no person will risk injury from the air blast or material projected by it. Hose ends should be firmly gripped to ensure the ends do not whip.

Many air dielectric coaxial transmission lines and waveguides use dry air under pressure supplied by an automatic dehydrator. Very few safety problems exist with this facility but some modern high power installations use sulphur hexafluoride gas to increase the power handling capacity of the system.

Whilst sulphur hexafluoride in its pure state is relatively non-toxic, the decomposition products that result during a voltage arcover situation form toxic gases including fluorine. This may constitute a hazard to station staff should a gas leak occur in the system. The toxic gases have been known to cause extreme lung irritation when inhaled. They are colourless and because their odour is difficult to detect their presence is not usually immediately apparent.

Where equipment containing the gas is inside the transmitter cubicle, or in the transmitter room area, adequate ventillation should be provided. Under a normal operational situation with scavenger fans and exhaust ducts, gas leakage is not a problem. However, care should be exercised when working in the vicinity on a transmitter which has been shutdown. Some installations have been provided with a valve mounted outside the building to allow the gas to escape and mix with the atmosphere should repair be necessary to the system or a change of gas be required following a flashover.

REFRIGERATION PLANT

Refrigeration plant is used on some large transmitting stations for cooling high voltage rectifier systems, and for chilled water equipment associated with transmitter computer or processor control units. Air conditioning plant on the station also uses refrigeration equipment. The following safety habits and protective measures are applicable:

(a) Only tools and equipment properly engineered for the purpose to be used.
(b) Care should be taken not to exert excessive pressure when tightening flare tube connections.
(c) Goggles to be used to prevent possible injury to eyes when working with or handling refrigerants.
(d) Under no circumstances is heat to be applied to a refrigerant cylinder by means of an acetylene torch. Should it be necessary to apply heat, a cloth which has been soaked in hot water should be used. A pressure gauge should always be attached to the cylinder.
(e) Before breaking any refrigerant connection, the connection to be loosened slightly, to be sure refrigerant in its liquid form is not present.
(f) A charged refrigerant cylinder must never be dropped or otherwise subjected to severe mechanical treatment.

The refrigerant used in many installations is freon 12. While this refrigerant is non-toxic and non-explosive, it should not be discharged into a closed room without ventilation, particularly if there is an open flame. Excessive heat will break down the freon into chlorine and fluorine gas, both of which are poisonous.

LIFTING HOISTS

Manually operated and electric power driven lifting plant finds wide application on a radio station during both installation and maintenance works. Some units such as those used for lifting transmitting tubes out of sockets may be required to lift only a few hundred kilograms but those required to handle large power and modulation transformers and engine generating sets may have to lift many tonnes.

Irrespective of the capacity of the plant, regular care is important from a safety viewpoint as well as for long life of the plant. The following safety maintenance inspection procedures are typical of these at many stations:

(a) All moving parts to be inspected at intervals recommended by the manufacturer, and immediate action taken to replace parts which may be out of tolerance.
(b) Ropes to be closely inspected over their whole length for signs of wear, kinks, corrosion, reduction in diameter, out of roundness etc.
(c) Brakes to be checked for their ability to stop the drive mechanism quickly, and for correct adjustment.
(d) Any chains used on the hoist to be carefully inspected for wear, broken or distorted links throughout the full length of the chain. Any link which

prevents free movement of the chain to be replaced where this is practicable. Otherwise, the chain to be discarded.

(e) Lifting hooks to be closely inspected to ensure that the throat opening is within manufacturers recommended tolerance. Hooks which have been bent, worn, damaged or are out of tolerance at the throat to be replaced.

(f) Rope drums and sheaves require regular inspection, particularly when operated in a gritty environment, such as in mast and tower erection work. When excessive groove wear has occurred, the sheaves to be replaced. Scored or rough surfaces to be smoothed, or the unit replaced.

(g) Regular lubrication of wire ropes and moving parts is essential. The type of lubricant applied to be in accordance with manufacturers recommendations.

(h) Any electrical equipment associated with the hoist, including motors, magnetic contactors, limit switches, and push button boxes, to be closely examined for correctness of operation and for safety, by a qualified electrician.

After inspection or any repair work, all guards and other safety devices to replaced before testing of the device prior to return to service.

WORKSHOP MACHINERY

A wide range of workshop machinery is generally necessary to satisfactorily maintain a large station complex particularly if the station is located in a remote locality. Part of the machinery installed in one station workshop is shown in *Figure 24.2.* It includes a large lathe, sheet metal bender, guillotine, power hacksaw, sawbench, grinder, drill, mobile gantry and acetylene welding plant. Machinery for maintenance of mechanical aids and motor vehicles is not shown in the photograph.

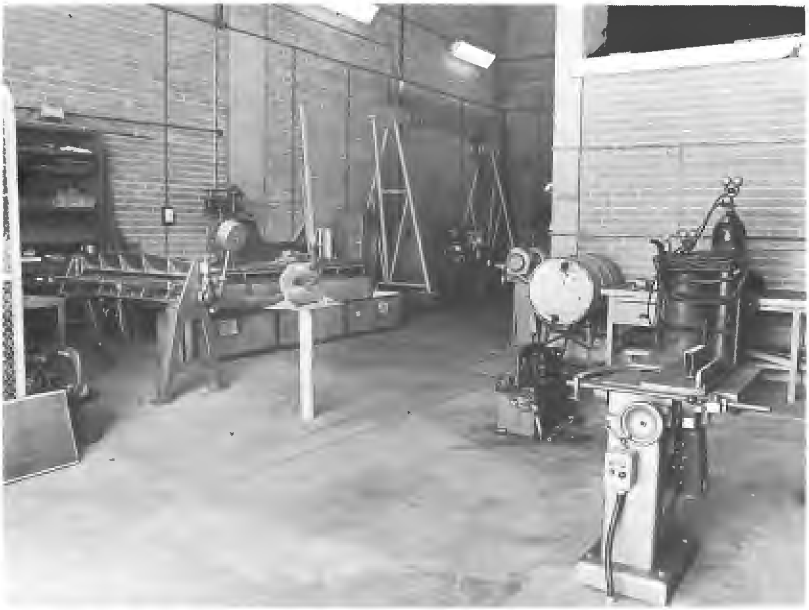

Figure 24.2 Radio station workshop machines

Guards and other safety devices are necessary on all machinery with moving parts, to ensure accident free work. Some factors which should be taken into consideration during the design, operation and maintenance of workshop machinery are included in the following list:

(a) Moving parts, which constitute potential injury producing conditions, to be guarded where practicable, or otherwise enclosed.
(b) Moving parts, which cannot be conveniently enclosed, as far as possible to be smooth in contour.
(c) Vibration of the machine or material being worked on to be kept to a minimum.
(d) Adequate factors of safety to be used in determining the strength of parts, the failure of which might result in injury to the operator.
(e) The operating surface and material being worked to be adequately lit, but sharp contrast between light, glare and shadow to be avoided.
(f) Noise generated by the mechanism of the machine to be kept to a reasonably low level.
(g) Parts of the machine requiring adjustment, lubrication or subject to wear, to be clearly visible and accessible.
(h) Parts controlling the operation of the machine, such as handles, levers etc. to be of such shape that they facilitate convenience in handling.
(i) Machine supports to be protected to minimise danger of accident from tripping or collision.
(j) No installed machine to be placed in service until all guards and other safety devices have been properly fitted.
(k) Where parts to be worked are heavy or difficult to manoeuvre, suitable handling facilities such as mobile gantry, rollers etc. to be provided.
(l) The workshop layout to be such as to allow safe operation of every machine.
(m) Regular removal of waste materials such as iron filings, sawdust, off-cuts etc, to be made, so that every machine in the work area is left in a clean and tidy condition. Oil and similar substances spilt on the floor to be removed immediately.

Chapter 25

Radiation Hazards

RADIATION CLASSIFICATIONS

The large effective radiated powers used in many modern broadcasting, radiocommunication and radar transmitters, and dielectric heaters has raised the problem of personal safety for staff working on or near these installations. During recent years, research programmes have attempted to enlarge the understanding of the biological effects of exposure to intense radio frequency radiation. The research has shown that exposure to high intensity radiations for even comparatively short periods may cause damage to human tissues and structures of the body, and in particular to the eye where damage can be irreversible.

The number of suspected cases of damage to eyes of operators and research workers engaged on equipment with high levels of electromagnetic radiation is of some concern, and indicates the need for drawing the attention of staff to the potentialities of these radiations in order that the use of this form of energy will be accompanied by appropriate respect and precautions.

Radiation hazards may exist at any radio frequency which is capable of being absorbed by the body. An examination of the electromagnetic spectrum shown in *Figure 25.1* indicates that the main classifications of radiation are as follows:

Radio frequency waves.
Infra-red or heat waves.
The visible spectrum.
Ionising radiation, including ultra-violet and X-rays.

Radio equipment which produces this type of radiation includes low frequency radio telegraphy, broadcasting, radiocommunication, television and radar systems. Industrial equipment such as that used for diathermy, induction heating, microwave ovens and dielectric heating, also use this portion of the spectrum.

Unfortunately there is no world wide consensus as to what levels of non-ionising radiation constitute a hazard to human beings and because of the complexity of the subject many workmen either ignore the entire subject and the possibility of hazard to themselves and others or they have an unreasonable fear of electromagnetic radiation injury in situations where in fact no real hazard exists.

It is not possible under normal living and working conditions to avoid exposure to electromagnetic radiation. Everybody in the community is exposed to it from outer space emissions and emissions from man made sources such as broadcast, television, radiocommunication, radar, industrial radio frequency devices, microwave ovens etc.

The degree of injury from electromagnetic radiation to living tissue depends on the absorbed energy within that tissue which in turn varies with the power density, duration of exposure, type of modulation and frequency of the source.

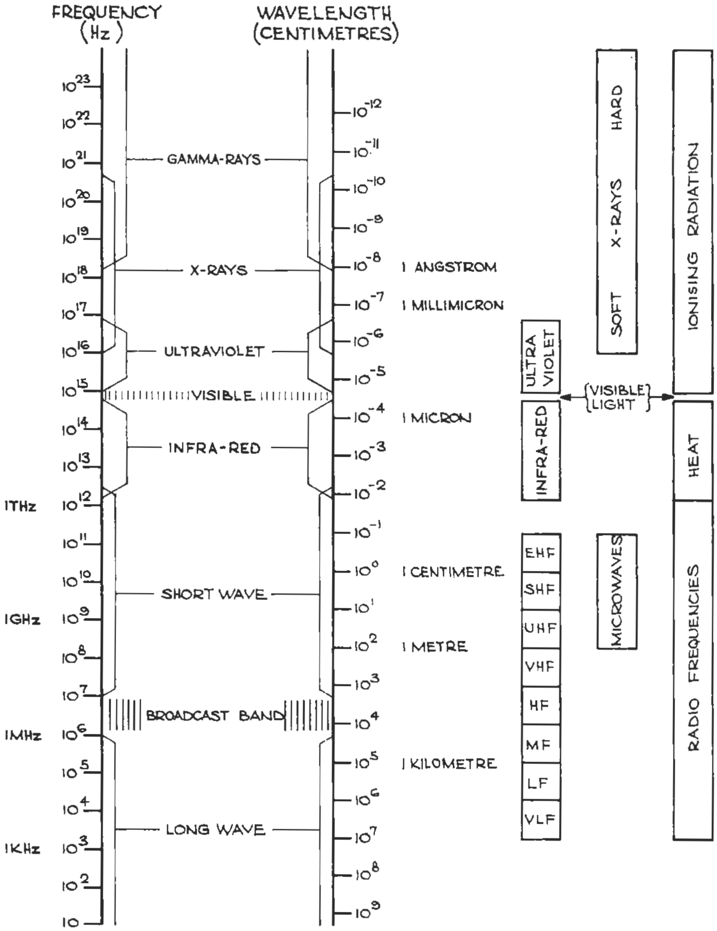

Figure 25.1 Electromagnetic spectrum

Injury may be in the form of heating or biochemical effects. The heating effect of microwaves is well known but the biochemical effects on human beings of microwaves where no local heating occurs are generally not clearly understood.

Microwaves have also the power to bring about decomposition of certain toxic materials. Persistent organic wastes and pesticides such as polychlorobiphenyls, kepone and phenylmercuric acetate can be detoxified by passing them through a reactor tube. A plasma is formed when microwaves are applied to the tube and the resulting electrical-chemical interaction triggers the decomposition of the toxic material.

BIOLOGICAL EFFECTS

The harmful effects of r.f. radiation have been attributed to a rise in total body temperature or to a selective rise in certain sensitive portions of the body. It has been reported that staff working continuously in close proximity to unshielded high power transmitting equipment may sustain a body temperature slightly higher than normal when the field strength is very high.

When a dissipative dielectric such as the body is placed in an electromagnetic field, currents are induced in the dielectric. These currents flowing in the dissipative medium cause heat to be produced. The heating is a function of the strength of the field, i.e. the average power flow per unit area, usually expressed in milliwatts per square centimetre. It is also a function of time.

The most vulnerable parts of the body are those with a restricted blood supply. Circulating blood acts as a coolant to distribute heat developed in an area subject to irradiation, and where the supply is abundant and the intensity not high, excessive local temperature rise may be prevented. However, the lens of the eye and some other organs with restricted blood supply can be subjected to high temperatures when exposed to sufficient r.f. radiation.

The extent of the damage appears to depend primarily on:

(a) the frequency of the radiation,
(b) the absorptive properties of the body,
(c) the duration of the exposure,
(d) the intensity of the r.f. field,
(e) the distance from the source.

Certain parts of the body are more prone to damage by excessive heat than others and it is these parts which are most apt to be damaged by the exposure. The organ most prone to damage under normal working conditions is the eye, which, with heating of the lens and tissue, develops opacities of the lens which can be irreversible. The eye is easily damaged because it has an inefficient blood transfer system for the transfer of heat to the surrounding tissue. The spectrum 2.5 to 3 GHz has been found critical for the production of cataracts; and this has been attributed to the fact that the depth of penetration at these frequencies corresponds to the area of the sensitive suture of the lens where most cataracts are observed to form. Unlike other cells of the body, the transparent lens of the eye cannot be replaced by regrowth.

The discovery of the production of cataracts was made in the laboratory by a researcher who was investigating the use of microwaves as a means of therapy to cure certain diseases of the eye. He had previously used high frequency therapy with some measure of success. The development of cataracts in the eyes of animals used in the tests emphasises the great importance of using particular caution whenever exposure of eyes to microwaves is necessary. In fact, it is considered by some researchers that the most serious pathological effects of microwaves, which has been observed so far, is the development of cataracts. Damage to eyes by exposure to high intensity r.f. radiation is permanent, and too much stress cannot be laid on the necessity for staff to take every precaution when working in a hazardous location or situation.

Some recent surveys on groups and individuals who have been exposed occupationally to high intensity fields indicate that analysis of the results is fraught with many difficulties. The validity of many claims has not been accepted by some medical authorities. For example, isolated field reports of microwave induced cataracts in man have been disputed by many ophthalmologists.

It is evident that there is considerable importance between the relationship of the microwave exposure levels and the health status of the individual. Like most clinical observations it is not easy to demonstrate a causal relationship between a disease and environmental factors and socio-economic conditions. When dealing with the long term effects of electromagnetic radiation on an individual it is almost impossible to quantitate the exposure with regard to such matters as the area of irradiation, position of the body with relation to the source etc. within reasonably close limits over several years.

From time to time reports have been prepared on instances where workshop or repair centre staff working on the adjustment or repair of microwave radiocommunication transmitter and oscillator units have claimed that their health had been affected by r.f. radiation. Most of the problems have been associated with eye strain symptoms but an examination of available medical records does not show proof of r.f. radiation factors being the cause.

At one repair centre which was examined in some detail, complaints had been made about the transmit oscillator and multiplier unit when brought in from the field for repair or adjustment. The oscillator produced about 1 W at 100 MHz and was amplified to about 20 W and then multiplied in three stages. The first stage multiplied by three producing a 300 MHz signal. The second stage multiplied by three again to produce a 900 MHz signal with the final stage multiplying by two to produce 1.8 GHz at a power output of 5.2 W. When this unit required realignment and retuning the procedure required would involve several days work. During this time the repairman was exposed to whatever radiation was present.

At about 1.8 GHz with the oscillator and multiplier unit set up on the bench in its fully tuned condition the radiation levels as measured at various points around the unit were at a very low level. Although the level increased when tools were used to tune the system, the maximum power density measured at eye distance (20 cm) from the device was less than 1 pW/cm^2. Radiation at the lower frequencies was also very low.

EFFECTS OF FREQUENCY

Tests have shown that at frequencies below about 1 GHz the body absorbs about 30–40% of the incident energy. Most heating takes place well below the surface of the skin. At a frequency of 300 MHz, penetration is between 1 cm and 10 cm and so radiant energy is transferred into heat in deep tissues. At this depth of penetration heat may cause damage to the brain, nervous system, liver etc. What makes heating at these frequencies dangerous is that a high rise in temperature can occur before the victim is aware of it.

In the frequency range 1 to 3 GHz, absorbed radiation is very high and approaches 100% under some circumstances. Heat is generated in the skin, fat and muscles, and a person will generally feel the rise in temperature on the skin, and act reasonably quickly to move away from the danger area.

At frequencies above approximately 3 GHz, about 40 to 50% of the incident energy is absorbed by the body. The remainder is rejected because of the reflective properties of the skin at these higher frequencies. Most of the heating occurs very close to the skin and, as the skin is sensitive to temperature changes, a temperature rise is quickly felt.

The reason heat is generated is that living tissues are lossy type dielectrics because they contain considerable amounts of conductive water and consequently are heated easily.

The radiation hazards produced by super-power broadcasting stations in the v.l.f., m.f. bands have been discussed many times by various workers but not much information appears to have been published in this field. Most of the biological research has emphasised the deleterious effects in the 3 to 30 GHz region where tissue heating has been shown to be a hazard. To check whether any ill effects would occur in animal life several pigs were put in the field at one large high frequency radio station, directly in front of a high gain curtain antenna with an effective radiated power of 50 MW and at a point where maximum field intensity was expected. The pigs were kept at the same spot for about 3 months and no increase in body temperature, loss of appetite or other ill effects were noticed. However the lack of knowledge concerning long term effects of exposure of man to radiation at broadcast and television frequencies implies the need for caution.

SAFE CONTINUOUS EXPOSURE LEVEL

The potential hazards that may arise from exposure to r.f. radiation fields are believed to be due, either directly or indirectly, to increases in body temperature resulting from the absorption of the electromagnetic energy. The temperature of the body of a normal person at rest is remarkably constant, and it is interesting to note that a temperature rise of only 5 °C above normal temperature can be injurious or even lethal if maintained for a sufficiently long enough period.

The mechanisms and factors which regulate the heat loss from the human body are far more complex than those concerned with heat loss from metallic conductors. The circulating blood acts as an effective distributor of heat in the body somewhat analogous to the circulation of water in a transmitting tube cooling system. It has been calculated that the average heat dissipation of the human body under normal conditions is about 5 $\mathrm{mW/cm^2}$ over a body surface area of about 2 $\mathrm{m^2}$. Because of the ability to regulate heat loss, the body can easily handle double this amount of heat dissipation.

This means that it is possible to develop within the body an additional amount of energy corresponding to 5 $\mathrm{mW/cm^2}$ averaged, over the body surface. As only half the body can usually be subjected to radiation from a one point source, 10 $\mathrm{mW/cm^2}$ of absorbed energy appears to be tolerable under normal conditions. Researchers generally agree that the body will tolerate this 10 $\mathrm{mW/cm^2}$ but more than this amount may cause harm, and should therefore be considered as being intolerable. An intensity level of 10 $\mathrm{mW/cm^2}$ has been accepted by most organisations, subject to further review, as the permissible upper limit for exposure averaged over any possible 0.1 hour period. The USA Standard C95.1-1966 recommends that this level be adopted for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz.

It is of interest that the USSR limits are considerably below the US Standard. The reasons for the adoption of these lower levels are that the USSR Standard is based on the possibility of any noticeable biological effect in contrast to thermal injury, larger factors of safety and the limits are pegged below the threshold of any detectable effect. In Western countries the view so far taken is that minor reversible effects are not necessarily hazardous to man. *Table 25.1* summarises recommended levels of exposure to electromagnetic radiation in various countries.

Table 25.1 RECOMMENDED LEVELS OF EXPOSURE TO ELECTROMAGNETIC RADIATION

Country	*Frequency range*	*Maximum recommended level*	*Conditions*
Great Britain (BPO)	30 MHz–30 GHz	10 mW/cm^2	continuous 8 h exposure, av. power density
USA	10 MHz–100 GHz	(a) 10 mW/cm^2	0.1 h period
Standard C95		(b) 1 mW h/cm^2	averaged over any 0.1 h period
US Air Force	not stipulated	(a) 10 mW/cm^2	continuous exposure
		(b) 10 to 100 mW/cm^2	maximum exposure time in minutes at W (mW/cm^2) = 6000 W^{-2}.
US Navy	not stipulated	(a) 10 mW/cm^2	continuous exposure, average power density
		(b) 300 mJ/cm^2/30 s	intermittent exposure
USSR	1.5–30 MHz	20 V/m	
	30–300 MHz	5 V/m	
	300 MHz	(a) 25 μW/cm^2	per 8 h/day
		(b) 100 μW/cm^2	per 2 h/day
		(c) 1 mW/cm^2	per 15 min/day
Czechoslovakia	0.01–300 MHz	10 V/m	per 8 h/day
	300 MHz	25 μW/cm^2	per 8 h/day
Poland	300 MHz	(a) 10 μW/cm^2	8 h exposure day
		(b) 100 μW/cm^2	2–3 h/day
		(c) 1 mW/cm^2	15–20 min/day
Sweden	10 MHz–300 MHz	5 mW/cm^2	continuous exposure
	300 MHz–300 GHz	1 mW/cm^2	
German Democratic	30 MHz–30 GHz	(a) 10 mW/cm^2	1 h limit for continuous exposure
Republic		(b) 1 mW/cm^2	continuous exposure

SAFE NON-CONTINUOUS EXPOSURE LEVEL

Where exposure to radiation is non-continuous, a greater intensity than 10 mW/cm^2 can be tolerated in the short period, since the important consideration is the permissible temperature rise within the body. However, the maximum permissible intensity is not easy to determine as many factors are involved. In the USA, the standard applicable for exposure to intermittent radiation sources requires that the average power flux measured over any interval of six minutes should not exceed 10 mW/cm^2. From a biological heating viewpoint the mean power is the significant factor, not the peak power.

EFFECT OF PEAK POWERS

Radiation from transmitters may be classified as continuous or pulsed. The continuous transmissions are associated with communication and broadcasting type systems whereas the pulsed transmissions are generally associated with radar and other distance measuring systems which emit high intensity pulses of short duration at given intervals usually referred to as the pulse repetition frequency.

Very little work appears to have been done to evaluate the relative dangers of pulsed radiations compared with those of a continuous nature. However, as far as heating is concerned there is no essential difference between the modes when compared on an average power basis. The average power of pulsed radiation is derived from considerations of the duty cycle, the pulse duration and the pulse repetition frequency. The average power of a system is therefore very much less

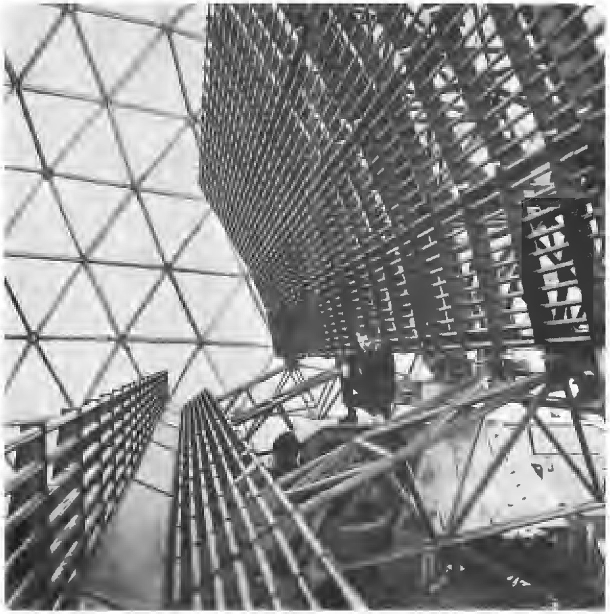

Figure 25.2 Typical airport radar installation (Courtesy The Marconi Co.)

than the peak power, since the pulse duration of a normal radar system is only a few micro-seconds and the pulse repetition frequency usually in the range 200–650 per second. In most non-military situations where the antenna is situated some distance from people and is in continuous rotation there is no biological hazard. *Figure 25.2* shows a typical airport radar installation employing a 500 kW transmitter. The photograph shows part of the parabolic reflector and the linear waveguide that extends for the full 16 m of the antenna. Part of the radome can also be seen. In the military situation however, such as on warships, personnel are in close proximity to high power installations and special precautions may be necessary to automatically cut or reduce power when the beam sweeps across exposed deck areas. Peak powers of several megawatts and high gain antennas are normal for naval installations.

POWER DENSITIES

The determination of the energy density of radiation in the space immediately surrounding the antenna is a somewhat complex procedure. Part of the energy is stored in the magnetic field and part is radiated. The stored energy generally exceeds the radiated energy but the determination of the value of each is not easy. At large distances from the antenna, however, the radiated field predominates and its determination is relatively simple.

The field in the forward direction of the standard parabolic type antenna reflector can be conveniently divided into two separate regions:

(a) The near end field or Fresnel region.
(b) The far end field or Fraunhofer region which is beyond the Fresnel zone and with the power density decreasing with the square of the distance.

The shape of the beam leaving the antenna is roughly cylindrical within the near end or Fresnel region, and changes to conical in the far end or Fraunhofer region.

At the beginning of the Fresnel region in the aperture plane of the antenna, the maximum power distribution is well defined and in the case of a circular antenna reflector may be easily computed. As this calculation will indicate the maximum power density that can exist on the axis of the beam, then if the calculation gives a result which is below the acceptable limit, no further calculation is usually necessary. If the calculation gives results which are above acceptable limit values, calculations are then made with the far field region in accordance with well established procedures. In the case of antennas with shapes other than circular the calculation may require a more complicated analysis. In the case of a standard medium frequency broadcasting station, factors which affect the intensity of the radiation at a particular point are the transmitter power, the directional characteristics of the antenna system, the conductivity of the soil, the tower height in terms of wavelength, and the frequency of emission. For a typical 50 kW transmitter on about 750 kHz feeding an antifading omnidirectional radiator the field strength to which residents in nearby houses would be exposed, would be of the order of 8 to 10 V/m. This figure could rise by up to four times for a residence at about 150 m directly in the path of the main beam of a multielement directional system. It is interesting to observe that the Czechoslovakian authorities have set a limit for continuous exposure on an 8 hour day basis in the medium frequency band of 10 V/m, while the USSR has fixed a maximum recommended level of 20 V/m for the frequency band 0.1 to 30 MHz.

Measurements using frequency selective instruments carried out at one medium frequency station where two transmitters each of 50 kW output were in operation, showed that field strength values varied from about 30 V/m close to the transmitter building to about 100 V/m near the coupling hut at the base of the radiator. Inside the coupling hut which housed a dual frequency matching network, the field strength adjacent to some of the inductors with high circulating currents was up to 10 times higher than outside the hut. Inside the transmitter hall, the field strength measured at the window of the radio frequency unit of one transmitter was 80 V/m compared with 100 V/m for the second transmitter on a frequency 100 kHz lower. Measurements taken two metres away showed that the field strength in both cases dropped to one tenth of that measured at the cubicle window.

Figure 25.3 shows three units used in carrying out power density and field strength level measurements. The unit on the left was used in connection with a 2 GHz problem and covers the range 1.8 to 2.2 GHz, the centre power density meter covers the range 450-12.4 GHz and the unit on the right indicates field strength over the range 25-500 MHz.

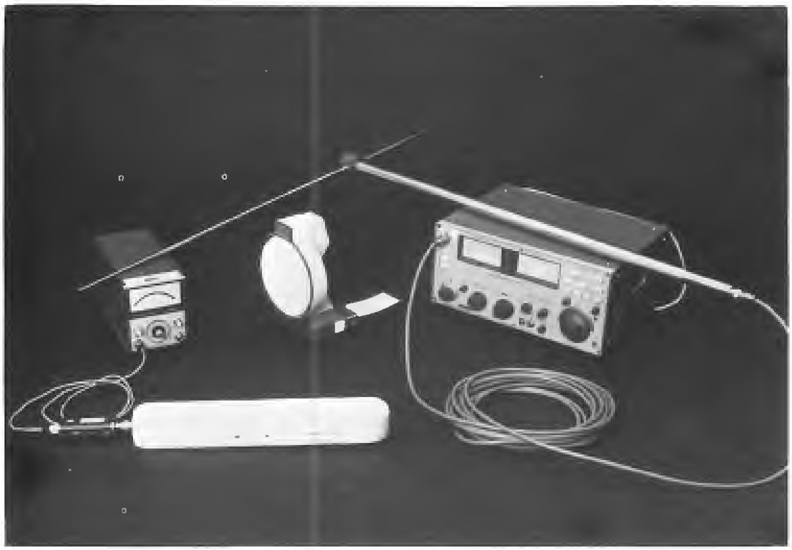

Figure 25.3 Appartus used to measure electromagnetic radiation

POWER DENSITY MEASUREMENT

The measurement of power density depends basically upon the determination of the power absorbed in a known area. The power density is computed by dividing the absorbed power by the area. In the case of pulsed transmissions power flux is measured by an instrument with its own time constant which is not related to biological safety factors. The mean power should be calculated on the basis of a six minute time constant. Calculation may not be always reliable in the near field because certain factors may appear which can appreciably modify the calculated values of density. Formulae are generally applicable only for free space. Multiple reflection from buildings, structures, the ground etc, will modify the power flux distribution.

In the case of equipment mounted relatively close to the ground, such as tropospheric scatter and radar systems, the ground will reflect radiations, the reflection co-efficient being dependent on frequency, polarisation, the dielectric constant and surface characteristic of the ground. For horizontal polarisation on a very smooth surface, the field strength at some points may approach 6 dB greater than the free space level. It is often difficult to assess the exact power radiated with high accuracy, and also the determination of the intensity of back-lobes and leaks in the waveguide system are not often amenable to calculation. The radiations could in fact give hazardous power density levels in some unexpected areas. It is highly desirable therefore to carry out field measurements where practicable.

The intensity of the field around the circuits of high power antenna matching equipment or transmitter tank circuits can be measured by means of suitable instruments, but if these instruments are not available can be estimated from a field strength measurement.

If the field strength of an incident wave is E V/m in free space, then the power density W will be

$$W = \frac{E^2}{377}\ \text{W/m}^2$$

$$= \frac{E^2}{3770}\ \text{mW/cm}^2$$

It is seen from this formula that a field strength reading of about 194 V/m corresponds to a power intensity level of 10 mW/cm^2.

WAVEGUIDES

Because of the small cross sectional area of waveguides, the power densities found in the vicinity of open waveguides can be high. The power density averaged over the cross sectional area of the waveguide, assuming a loss-less condition, may be calculated from

$$\text{Power intensity} = \frac{W}{ab}$$

where W = propagated power and a, b = waveguide dimensions.

The power density in the vicinity of the aperture of a typical 4 GHz waveguide in a television link or communications system with a power of 5 W is about 480 mW/cm^2 but this drops to 10 mW/cm^2 at a distance of about 5 cm. Another waveguide of a 2 GHz system with a 10 W power input gives a power density of 160 mW/cm^2 but does not fade to a safe 10 mW/cm^2 level until a distance of 15 cm is reached. With many of the high power radar systems, the average power levels propagated in the waveguide are very much higher, and extreme caution must be exercised when working near these open ended waveguides.

Although there is little danger from total body radiation from a well engineered waveguide system the higher power density can cause damage to selected parts of the body, particularly the eyes.

SAFETY PRECAUTIONS

Safety precautions are necessary to prevent possible harmful effects to personnel due to intense electromagnetic radiation from radio equipment operating in the frequency range 10 MHz to 100 GHz, this being the frequency range which with current practice, harmful effects are most likely to occur.

When measurements have established the boundary of the potentially hazardous zone, appropriate measures must be adopted to keep personnel from entering the zone. In the case of pulsed systems, such as radar, the radiation should be averaged over complete trains of pulses, including any intervals between pulse trains.

Measurements should normally be made at heights of up to about 3 m above the local ground area illuminated by the radiating system, with special attention being paid to areas regularly frequented by workmen or the public. Measurement should also be taken at higher levels where for example, the beam will strike an occupied building. The area should be suitably fenced, and warning signs indicating 'Danger' clearly displayed at appropriate locations.

Areas of intensity which exceed the limit should be accessible by only authorised staff and interlocks should be incorporated on gates to ensure that the transmitter is automatically shut down or power reduced to a safe level when personnel enter the area. Where access to waveguides, horns and other units of equipment with a dangerous radiation level can be gained by opening doors or removing panels, these should be interlocked with transmitters to automatically shut down, or reduce power to a safe level when the door is opened or the panel removed.

Repeat measurements of radiation levels should be made when changes are made in the r.f. equipment or in the environment such as erection of additional plant which is likely to result in significant changes in the radiation intensity. Where there are several different transmitters on site, the power densities should be added directly to obtain the total radiation intensity. Stations should where practicable be so sited that the permissible radiation intensity is not exceeded in any area in which the public has access.

Where it is necessary and essential for staff to be exposed to radiation intensities exceeding the limit special clothing, screening or other measures should be used to ensure that the intensity of the radiation on the body does not exceed the recommended level. Portable wire mesh enclosures properly engineered for the purpose have been successfully used to provide a safe working environment in hazardous areas. Special clothing and headgear of knitted silver wire have also been used by some organisations.

Staff should not be allowed to work on antenna support structures near radiators where the intensity of radiation exceeds the safe limit. Even when the radiated intensity is below the safe limit, staff should be warned against looking directly into open ended waveguides or even having a side look from near the edge of the reflector as there is in some cases, an area behind the reflector where energy coming directly out of the waveguide horn can radiate past the edge of the reflector.

It is usual practice with many workmen to wear wire mesh type goggles when working in the vicinity of microwave antennas. The goggles which are also used for physical protection of the eyes against paint chips and paint when carrying out maintenance on masts and towers have a mesh spacing of about 1.1 mm and a brass wire diameter of about 0.2 mm. Measurements show that the goggles give an effective attenuation of about 6 dB in the 4 and 7 GHz bands normal to the source. This figure is well below the 20 dB recommended by some authorities. Eye shields using a reflective gold film on glass are more effective. However, eye protection alone, without protection for the back or top of the head should not be considered to be a satisfactory alternative to total head protection.

X-RAYS

Ionising radiation—X-rays of long wavelength—may be generated whenever high energy electrons strike a target. Targets of high atomic weight yield more copious X-rays, and the greater the speed of the impinging electrons, the more penetrating or the 'harder' the X-rays are.

The first X-rays were produced with a Crooke's tube, a diode without a filament. Provided that enough energy is used, any tube with these elements will produce X-rays. Since radio transmitters use high voltage tubes the inference that X-ray radiation might be emitted at harmful levels during the course of normal operation naturally has become the subject of many investigations. Television receivers have also recently been the subject of similar study.

In high voltage tubes, X-rays may be produced when electrons are emitted from cathode or grids and accelerated at high speed to the plate. The extent of the radiation depends upon the current and voltage, but can be detected when the plate voltage reaches about 10 kV. In the case of television receivers, monitors and visual display units considerable research has been carried out on both black and white, and colour sets, and it has been concluded that the possibility of somatic radiation injuries to the viewer or operator from conventional well engineered sets is very remote. Even with voltages up to 25 kV only a minute fraction of the emitted radiation is transmitted through the glass panel at the front of the television tube or through shields. Although there is no known instance of radiation injury from television set or visual display unit viewing there remains the question of possible long term effects.

Both the National Health and Medical Research Council and the International Commission on Radiological Protection recommend that the exposure rate of ionising radiation produced by equipment should not exceed 0.5 mR/h averaged over a ten square centimetre area at a distance of 50 mm from any point on the external surface of the equipment.

Tests carried out on eight visual display units and nine television colour receivers and monitors selected at random from manufacturers in the United Kingdom, Germany, Japan, United States, Holland and Australia showed that no radiation above background level was detected in any of the units when operated in their designed situation. However, in the case of colour television sets high levels were measured close in when shields were removed. In the case of one monitor set installed at a television transmitting station a level of 100 mR/h was measured at a distance of 15 mm from the regulator tube. Radiation from the e.h.t. cage at the same distance was 0.4 mR/h. One commercial television set gave a reading of 96 mR/h at a distance of 15 mm from an opening in the e.h.t. cage with the outer case removed. Only one monochrome receiver was observed in the test programme and this gave a level of 0.5 mR/h at a distance of 15 mm from the e.h.t. printed circuit board when the rear cover was removed. All the sets were fitted with signs warning that excess radiation could be present if protective shields were removed.

Many of the high voltage tubes used in high power transmitters, and virtually all those designed specifically for pulse-modulation service, can be classified as potential X-ray hazards. High voltage rectifier tubes also produce X-rays when operated above 10 kV, particularly during the inverse part of the cycle. The tube envelopes afford only limited shielding and it is desirable to provide some form of X-ray shielding with tubes operating above 10 kV. If the installation includes pulse-modulator tubes, it may also be necessary to shield the pulse transformer. Lead glass which attenuates X-ray is suitable for use as viewing windows for cubicles in which the tubes are mounted.

To measure and locate any areas of high X-ray emission from television receivers, monitors, high voltage tube equipment etc., one organisation controlling a large network of television and broadcasting stations purchased a Berthold radiation measuring instrument which has a measuring range extending from 10 μR/h to 10 R/h. The unit is rotated throughout stations of the network at six monthly intervals for measuring purposes.

INFRA-RED AND ULTRA-VIOLET RADIATION

Infra-red radiation is effective only as heat, and is readily recognised.

Ultra-violet is present within the tubes of transmitters along with visible light and infra-red when the filaments are switched on. In the case of ceramic envelopes the filament cannot of course be seen. The glass envelope of the tube filters out the ultra-violet rays just as an ordinary glass window filters out the ultra-violet from sunlight. There is therefore little hazard involved.

Where, however, arc welding equipment is used on the station, extreme care must be taken to prevent damage to the eyes. A brief flash from an arc welder is sufficient to injure the eyes temporarily. Correctly designed protective goggles must be worn at all times.

TYPICAL SAFETY INSTRUCTION

The following Instruction issued by one Authority is appropriate for staff who may be required to work on or near equipment which produces electromagnetic radiations of high power density.

SAFETY: RADIO FREQUENCY RADIATION HAZARDS

1. *GENERAL*

1.1 This instruction is intended to warn personnel, particularly those engaged in the installation, maintenance and testing of radio equipment, to exercise extreme care to avoid exposure to intense radio frequency electromagnetic radiation. With regards to the parts of the body likely to be exposed it should be remembered that the eyes and reproductive organs are particularly susceptible to damage.

1.2 For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz, the radiation protection guide is 10 mW/cm^2 as averaged over any possible 0.1 hour period. This means the following:

Power density:	10 mW/cm^2 for periods of 0.1 hour or more
Energy density:	1 mWh/cm^2 during any 0.1 hour period.

This guide applies whether the radiation is continuous or intermittent.

1.3 For non-continuous exposure, involving higher power densities than 10 mW/cm^2 for short durations, the important consideration is the permissible temperature rise within the body.

1.4 The level of radiation considered safe has been under discussion for some time and there is evidence that lower levels may need to be specified.

1.5 In a typical field situation, as an example, with a 4 GHz radiocommunications bearer employing a 2 m diameter dish the maximum power density from the antenna may be about 0.2 mW/cm^2. In the case of the waveguide associated with the system, maximum power density in the aperture may be about 480 mW/cm^2. This figure indicates that there is some danger involved in working close to an open ended waveguide operating at full power. Although there is little danger from total body irradiation, the intense local field could cause damage to certain organs, most particularly to the eyes.

1.6 Whilst there is little evidence of cases of injury or damage to personnel since the first installations by the Authority of microwave radio communication equipment, there have been a few cases where staff have been doubtful whether radiation might have caused temporary discomfort to the body and in particular the eyes. Unfortunately it has been difficult to obtain firm evidence that radiation has been the cause.

2. *PRECAUTIONS*

2.1 Visual inspection of feed horns, open ends of waveguide and other equipment opening through which electromagnetic energy exceeds the permissible upper limit (10 mW/cm^2) at the observation point shall not be carried out until the equipment has been made safe for the purpose of such inspection.

2.2 Where staff are carrying out work on or near energised equipment and they could be exposed to a level of intensity above the permissible upper limit, e.g. while panning dishes or adjusting transmitters or waveguide equipment, they shall be provided with and be required to wear personal safety equipment such as eye protectors, head protector and overalls fabricated from silverised wire knitted mesh material.

2.3 Notices shall be prominently displayed on all radio equipment, and in fenced zone areas which are subject to a radiation intensity exceeding the permissible upper limit, warning against entering zone areas and the danger of working on such equipment.

2.4 Access to area subject to radiation intensity above the permissible upper limit shall be accessible only to authorised staff.

2.5 Any increase in the temperature of the body or loss of acuity of vision resulting from r.f. radiation exposure shall be reported by the workman immediately.

2.6 Staff or station visitors who have bone fractures repaired by metal or plastic implants or who wear cardiac pacemakers shall be specially warned against exposure to excessive radiation because of the possibility of heat dissipation in the metal or plastic implant or to interference with the operation of the cardiac pacemaker. Electromagnetic radiation can under certain conditions disrupt the normal function of some early model

WARNING

R.F. RADIATION HAZARD

STAFF ARE WARNED THAT R.F. RADIATION FROM THIS EQUIPMENT EXCEEDS THE PRESCRIBED UPPER LIMIT AND MAY BE A HEALTH HAZARD. DO NOT MAKE A DIRECT VISUAL EXAMINATION OF THE RADIATOR, REFLECTOR, WAVEGUIDE OPENING OR WAVEGUIDE HORN UNTIL THE EQUIPMENT HAS BEEN MADE SAFE.

ALL LETTERS AND SYMBOLS TO BE GREY.
HORIZONTAL LINE AND OUTSIDE EDGE TO BE GREY.
TOP PORTION:- BACKGROUND TO BE RED.
BOTTOM PORTION:- BACKGROUND TO BE BLACK.

Figure 25.4 Warning notice with colour details non-shielded pacemakers and create a potential hazard to the user. *Figure 25.4* shows a warning notice designed to meet the requirements of paragraph 2.3.

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Chapter 26

Maintenance of Masts and Towers

METHODS AND PROCEDURES

The work of maintaining masts, towers and antenna systems is necessarily a hazardous occupation and it says much for the skill of the workmen concerned, and the practices which have been adopted for carrying out the work, that serious accidents have been so few. The complexity of the mast and tower mounted equipment, parabolas, horns, television antennas, waveguides and large high frequency antenna systems all add to the problems of working aloft.

Other factors with which the riggers and other radio lines staff have to contend are:

(a) High velocity winds from which shelter is not usually available.
(b) Sudden rain squalls which make surfaces slippery and hazardous.
(c) Extremes of temperatures from which it is virtually impossible to obtain relief whilst on the structure.
(d) The need to work in confined and difficult positions causing cramp, discomfort and other muscular complaints.
(e) Much greater physical fitness is needed for climbing and handling equipment on tall structures.
(f) The need for continuous alertness of safety requirements of the man, his colleagues and the plant.

Particular care is necessary where there are moving parts, for example switches or rotating antennas, operated by remote control, to ensure that these cannot be set in motion while staff are working on or near them. The switches controlling such movements should be locked in the open position and tagged before the work is started.

Practically all types of accidents which occur on the ground also occur in working aloft on masts, towers or antenna systems. In addition, there are hazards of a nature peculiar to structural activities. These include high wind gusts, rain and cold. Dangers due to slippery surfaces, cramped and awkward working situations, radio frequency voltages, swinging materials and ropes and exposure to falling materials and tools are ever present.

A great part of a rigger or radio linesman's knowledge involves an understanding of the safety aspect of his work, and the techniques and procedures which have been developed over the years are invariably those methods which have proved to be safe methods. As a consequence, the safety regulations and rules are the outcome of years of practical experience. Government Regulations tend to refer generally to activities such as engineering construction, lifting operations etc., but the variations are restricted to detail, and the principles of safety in radio mast and tower work are much the same all over the world.

Methods and procedures for doing structural work must be developed with safety in mind. The riggers and radio linesmen doing the work should be equipped with the best devices, equipment and tools available. They should have good safety equipment such as cages, lifts, work boxes, safety chains, belts, ropes etc. that are inspected and tested on a regular routine basis to ensure they are in first class condition.

MAST AND TOWER INSPECTION EQUIPMENT

Some form of climbing facility is necessary on masts and towers to allow maintenance of the structures and the equipment which they support. It is generally practice to provide ladders on lattice type structures and step bolts on casing type structures.

Ladders are usually placed on the outside of structures of small cross section and on the inside of the larger ones. Construction workers generally prefer the ladder on the outside of all structures because there are fewer obstructions to their movement. Station technical staff, however, who have only occasional need to climb the structures find greater security with the ladder mounted inside and surrounded by a safety cage of wires or bars. A great aid to improved safety is a fall arrester, fitted to the ladder or other part of the structure, which allows the workman to have his safety belt fitted and attached during the whole of the ascent and descent. Should the worker fall, the slide which runs on a tube will catch on a notch on the tube and arrest his fall.

On some very tall structures, a motor driven lift is provided. The device increases considerably the overall cost, as it also adds to the wind loading imposed on the structure. Whilst all local regulations must be complied with in relation to lifts which carry passengers, the size is kept to the absolute minimum and is generally about 1 m × 1 m × 2 m. Construction is of steel or light weight alloy material with an expanded mesh type covering. The unit is fitted with necessary safety devices such as limit switches, guide cam grips, fail safe brakes, and a two way communication system, but most structures are also fitted with a ladder for emergency purposes. The driving mechanism of many lifts is a traction type with a high starting torque and low starting current and provides a speed of about 30 m per minute.

The lift does not provide a satisfactory means of carrying out maintenance works such as painting because it is fixed in position by the guides and cannot be moved in a horizontal direction. To permit maintenance works within the structure, temporary scaffolding may be provided or if the work is such that it can be performed by one man, a safety chair suspended by a vertical rope may be used. The workman in the chair has good freedom of movement and can reach any part of the work. Spinning of the chair is prevented by means of a ring passing over the downhaul and attached to the chair by a short chain.

Cradles are provided at some stations for work on the outside of masts and towers. Two or more cradles, each controlled by a separate winch, allow several men to carry out work quickly, safely and efficiently. For masts where the sides are parallel, steel ropes suspended from frames at the top of the mast control upward and downward movement of the cradle. The cradle runs in guides attached to the mast to prevent sideways and outward movement due to wind or the actions of the workmen. Although raising and lowering can be by manual operation from a winch on the ground, a motorised unit is generally used. For towers where the sides are not parallel, the guide wires are fixed at the top and pass through eyes on the skip to mobile attachments at the base so that the skip can be moved horizontally across the face of the tower.

The installation and maintenance of high power curtain antennas is often a difficult problem, particularly where they are permanently fixed to the structure or where several antennas are supported from the one catenary. Mechanically driven work boxes have been provided on some stations for this purpose. A fixed catenary between and parallel with radiating elements and the screen is provided for the work box. By the use of rope systems which can be manually or motor controlled, the box can be moved horizontally or vertically to reach any component of the antenna system. Work boxes which can accommodate two men plus working tools are available for this purpose. One such work box being prepared for hoisting is shown in *Figure 26.1.* *Figure 26.2* shows another type which is in the form of an elaborate bosun's chair. It is electrically driven by trailing cable with control being exercised by the feet, leaving the hands free to guide the chair past wires and hardware during manoeuvring operations.

For the maintenance of parabolic antennas used for television on radio relay purposes, access is usually obtained by means of a permanently erected platform,

Figure 26.1 Mechanically driven work box for curtain antenna maintenance

a portable lightweight ladder or scaffold system which can be erected as required or by means of a safety chair suspended from a jib. The chair is hoisted to the antenna position by means of a winch and a running halyard. Horizontal movement is obtained by shifting of the head pulley along the jib. Another method preferred by some riggers is to completely enclose the dish with a safety net tied back to the tower. Access to feed points etc., is then gained by climbing inside the safety net from the top of the dish.

Figure 26.2 Electrically driven bosun's chair

GUY INSPECTION EQUIPMENT

The inspection of guys of a tall mast is an expensive and difficult operation. Although most station engineers have programmes for the regular inspection of the structure proper, very few carry out regular detailed inspection of the guys. The inspection is generally limited to observation from various ground and mast points with the aid of binoculars. Although many cases of broken wire stands, cracked or chipped insulators have been detected by this means, it does not allow a full and proper inspection.

Guy wires need maintenance from time to time, particularly to replace protective grease, and unless a special device is provided to allow the application of this grease in situ, it is necessary to lower the guy to the ground. In an aggressive coastal environment it may be necessary to regrease the guys every three to five years and the erection of temporary guys and lowering of permanent guys can add considerable costs to the station operating charges. Even so, the inspection of guys on the ground is no simple matter owing to the difficulty of handling the heavy insulators and rope without causing damage. Several engineers have expressed the opinion that more damage is done in a day while handling and inspecting guys on the ground than in a year, if not touched. There is also the difficulty of handling those guys where the insulators are not permanently cemented into fittings. The insulators frequently fall to the ground when the guy is being lowered, and considerable skill is necessary during re-erection to ensure that adequate tension is continuously maintained.

An alternative to complete lowering of the guy is to release the guy at the anchor block, after fitting the temporary guy, and to allow part of the guy to hang vertically alongside the mast. It can then be inspected at close quarters from the mast. The inspection of the section on the ground suffers from the same drawbacks as in the previous method.

To carry out a thorough inspection of the guy in situ it is necessary to provide a traversing device. The most commonly used devices are a mechanically driven cage unit capable of supporting two men and a small bosun's chair type, suitable for one man.

The cage unit supported from the guy rope by fibre pulleys is hauled along the guy by a light rope operated from a winch on the ground. This rope runs from the cage to the head of the mast, over a pulley to the base of the mast and then via another pulley to the winch located near the guy anchor. The cage is suspended from the trolley wheel unit by a hinge and can be moved relative to the trolley wheel unit by a screw thread and its position relative to two jockey wheels can be adjusted by winding the cage up and down the screw thread, using a hand wheel and belt arrangement on the sides of the cage. On reaching an insulator the cage is dropped back and the front wheel rises off the guy as the cage passes over a rear wheel. The machine is then hauled forward until the rear wheel reaches the insulator. The workmen in the cage then wind the unit forward until the cage passes over the front wheel and the device tilts, lifting the rear wheel off the guy so that the unit can be hauled forward over the insulator. The process may appear complicated but in practice it is relatively simple and straightforward. The cage contains a small petrol motor to drive the trolley along the arm. The weight of the device when fully loaded with two men, grease and tools is about $\frac{3}{4}$ tonne and the tension placed on the guy of a typical 230 m mast would be less than half the maximum wind load capability of the structure.

Figure 26.3 Guy inspection cage

Figure 26.3 shows the device in use during guy greasing operations.

The bosun's chair unit is a relatively simple and lightweight device. It is attached to the guy at the mast end and lowered by gravity. A restraining rope is released by a workman on the mast at a speed sufficiently low enough to allow a proper inspection of the guy and insulators. The operator can also control his speed by adjustment to a manual braking system. A hook and loop arrangement allows the operator to safely 'walk over' the insulator. The chair is shown in *Figure 26.4* with the operator applying the manual brake on approaching an insulator.

Figure 26.4 Bosun's chair guy inspection device

LADDER FALL ARRESTERS

There are several variations of fall arresters in use. Some use wire ropes while others use a notched tube to arrest the fall. In the wire rope system, the safety anchor device contains a weight freely supported on steel springs. At the top of the weight are several steel balls held in a cage. Should the workman fall, the weight will move up relative to the casing and in doing so the steel balls will be forced between a wedge attached to the outer casing and the wire rope. The action causes the balls to be wedged, and the rope to be firmly gripped, and so prevents the workman from falling.

In the notched tube system such as SAF-T-CLIMB, a galvanised steel tubing and guide channel are designed to form a carrier rail over which a sleeve travels. The rail is notched every 15 cm to provide stop and lock points for the locking pawl of the sleeve to engage. A manganese bronze sleeve rides freely up and down the notched rail. The sleeve houses a spring actuated pawl which remains disengaged in the normal climbing position. In the event of a fall, the pawl is actuated and locks instantly to the nearest notch on the rail.

Sections of carrier rail can be installed on almost any type of mast or tower and to any desired height. The installation is extremely rigid and becomes an integral part of the structure. The rail is designed to accommodate a heating cable where de-icing requirements exist.

The most dangerous moment for a climber comes when he reaches the top of the structure and has to disengage himself from the ladder fall arrester in order to carry out some work which cannot be reached from the ladder. The general practice is to extend the steel tube beyond the top of the ladder. This extension with a portion of the guide channel removed allows the sleeve to rotate with the climber, giving him an opportunity to get firm footing and perfect balance on the platform before he disengages himself from the safety of his sleeve.

The belts used with these devices are generally designed to withstand a

Figure 26.5 Fall arrester (Courtesy G.K.N. Building & Engineering)

minimum drop test of 100 kg over a 2 m free fall. The body pad consists of 7.5 cm three ply cunilate treated web and the body strap is made of nylon web with a leather wrap. A workman ascending a tower and using the device is pictured in *Figure 26.5.*

The following examples illustrate the danger of workmen climbing masts and towers without proper safety devices.

EXAMPLE 26.1

A routine ground inspection of a 210 m mast revealed that aircraft warning lights at the 120 m and 170 m levels were extinguished.

The mast was fitted with a ladder fall arrester device and two workmen proceeded to climb the tower to replace the lamps. At about the 30 m level, the wind velocity was fairly high and increased as the men climbed the mast. The surface of the structure was wet making conditions somewhat hazardous.

The men reached the 120 m level and changed the lamps without incident. While climbing to the next work level, the leading man was struck by a sudden wind gust at the 150 m level. He lost his footing and because of the suddenness of the action, he had no opportunity to grab hold of the mast members. However, the safety belt and ladder fall arrester device prevented a fall. Although he did not fall, the man was hanging upside down along the outer face of the mast. Fortunately he suffered no injuries and was able to right himself to regain his footing on the ladder.

EXAMPLE 26.2

The lamps at the top of a 210 m m.f. radiator were extinguished and a workman was despatched to replace the faulty units. The rungs of the ladder were wet at the time as a result of a shower.

The workman reached the work position without incident, replaced the faulty lamps and while descending was struck by a fierce cross wind at the 170 m level. He lost his balance and fell from the ladder. The fall arrester held in position and he was able to regain his hold and climb back on to the ladder. The device had saved him from certain death.

EXAMPLE 26.3

In order to carry out repair work on some equipment, a linesman climbed a ladder fixed to a tower which was located on the ridge of a mountain top. The rungs of the ladder were covered with a thick layer of ice at the time. When about 17 m above ground level, the linesman suddenly lost his hold and fell. The ladder was not fitted with a fall arrester device and he fell to the gound rolling several hundred metres down the mountain side before coming to rest. He was dead when reached by the rescue team.

MAINTENANCE PLATFORM

One type of maintenance platform utilises short sections of extension ladders or telescoping scaffolding frames to raise a work platform to the desired height.

In extended positions the platform is suitable for work at a height of up to 8 m. In its fully collapsed position, the equipment forms a compact unit which can pass through ordinary station doorways. The work platform is surrounded by a railing for the protection of maintenance and installation staff when working on transmission lines, antenna switch systems and transmitter parts such as transition sections, coaxial lines, line filters and steam pipes which may be high above the floor. This form of platform is available with either manual or power operating mechanisms for raising or lowering the platforms.

Another platform used extensively on large stations is an elevating platform consisting of a fibreglass cage or bucket mounted on booms firmly attached to a truck. The platform is operated entirely by hydraulic means from a pump driven from the power take-off of the vehicle or an electric motor. All movements of the boom are controlled from the cage by hand levers situated either on the bucket or the top of the upper boom.

The platforms are available in load capacities up to 200 kg and working height up to 35 m above ground level. They are ideally suited for erection and maintenance of transmission lines and antenna systems, particularly log periodic and curtain types. The inching type controls enable the operator to accurately regulate the speed of his approach to a hazardous location from dead slow to a

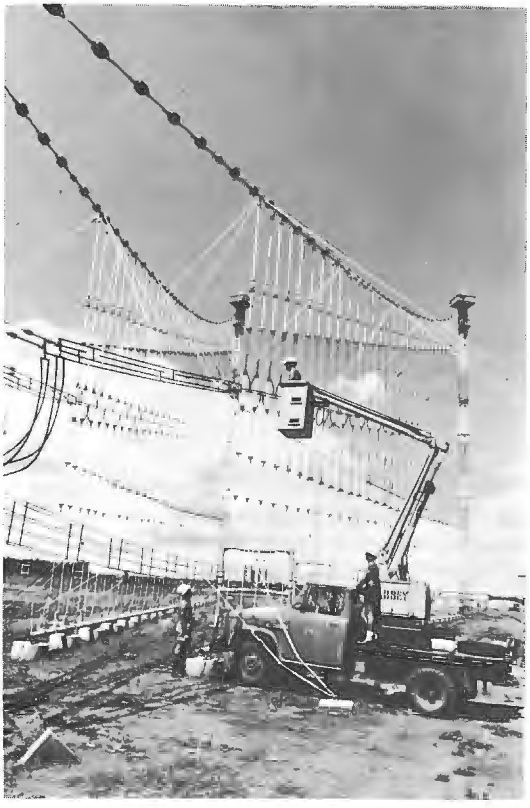

Figure 26.6 Elevating work platform

preset maximum. A series of fail safe valves incorporated in the hydraulic system prevent the booms from collapsing in the unlikely event of any hydraulic lines bursting. The booms cannot be raised if this happens, but they can be lowered under gravity at a slow, controlled rate, and the basket steered into its cradle, by operating the normal controls. Additional safety features include the fibreglass bucket and a fibreglass insert in the upper boom for protecting the operator in the case of accidental contact with live wires.

A deadman lever prevents unintentional operation of all controls and provides automatic emergency stop facility. To allow the use of tools whilst working on the antenna or other plant, electric, hydraulic and pneumatic power connections are available as options for portable tools. The work basket is kept level throughout the working range by a non-stretch parallelogram rod system and the geometry of the plant is such that booms will return to rest position from any elevation by gravity, even with the transporting vehicle on uneven ground. ***Figure 26.6*** shows a typical unit being used for inspection of a high power transmitting antenna.

SAFETY BELTS

Designs for safety belts are available that permit the wearer to move freely but limit a fall without undue shock. The safety belt is a simple device and its principles have been known and tested over a long period of time. Yet from time to time and usually through some human fallibility, its purposes are defeated and accidents happen which it should have prevented. The main requirements of a safety belt are:

(a) To have sufficient strength for the purpose for which it will be used.
(b) To have good resistance to wear and deterioration when subjected to the environmental, handling and storage conditions under which it will normally be used.
(c) The maintenance requirements must be simple and be kept to a minimum.
(d) The appearance of the belt must be such as to give the workman confidence in it.
(e) Adjustment to be simple, easy and safe.
(f) It must be possible to fasten and release the belt with one hand.

The great majority of riggers and radio linesmen's belts are now made of Terylene fibre and care has to be exercised to ensure the belts are kept away from hot objects. One rigger while carrying out welding operations on a pulley system bracket on top of a 130 m mast allowed his belt to touch the member on which welding was being performed. The heat in the member caused the Terylene to melt and released the belt. Fortunately the rigger was able to grasp the ladder so preventing a fall.

Belts frequently become dirty particularly after work on creosoted transmission line or antenna support poles. Regular cleaning is obviously advantageous but care must be taken to ensure that phenol compounds, strong acids and alkalis are avoided. Toluene is a recommended solvent but should be used with care and caution. Petroleum spirit is also effective but not as quick as Toluene. Detergents are not very effective.

MARKING AND LIGHTING OF STRUCTURES

It is the policy of authorities, both civil and military, responsible for the control of aviation to prohibit any new construction which would constitute a potential hazard to aircraft moving in the navigable air space in the vicinity of an airport, and to remove or alternatively mark by painting and lighting all existing objects which are a potential hazard to aircraft. This applies particularly to structures used for broadcasting purposes because they are generally of considerable height. In general, the prohibition is applicable to new construction extending above the following limits:

(a) A surface, known as the horizontal surface, 50 m above the airport limit and extending to a radius of 4000 m from the centre of the landing area.

(b) A conical surface extending outwards and upwards from the perimeter of the horizontal surface to a height of 50 m above the latter. Where it is not practicable to remove or prohibit such obstructions it is usual to require that they be marked and lighted.

Each obstruction in the foregoing category is considered individually by the authorities in relation to the approach and departure pattern in use at the particular airport. The requirements are sometimes made more stringent in proximity to the approach to an instrument runway, i.e. a runway equipped with precision approach aids for use in conditions of reduced visibility. In such cases it is not uncommon to require marking and lighting of structures which do not infringe the limits stated previously. The converse applies to structures which are technically obstructions but are situated well away from approach paths. The authorities may not always insist on lighting in these cases.

The restrictions applied to the erection of new structures are in general more stringent than the policy adopted for the demolition of existing structures which may have been erected before the establishment or expansion of the airport. Furthermore, the policy may vary from one location to another depending on the general nature of existing obstructions, trees and the like in the area or the type of aircraft operations proposed.

At locations remote from airports, lighting of masts and towers is seldom required but daylight marking is usually considered necessary, particularly in those areas where agricultural aircraft are likely to operate. There is a similar requirement for marking in areas around airports where light aircraft operate. As yet, few light aircraft are equipped for instrument flight and their operations are thus restricted to daylight hours and good visibility conditions. However, it must be expected that this situation may change in the future and the wise engineer will make provision for future addition of obstruction lighting on any structure erected near an airport.

Typical recommendations for lighting and marking of masts and towers are as follows:

(a) Lighting equipment is to consist of a double red light at the top of the structure and where the height exceeds 50 m, additional single red lights are to be provided at intermediate levels. The number and arrangement of lights at each intermediate level is to be such that the obstruction is indicated from every angle of azimuth. Thus, on a triangular section mast, three single lights would suffice, on a square section mast or tower four single lights located on the corners or two double lights on diagonally opposite corners would meet these requirements. A set of intermediate lights should be provided for each 50 m of height, or fraction thereof and should be spaced at equal intervals between ground level and the top of the tower. Fittings should be Westinghouse multiple service obstruction lights or similar, and equipped with 100 W lamps.

As there is often considerable vibration on tall structures the use of 32 V lamps has often been found to give longer life than high voltage lamps, because of their more robust filaments. However, it is essential to ensure that the correct lamp is used for a particular fitting. Variation can occur between individual lamps of the same type and for critical applications it may be necessary to check, and perhaps re-adjust, the focusing of the fitting when a replacement lamp is installed. Movement of the lamp filament away from the focus of the optical system generally results in a loss of concentration of the light with a consequent reduction in the maximum intensity of the beam.

Where more than one obstruction light is required, or double lights are used, the lamps should be wired on two circuits, fed through separate fuses so that as far as possible the outline of the obstruction will remain defined on failure of one or other of the circuits. Where practicable the circuits should be connected to different phases of the power supply. In the case of a structure used as a radiator for a broadcast transmitter, special arrangements may be necessary to take the power on to the structure without affecting its efficiency as a radiator. The most common arrangements are, the use of an isolating transformer, an r.f. filter network or where a shunt inductor is used, the power leads may be fed through the tubing of the coil. A similar feed-through arrangement is necessary at the section point of a sectionalised radiator.

The authorities may require that the lights on an obstruction in an approach area be provided with standby power which is to be connected automatically in the event of the normal power supply failure. Even when the structure is not in the approach area and emergency power is available on the station, it is desirable that the lights be connected to this source during mains failure.

(b) Daylight marking is effected by painting the structure in alternate horizontal bands of white and international orange, not over 6 m in height and so arranged that the top and bottom bands are orange. Where orange provides insufficient contrast with the background, Signal Red (British Standard Colour No. 537) may be used.

In all daylight marking schemes the colours of the pattern must contrast with each other and with the background against which they will be seen. Orange and white or red and white will be found to meet most situations but at some stations where the country-side is composed of reddish-brown ferruginous deposits, black and white markings have been required.

TYPICAL SAFETY RULES

The following list summarises some of the most important safety rules in connection with maintenance activities on masts, towers and antenna systems:

(a) No person should be permitted to climb any mast or tower without proper authority.

(b) Authority to climb a mast or tower should be given only when the ascent is necessary for the purpose of installation, inspection, maintenance, modification or for making alterations or adjustment to the antenna system.

(c) No person should be permitted to climb a mast or tower unless he is willing to do so, is physically fit and is capable of carrying out the required work.

(d) No ascent should be permitted when weather conditions make it unsafe. The responsibility for the decision must rest with the immediate supervisor. Factors making conditions unsafe include high wind, especially at the top of the structure, rain, a low and falling temperature favouring the formation of ice, and the actual presence of ice on the structure.

(e) Safety belts of approved type must be worn and should be anchored securely while the wearer is working on the structure and also during rest pauses while ascending and descending. Workmen should be held personally responsible for seeing that their safety belts are safe before using them, and for using them in a proper manner. Any defects must be brought to the notice of the immediate supervisor.

(f) Workmen must not support themselves on any portion of a mast, tower, antenna system, pole, ladder or other form of structure without first making sure that the supports are strong enough for the purpose. Where a portable lightweight rest or work platform is provided, he should ensure that it is clipped to the structure securely before applying his weight.

(g) When any person is on the mast or tower, another person should keep him under observation from the ground. Suitable binoculars should be provided for the purpose, where tall structures are involved.

(h) All safety belts, chairs, lifts, cradles, hoists, skips, ropes and fittings, used for the support or transport of materials or persons on structures should be of good design and construction, and should be maintained and operated in accordance with sound engineering practice. Lifting devices should be equipped with adequate brakes and where operated by workmen on the ground should have indicators fitted which show in clear view of persons operating them the position of the device at any time. Where practicable and necessary the device should be fitted with adequate overwind and overspeed control facilities. Any person operating a lift, hoist, cradle, skip or safety chair in which workmen are being transported must be competent to carry out the duties, and must be constantly on duty at the control point whenever workmen are occupying the device, unless there are alternative and satisfactory means of egress.

(i) Any defects found in the steelwork, antennas, feeders, cables, waveguides and ladders should be reported to the engineer-in-charge as soon as possible.

(j) No antennas on the structure or in its vicinity should be powered if this would cause men working on the structure to be exposed to a dangerous radio frequency field.

(k) All staff should be warned of danger from contact with live conductors supplying power to lighting circuits etc.

(l) Care must be taken by staff working aloft to avoid the risk of tools or materials falling on persons on the ground. All surplus materials and tools no longer required should be lowered by rope, or skip or brought to the ground by the workmen.

When the work is in progress and the presence of other workmen is necessary beneath the structure, they should be sure that their position on the ground is well clear from where any tools, or materials accidentally

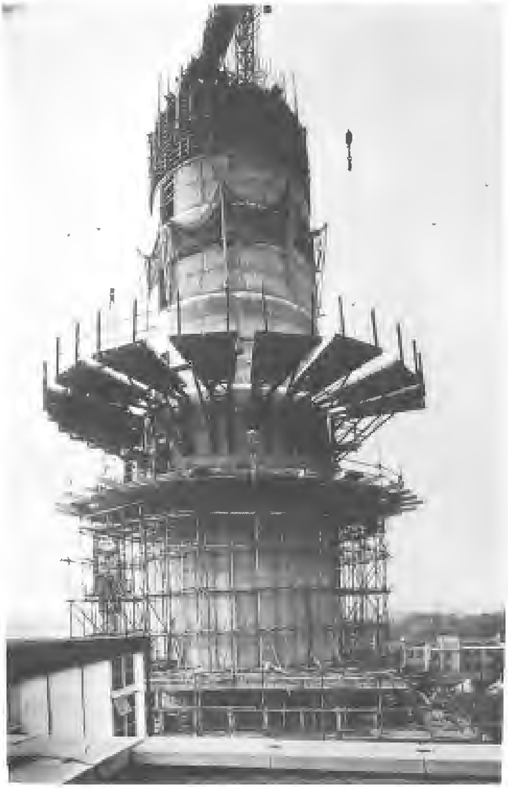

Figure 26.7 Safety net fitted to tower

dropped from above would fall. In this regard, tools and loose materials such as nuts, bolts, gusset plates etc. should be kept in tool bags or work baskets secured to the structure.

As far as possible, staff should avoid going into the danger area and any persons who have to work there must wear protective helmets. Whenever work is being carried out aloft and there is danger from falling materials, warning notices should be prominently displayed in the dangerous zone near the base. For structures up to 80 m, a radius of about 20 m may be regarded as a dangerous zone and for structures above 80 m the zone should be increased to about half the mast height. A larger area may be justified if wind velocity above ground level exceeds 10 knots.

(m) The increasing demand for cylindrical towers has introduced important problems in safety, particularly for the construction crew. The technique of construction requires no external scaffolding and the workmen are required to climb fly-like around the outside of the tower when working on shutters or fixing attachments. Workmen are suspended by lines and safety chairs.

For this manner of work a nylon safety net similar to that shown in *Figure 26.7* should be fitted to outriggers immediately below the work area. The net should be so placed that it will also catch falling equipment and tools which otherwise might be a hazard to people and buildings below.

Figure 26.8 Remotely operated earthing swtich

(n) Masts used for broadcasting purposes and which may be insulated from ground should be solidly earthed before an ascent is made. Where the earth is applied by a manually operated switch a warning notice should be attached to the switch. Where the earth is applied by a remotely operated switch the key should be removed and handed to the workman carrying out the work on the structure. If operation is by push button only, a suitable guard or tag should be placed on the button. A typical remotely operated antenna earthing switch is shown in *Figure 26.8*. It is used to ensure safety of staff during mast maintenance work and also for protection of antenna matching equipment from lightning damage after normal station shutdown. As an extra safeguard, it is the practice of many riggers and radio linesmen to bridge the lightning horn gap before they ascend the mast. In the case of sectionalised radiators, additional precautions may be necessary, where there is a break in the electrical continuity of the steel work.

(o) When work is done by a contractor on a mast or tower belonging to the organisation, the contract should make it clear that the contractor is responsible for the safety of his employees, and that in addition, he must accept the decision of the principal's engineer or station manager on whether or not conditions are safe for work to be performed on the structure.

The contractor's staff should not be permitted to use any equipment belonging to the station unless the engineer or station manager is satisfied that the contractor's workmen are familiar with any risks that may arise, for instance, from possible contact between mobile mechanical aids and overhead live transmission lines. After plant or equipment has been accepted by the engineer or station manager, the contractor's staff should be forbidden to work on the plant or equipment without a permit from the engineer or station manager and then, only in accordance with the recognised procedures.

(p) The complete structure including steelwork, insulators, halyards, catenaries, guys, anchors, winches, lifts, safety chairs and other plant used for inspection or maintenance purposes, must be inspected annually by a qualified inspector. Particular attention should be paid to wire ropes as they can become extremely dangerous to use if maltreated.

(q) All work carried out on a mast or tower should be constantly supervised by a qualified and experienced rigger or radio linesman. All foremen and others who may be called upon to perform supervisory duties should be adequately instructed in the art of rigging.

Many accidents have resulted in serious injury and damage to plant and equipment because of ignorance in the proper use of blocks and ropes and the various knots, bends and hitches which can be used safety in slinging and hooking loads.

(r) No staff should be permitted on the structure during guy tensioning operations. If guys are being fitted to a new structure or being replaced on an old structure after maintenance, staff should descend and retire to a safe distance after the guys have been attached to the structure, and before the free ends are pulled out to the anchor blocks. The fixing of guys to anchor blocks and the guy tensioning procedure is a very critical operation. Many structures have collapsed or been damaged during these stages of the work.

(s) All lifting gear must be in good condition and of sufficient strength to handle the load. It must be laid out and fixed in the most convenient position, but not where it will interfere with the operations. The ground in the vicinity of the mast should be cleared of all rubbish and surplus materials.

(t) All lifting gear, including slings, hooks, shackles, swivels, eyelets and ropes should be inspected before use by an experienced inspector. The gear must also be tested and examined regularly in accordance with the station safety instructions.

All pulleys, shackles and other auxiliary lifting equipment must be distinctly marked with their safe working loads. All wire ropes should be lubricated at regular intervals in order to prevent corrosion, to minimise abrasion and to keep the rope pliable.

(u) Care must be exercised in the use and storage of synthetic ropes as some types can be seriously weakened by sunlight. In particular, polypropylene and polyethylene ropes can be adversely affected by the ultra-violet rays if not appropriately sheathed.

(v) Portable electrical tools used for work on masts and towers should be adequately maintained by qualified staff and properly stored when not in use.

Practices adopted in the use of these portable tools on structures vary considerably. Some organisations permit the operation of tools directly from 240 V mains, others from 110 V circuits and some insist on 32 V tools. Where it is practice to permit the use of 240 V tools, the tools should be regularly inspected and maintained in first class condition.

Table 26.1 SAFETY ANALYSIS EXERCISE

Activity		*Hazard*		*Safety Plan*
1 Carry out tower maintenance				
1.1 tighten loose nuts and bolts	1.1	workman could slip or fall or be injured by wind gusts	1.1(a)	wear safety belt or harness securely attached to tower, hard hat and safety footwear
			1.1(b)	work to cease during electrical storms, rain, ice or when wind makes work hazardous
1.2 replace rusted nuts and bolts	1.2	materials and tools could fall to ground	1.2(a)	materials and tools to be kept in bag
			1.2(b)	workmen on ground to wear hard hats
			1.2(c)	define danger zone around tower base Clear personnel from the zone. Post warning signs
			1.2(d)	protect roofs of buildings in zone
			1.2(e)	warn staff in nearby buildings of work in progress
1.3 wirebrush rusted members and apply galvabond	1.3	dust particles and liquid could enter eye of workman	1.3	wear safety goggles
1.4 check tower lighting conduit and fittings	1.4	power could be applied	1.4	disable tower lighting circuit and lock out breaker

Table 26.1 SAFETY ANALYSIS EXERCISE

Activity	*Hazard*	*Safety Plan*
2 Carry out antenna panel maintenance		
2.1 attach block and tackle to maintenance beam at top of tower	2.1 workman could fall	2.1 wear safety belt or harness secured to tower
2.2 haul up bosun's chair	2.2(a) chair could be released	2.2(a) (i) control chair with appropriate fail safe winch
		2.2(a) (ii) verify capacity of hoisting equipment is adequate for the purpose
		2.2(a) (iii) verify that hoisting equipment has been inspected by competent officer before use
	2.2(b) chair could be swung about by wind	2.2(b) attach tail rope to tower
	2.2(c) chair vertical movement could be erratic	2.2(c) (i) provide workman in chair and winch operator with radio transceivers
		(ii) provide winch operator with binoculars
2.3 inspect antenna panels, power dividers etc.	2.3 antenna could be energised	2.3 lock out transmitter power breakers or lock transmitters to dummy loads *Note*: At some stations with two antenna stack levels, one stack is isolated to allow work while the other continues operation. In these conditions screens necessary to protect workman from harmful radiation or high voltages should be in position before work commences.
3 Clean up operation	3.1 station personnel could be injured by loose material and debris	3.1(a) clean up the area of all materials, debris etc. and remove roof protection materials
		3.1(b) carry out final inspection of tower to verify that no loose materials or components have been left on the structure

(w) Portable ladders should be in a safe position before being climbed. The slipping of the ladder at either end should be carefully guarded against, especially where the supporting surfaces are smooth or vibrating. In all cases where there is a liability of the ladder slipping, the ladder must be secured by tying the bottom to the base of the structure where this is practicable. Under no circumstances should a workman be permitted to stand on the top of the stile of the ladder. All ladders used on the job should be long enough for a safe hand grip on the ladder to be obtained at the required height. Long ladders should be ascended carefully and slowly so as not to set them into oscillation.

Figure 26.9 Guy anchor near the sea (Courtesy Far East Broadcasting Co.)

(x) Extreme care must be exercised when working on guy terminations anchored in hazardous locations. Such locations frequently occur with structures erected on mountain top peaks and close to the sea. *Figure 26.9* shows one guy anchor point of a four mast 100 kW directional antenna fixed in rock covered by the sea at high tide.

The hazards of work on masts and towers are well known to broadcast engineers and many organisations have adopted strict regulations to assure the safety of staff involved in the erection and maintenance of structures. Safety Analysis Exercise sheets are frequently prepared for major project works in order to identify the hazards arising from each activity, and to broadly specify the safety plan to prevent injury to staff as well as damage to equipment. The sheet enables the engineer in charge of the workgroup to organise the activity with a full appreciation of safety aspects involved. A typical Safety Analysis Exercise sheet prepared for work associated with the maintenance of the tower and antenna panels of a television transmitting station is shown in *Table 26.1.*

DAMAGE TO STRUCTURES IN SERVICE

The failure of any element of a structure used for broadcasting purposes can occur by yield, buckling or fracture on the application of a load of sufficient magnitude. Failure may also occur by time dependent modes such as fatigue, creep, corrosion and embrittlement. Where a structure is used as a radiator, for example, for medium frequency broadcasting, mechanical failure can occur as a result of the effect of the applied working voltage. Internal heating of insulators may be sufficient to bring about mechanical failure to these elements. Also, arc-over to a guy rope section can result in burn-through and collapse of the guy.

The following examples taken from a long list are typical of troubles experienced by broadcast engineers throughout the world. They amplify points raised throughout the text concerning safety to equipment, to staff who work at the station and to aviators who use the air space.

EXAMPLE 26.4

Damage to 230 m Broadcast Radiator, Prestons

At 1.30 am on 12 November 1969 serious damage was caused to a 230 m dual frequency broadcast radiator at Prestons, New South Wales, by an intruder. A charge of high explosive was fired at the base of the mast, destroying the main base insulator and causing the 50 tonne mast to drop about 60 cm.

The mast of 240 cm sides was triangular in section and of constant width for the full height. It was used as a common radiator for two 50 kW transmitters.

The explosion resulted in considerable damage, including the following:

(a) The large porcelain base insulator, was completely demolished and very little of the porcelain remained near the base area.

(b) Part of the 45 cm diameter 50 mm thick steel jacking plate was hurled a

Figure 26.10 Damage at mast base

Figure 26.11 Damage to antenna matching equipment building

distance of 50 m from the mast after punching a hole through the safety fence.

(c) The mast, in dropping about 60 cm caused severe distortion of the steel members of the lower section of the structure, further damage to the jacking plate and damage to the concrete thrust block. The extent of the damage can be seen in *Figure 26.10.* The broken jacking plate is resting on the thrust block base plate and top end cap of the base insulator.

(d) The antenna matching equipment building was extensively damaged. Part of the roof was blown off and a section of the wall demolished. This is

Figure 26.12 Broken guy insulator

shown in *Figure 26.11.* The dual frequency matching equipment inside the building was also damaged.

(e) The chain wire safety fence surrounding the base of the mast was damaged. A high voltage warning notice mounted on the fence was ripped off the fence by the explosion and embedded in the ground 70 m away.

(f) Seventeen guy insulators were damaged by shock impulses transmitted by the structure. One of the damaged insulators is shown in *Figure 26.12.* The structure was guyed at three levels at 120 degree intervals, with the upper guys being attached at the 180 m level.

Engineers and staff associated with the restoration of the mast had an extremely difficult and hazardous job. A 60 cm by 22 cm beam, 6 m long was bolted across two legs of the structure about 5 m above the ground and two smaller beams were connected from the first beam across the third leg in the form of a tee. Extendable columns were taken down from the free ends of the beam to specially formed concrete footings.

The displaced base of the mast was centralised to within about two cm of its original position by means of a hydraulic ram installed for the purpose. The mast was raised slightly on the temporary columns and the damaged taper section was cut away. This allowed access to the cracked concrete footing which was removed and the new block poured.

When the new taper section was delivered, the legs were cut and drilled for splicing to the new section. The mast was raised step by step on the temporary columns, the guys being slackened gradually as it went, until it was high enough for the new base and new insulator to the fitted.

EXAMPLE 26.5

Damage to 94 m, Sectionalised Broadcast Radiator, Emerald

Six days after a newly commissioned 50 kW medium frequency broadcast station at Emerald, Queensland, commenced transmission, the radiator which was of the sectionalised type partially collapsed on 10 February 1966 as the result of the support insulators failing at the base and at the sectionalising point of the mast.

The 94 m mast was sectionalised at the 49 m level and was an 18 point guyed structure with guys attached at the 15 m, 33.5 m, 49 m, 61 m, 74 m and 90 m levels. The lower three guy sets were each connected to a common anchor block spaced 120 degrees and located 37 m from the base. The top three were connected to common blocks located 77 m out from the base.

The structure was of lattice steel triangular configuration of 45 cm sides with tubular legs of 6 cm outer diameter. The weight of the 49 m lower section was approximately $1\frac{1}{2}$ tonne and the top section $1\frac{1}{4}$ tonne. Initial tension in each guy rope was 836 kg.

It is believed that the base insulator failed first, dropping the base of the mast about 36 cm and displacing it sideways 36 cm and inducing movement in the lower section of the mast causing the sectionalising insulator to fracture. This allowed the upper section to drop about 17 cm and displace the lower end of the upper section in relation to the top of the lower section. Subsequent examination of the sectionalising point indicated that the top section had been prevented from slipping off the lower section by the fractured insulator becoming wedged against a bolt head. The extent of the displacement at the sectionalising point

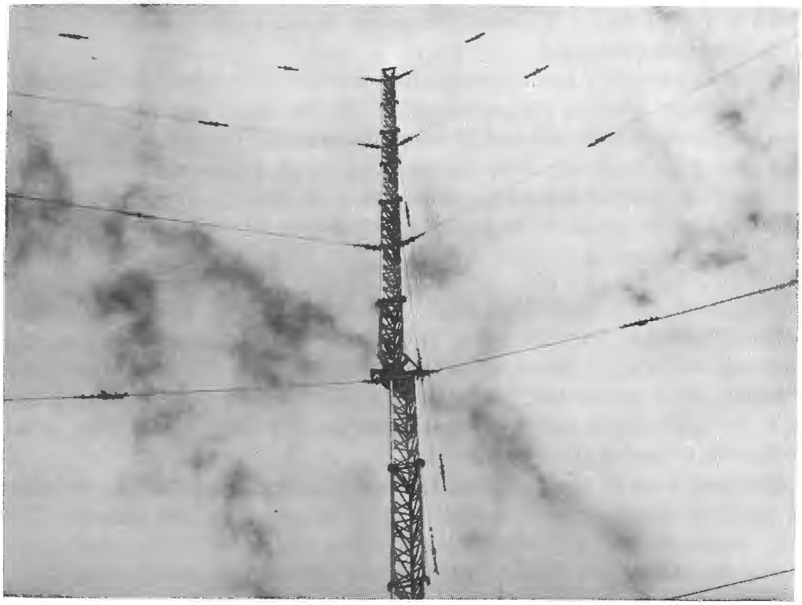

Figure 26.13 Displacement of top section after fracture of sectionalising insulator

can be seen in *Figure 26.13.* As a result of the insulator failures, all guy ropes were quite slack and the two mast sections were in relative swaying motion under the light breeze.

The lower section of the structure was bowed by the displacement of the base and the eccentric load of the upper section. The bulk of the remains of the shattered base insulator were beneath the mast base plate and scattered over the copper covered concrete thrust block. Some fragments were also found outside the mast fence enclosure. When the insulator failed, about 1 h 40 min after commencement of transmission, the epoxy insulator fragments were alight and two CO_2 cylinders were emptied in extinguishing the fire.

Both the base and sectionalising insulators were made of mass casting epoxy resin, hardened with an amine compound and loaded to approximately 60% with powdered quartz material. The structure of the insulators was such that cast aluminium end pieces were attached as an integral part to the epoxy resin casting. Examination of portions of the failed insulator showed that it had been manufactured from a badly aerated heavily filled synthetic resin material. *Figure 26.14* shows the bottom section of a fractured insulator and indicates the extent of aeration of the material.

Subsequent tests on a spare insulator at medium frequency, showed that a surface temperature rise of 10 °C occurred after six hours with 10 kV applied and a temperature rise of 51.5 °C after $3\frac{1}{2}$ hours with 20 kV applied. After this latter $3\frac{1}{2}$ hours test period, the insulator fractured right through, and a measurement of the exposed surface temperature indicated 114 °C.

It is interesting to note that at the time of failure the sectionalising insulator was short circuited and consequently its failure could not have resulted from the effects of excessive internal heating as in the case of the base insulator. Failure

Figure 26.14 Bottom section of fractured insulator

was most likely of mechanical origin and probably due to shock transmitted through the structure after collapse of the base insulator.

The restoration of the mast was a task requiring considerable expertise and was carried out in a commendable manner. Immediate steps were taken to first make the mast safe to give time to enable restoration methods to be worked out and to bring plant to the site. The base was tied back to the holding down bolts with steel straps and the lower three guys tightened. This action made the structure rigid but a slight bow was introduced into the lower section. The end of the broken sectionalising insulator was secured by a collar anchored to a plate on which the insulator was resting.

Further work was then carried out in three stages:

(a) Centralising the upper section of the mast above the lower section.
(b) Raising the base of the mast, centralising it, and fitting a replacement base insulator.
(c) Raising the upper section of the mast and fitting a replacement sectionalising insulator.

The centralising of the upper section was the most difficult and as it was considered undesirable for staff to work aloft, a remotely operated hydraulic ram was used with the pump at ground level and the ram at the sectionalising point. The ram and pump were connected by some 60 m of hydraulic hose which enabled the pump to be set up at a point about 20 m clear of the mast base point. Once the centralisation activities were completed, the insulators were replaced by normal procedures for this type of work, using jacks. Conventional porcelain insulators were fitted as part of the restoration work.

EXAMPLE 26.6

Partial Collapse of 198 m, Sectionalised Broadcast Radiator, Brandon

During the course of replacement of a damaged insulator and guy section, the top 94 m of a 198 m sectionalised broadcast radiator collapsed on 19 February 1963 at Brandon, Queensland.

The guyed three sided mast of lattice angle iron construction was used as the radiator for a 50 kW medium frequency broadcast station. It was sectionalised at the 160 m level with an inductor, and fitted with a 20 m diameter armature at the top. The armature was so constructed that it could be held in any position. from 90 degrees to the mast, where it gave maximum capacitance effect. In this particular application, it was fixed in the 90 degree position. The armature consisted of six equally spaced horizontal arms of steel frame construction and twelve radial copper cables, two of which were positioned between each adjacent arm. Electrically the armature was continuous with the mast and was provided as an integral part of the mast construction.

During evening transmission hours, some months before the collapse, the mast was struck by lightning. The stroke caused a flashover of a guy insulator at the top on one of the three top level guys and the arc was maintained by the r.f. power output of the 50 kW transmitter. It apparently continued for some time and was noticed by an off duty member of the staff who lived in one of the station houses. He heard the transmitted programme being emitted at a high level by the modulated arc.

When the transmitter power was later switched off it was observed that the top insulator assembly, one of a string of eight in that particular guy, was glowing, and it cooled only slowly. An inspection the following day showed the insulator to be shattered. Also, the insulator cage and portion of the guy rope showed signs of having been raised to a very high temperature. The guy was temporarily safeguarded by attaching a wire rope bridge between the guy section below the damaged portion and the guy attachment point on the mast. Later, arrangements were made for the replacement of the damaged insulator and guy section.

To allow replacement of the damaged insulator and guy section, all three guys were slackened to about three quarters of their normal working tension and a temporary wire rope of about 22 mm diameter was attached in parallel with the damaged guy rope. The damaged guy was uncoupled from the fixing pin at the anchor block and then allowed to swing in towards the mast. The combined weight of the two rear guys with their heavier rope (37 mm diameter) and insulators apparently took control causing the temporary guy rope to stretch sufficiently for the pivoted section to pass the critical point of stability, and collapse resulted.

In falling, the top 38 m section struck one of the lower guy ropes, causing the remaining structure to oscillate violently. This caused a section of about 56 m to break off and fall to the ground resulting in further structural damage. The falling steelwork carried away about 20 m of the top of the 80 m station emergency antenna erected some 73 m away and caused breakage of the open wire 6 wire transmission lines to both radiators, so putting the station off the air. *Figure 26.15* shows part of the wreckage near the main antenna matching hat and *Figure 26.16* shows the top section with the damaged capacity hat.

Only about 104 m of the original structure was left standing. This section suffered considerable damage in the form of buckled members and sheared bolts. However, as the base insulator and matching hut equipment were not damaged the engineer and station staff soon had the radiator back in service after repair of the transmission line and readjustment of the matching equipment.

Figure 26.15 Damaged section near main antenna matching equipment building

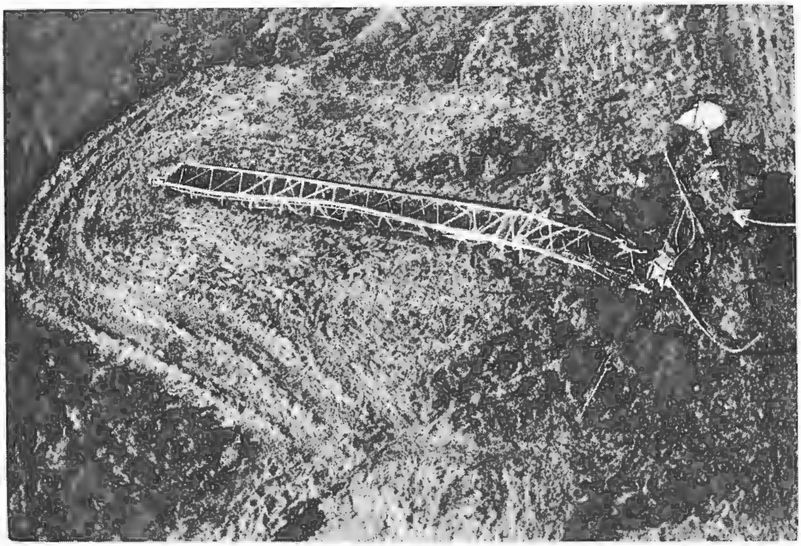

Figure 26.16 Damaged top section and capacity hat

EXAMPLE 26.7

Damage to 320 m Mast, Jyväskylä

The 320 m lattice steel mast at the Jyväskylä transmitting station was damaged on 8 April 1970 when an aircraft of the Finnish Air Force crashed into it at an estimated speed of 500 km/h during an exercise flight in bad weather conditions. The port wing of the aircraft struck the mast at about the 134 m level. The wing was torn off and the aircraft crashed some 100 m from the mast. The aircraft carried a crew of two and both were killed in the accident. The mast carried antenna systems for f.m. and television services.

It was the second time that the same mast had been involved in an aircraft accident. Some years earlier a light plane struck one of the guy ropes during a period of poor visibility. The mast on that occasion was not damaged and indicates the punishment which under certain conditions a guyed structure can tolerate.

The three sided structure was constructed of round members comprising sections 10 m in length. The aircraft impacted at the mid point of one of the sections and damage was confined to the point of impact. Repairs were carried out ***in situ*** by first replacing eleven damaged diagonal members to ensure the integrity of the structure. The insertion of the new diagonal members caused the bent vertical members to straighten considerably.

The verticals, although still left with a slight bend did not require replacement and the mast was considered to be safe under the loading conditions which prevailed.

The accident also resulted in part of the ladder rack being broken and the antenna feeders badly crushed and bent. Temporary repairs were carried out to cables and the frequency modulation transmissions were able to resume after a break of a few hours. However, the television service was not restored until the following day.

EXAMPLE 26.8

Collapse of Television Mast, Yllästunturi

The 212 m lattice steel mast of the Yllästunturi television station in the north of Finland, collapsed in the evening of 23 November 1970 during a period of severe icing condition. The structure was located some 200 km north of the Arctic Circle and the site was 700 m above sea level.

The mast which was triangular in section was supported at four levels by three equi-angle guys of stranded steel cable. It supported a television antenna and a frequency modulation service antenna. The television antenna which carried region III programme on channel 11 was a four level type with 16 panels of four full wave dipoles located at a height of 182 m at a mast section with a 1 m edge. The f.m. antenna was four level with 16 panels of two half wave dipoles at a height of 150 m in a section with 1.8 m edge.

The falling structure narrowly missed the equipment building as can be seen in *Figure 26.17.* The building was staffed at the time by a technician but he was not injured.

The Ylläs mast was a type that had been used in Sweden and Finland since the latter half of the 1950s. Altogether 80 of these masts had been erected in these countries and the Ylläs mast was the only one of this kind to have collapsed. The Board of Inquiry which investigated the failure reported that the collapse began when the bolts connecting the southern main member with the upper cone failed below the uppermost stay and it continued from there as a chain reaction, all the way down to the base of the mast. There were three separate phases in the collapse:

Figure 26.17 Mast wreckage near transmitter building (Courtesy Finnish Broadcasting Co. Ltd)

(a) In the first phase the impact load caused by the falling down of the upper part of the mast broke off the anchor bolts in the base of one of the uppermost stays thus causing the lower end of the stay to come loose and the section of the mast located betweeen the two uppermost stay levels to rupture.

(b) In the second phase, the top mast section that had broken off slipped down along the eastern second highest and second lowermost stay, breaking the parts anchoring the stay and loosening the lower end of the second lowest stay. The loosening of the stay exerted a powerful horizontal force on what was left of the mast. This force broke the parts of the mast between the lowermost and the third lowest stay levels.

(c) In the third phase those parts of the mast that fell to the ground damaged the base of the mast and also caused the lowermost part of the mast to collapse.

The Board concluded that on the basis of both static and dynamic analyses, the tensile strength of the joint at the point where the break presumably occurred proved to be the weakest of the mast. This was true for several different calculated loading combinations. The strength of the joint might have been lower than assumed due to loosening of the bolts. Inspections of other similar masts showed that nearly one-third of the bolts examined were strained and hence loose. The strong vibrations present at the instant of collapse, combined with a heavy load of ice, were probable reasons for the connection bolts of the southern main member of the upper cone below the uppermost stay to fail. Registered variations of the received fieldstrength in the radio link before the collapse and strong vibrations in the mast observed during previous years also supported this theory.

FURTHER READING

British Standard 2830, *Specification for Suspended Safety Chairs and Cradles for Use in the Construction Industry*

ROSSNAGEL, W. E., *Handbook of Rigging in Construction and Industrial Operations*, McGraw-Hill, New York, 1950

Part 3

Installation and Construction

Chapter 27

Designing for Safety

The types of accidents which occur in radio engineering installation and construction works are also met in other works involving electrical and mechanical equipment plant, but as discussed earlier there are additional hazards of a nature peculiar to radio engineering. Safe working demands intelligent radio engineering design, skilled workmen, experienced supervisors and an awareness of the dangers on the part of the whole work force.

A great part of the knowledge of installation and construction staff involves an understanding of the safety aspects of radio engineering and techniques and methods developed over the years have been those which have been proved to be sound and safe methods. As a consequence, most current safety precaution rules are the outcome of years of practical field experience. Many rules have changed from time to time as experience and new developments pointed to better ways of safeguarding workmen and equipment.

Since each new job and project has its own particular hazards, it is not possible to develop a standardised safety programme that will operate effectively on all types of installation and construction works. For instance, safety practices that

Figure 27.1 Modern 2 MW m.f. transmitter (Courtesy Brown, Boveri & Co.)

are highly satisfactory for the installation of a transmitter may be of little value when applied to the erection of a tall mast or tower. Also, it is not easy to always draw a clear line between installation and maintenance works because the fields in some areas and respects overlap. In many cases rules and precautions for maintenance works apply equally well to installation works and vice versa.

Proper design is essential for the safe installation, operation and maintenance of radio station equipment and plant. Responsible persons concerned with human safety all recommend that the proper course is to consider at the design stage of development, the nature and form of safeguards necessary for removing potential hazards. Such safeguards should include not only the protection of dangerous components and parts but also the most advantageous position and designation of control facilities to reduce operational error to a minimum. A good design must not only meet the required technical performance and standards, but must also provide adequate protection and a safe working environment for personnel. *Figure 27.1* typifies this philosophy in a modern well designed and engineered high power installation of a 2 MW medium frequency transmitter. The photograph shows the neat and well balanced layout of the control desk, paralleling unit and one of the two 1 MW transmitters.

It has to be recognised by designers that even the best engineered systems may fail. Every precaution must therefore be taken to ensure that failure does not create a hazardous situation to the system or the operator. If failure of a component or item does cause a dangerous overload, high voltage peaks or other form of electrical or mechanical hazard, the failure is said to be unsafe.

There are several objectives which the designer must strive to meet in producing a safe design:

(a) Safety to Installation Staff.
The design of the equipment and plant should be safe to allow proper installation or erection. The designer should make a close examination of the techniques and practices which are used by the staff during the installation process in order to obtain a proper appreciation of the hazards which might have to be overcome. For example, a transmitter must first be moved, erected, aligned, placed on plinths and fastened down, and the handling of heavy or bulky equipment and components always presents a safety problem.

Masts, towers and antenna systems usually require the lifting and fitting of heavy and large sections at great heights, and the awkward working positions and wind may make this work hazardous. The remoteness of the winch operator and the men handling the materials on the structure also tend to create hazardous situations, if not properly controlled. The designer has to take all these situations into consideration in deciding the break-up of the various steel sections. In some cases erection arrangements may strongly influence the final shape of an assembled section.

The start-up and test period of high power transmitters and large generating plant, can be particularly hazardous. The various mechanical and electrical checks for proof-of-performance that must be made at the pre-commissioning stage often result in dangerous situations. The designer should make himself thoroughly familiar with the reasons for tests, the methods of carrying them out and he must plan his design so that the programme can be carried out practically, simply and safely by the people responsible for the work. If these aspects are adequately considered it will make it unnecessary for installation and maintenance workers to resort to unsafe practices.

There is a tendency among many designers to play down the installation hazards as these activities occur only once, as a rule, during the life of the equipment or plant. This attitude must be closely watched, as there are many other factors which make installation works hazardous enough and which cannot be corrected by design. It will often be found that in designing around an installation hazard, operating and maintenance hazards are obviated as well.

(b) Safety to Operating and Maintenance Staff.

The design must ensure that operating and maintenance staff are adequately protected when working on the equipment or plant. It is obvious that a safe equipment design must guard staff against contact with live or moving parts. It is true that more than one type of satisfactory solution is often possible but it has also been shown by calculation and test that many arrangements which might appear safe at first glance would be extremely dangerous should there ever be an insulation breakdown to the operating mechanism or structure.

Routine operations of radio equipment require consideration of the electrical, mechanical and thermal hazards involved, such as starting up, shutting down, switching, control and observation of system functions. The use of insulation materials and components with higher temperature ratings allows modern radio equipment to operate at higher temperatures than were previously possible. For example, modern high power transmitting tubes using vapour phase cooling now operate in a steam environment compared with earlier hot water designs. The designer must be mindful that these higher temperatures increase the hazards of severe burns unless the hot areas are properly isolated and adequate handling facilities are provided for tubes etc.

Faults in equipment must first be located, and accidents can easily occur during the inspection and tests which may be necessary to determine the location of the trouble. Critical equipment and plant should be easy and safe to disconnect from the power source. Equipment fitted with provisions for check testing of its various functions will reduce hazards. Proper wiring and terminal identification is essential. There is always the tendency for some staff to bypass safety devices to expedite the fault location, and the designer must keep this in mind by making it as difficult as possible to bypass these devices. The safe location of faults and restoration of service is markedly improved if designers provide for convenient and easy removal, handling and replacement of equipment components or sub-assemblies. The module concept of sub-assemblies which can be maintained and tested prior to replacement into the equipment reduces hazards considerably, when properly engineered.

Awkward arrangements for changing large tubes and vacuum capacitors, adjusting switches, lubricating moving parts, reading meters and gauges, and also designs which require elaborate preparations for handling and replacement, are potential safety hazards. Equipment design should be such that manual operations are as simple and straight forward as possible. The proper grouping of instrumentation and the associated controls will considerably reduce the possibility of misoperation.

Any component in the equipment when subject to overload due to circuit fault or other conditions, should neither interfere with the operation nor cause damage to adjacent components or materials. Component construction should be of such a design that they will fail-safe by not causing excessive heat, fragmentation or the emission of harmful gases, fluids or solids. Components and materials in their normal state should under no circumstances emit free silicone or other deleterious materials or any other toxic or corrosive fumes, liquids or solids which could be detrimental to personnel or the operation of other plant.

(c) Safety to Property.

The design of plant, particularly masts, towers and antenna systems, must ensure that they are not a hazard to public property. Equipment installed within buildings and shelters, as a general rule, does not present a great hazard to property other than that belonging to the station management. However, external plant such as masts, towers and antenna systems can be a considerable hazard during both erection and operating periods when located in built-up areas and on top of city buildings.

A structure, whether it be the supporting structure or the antenna systems mounted thereon, is assumed to be safe if it safely withstands the loads that are applied to it during its working life, and continues to serve the functions for which it was designed without causing danger or undue disquiet to the owner or the general public. The designer endeavours to achieve the required degree of safety as economically as possible, but in doing this he may run some risks such as excessive deflection, buckling, cracking or breaking of structural parts which may, for example, allow antenna dishes or wires to fall to the ground, and, in the extreme case, collapse of the complete structure.

(d) Cost.

No matter how closely a design meets all the safety requirements of the specification, it will seldom get a chance to demonstrate the ability if it is not economically attractive to management. When management cannot justify the extra cost required for a safe piece of equipment or plant, the designer has probably failed in his job.

It should be remembered that safe equipment does not have to be expensive equipment. In fact, it often transpires after a closer examination that a design in which safety has been obtained at a higher additional cost is poorly conceived and badly engineered. The safety aspects of the installation, operation and maintenance of the equipment or plant must be constantly kept in mind during the whole process of design. If it is not, then it becomes increasingly difficult to economically rectify hazards.

ANALYSIS FOR SAFE DESIGN

Omissions of safety requirements during the design process account for a large proportion of accidents. Some form of design safety analysis is, therefore, essential to ensure the attainment of appropriate inherent design safety levels.

Several methods of design analysis may be applied, but the prime requirement is a systematic method for performing a complete safety analysis during the early design phase of the development of the equipment or system. Typical methods include:

(a) Periodic design reviews during the progress of the design and development work.

(b) Information studies such as test data evaluations, effects of environmental extremes, etc.
(c) Catastrophic failure analysis derived from collapse, failure, accident or malfunction.
(d) Hazard analysis which is an independent analysis of design and procedures.

IDENTIFICATION

All radio and electrical equipment and associated parts and plant should be suitably identified where necessary for safety purposes. The identification may be by position, colour, number, name, plate, label, or other means, but the means of identification chosen should be uniform throughout the station. The voltage and intended use should be shown wherever it will help to reduce the hazard. Switches which form part of safety facilities should be appropriately designated so that there is no ambiguity as to their purpose.

Identification marks should not, if avoidable, be placed on removable covers such as equipment covers, where interchanging of these removable parts might lead to operational errors. Where paint colours are used to identify the contents of pipes such as hot water, chilled water, compressed air, nitrogen etc., care should be taken to ensure that these colours are maintained, should any repainting or replacement maintenance works be carried out.

All station staff should be thoroughly familiar with identification marks, symbols, colours, etc., and it is practice with many organisations to ensure that all new members of installation and operations staff are checked for colour blindness before being permitted to work on equipment.

All control equipment installed in an environment exposed to the weather, and which requires the identifcation of colours for its safe operation, should be subjected to regular inspection routines to ensure that any faded identification colours are made good, as the need arises. Wherever possible identification markings should be indelible and remain legible through the life of the facility.

UNSAFE VOLTAGES

The risk of electrocution is a function of many factors, such as the level of the current, its duration and path. Fundamentally, current rather than voltage is the criterion of shock intensity. The most dangerous contacts are between head and feet, and between hands and feet. The circumstances which make electric shock accidents possible include:

(a) The presence of a workman in such a position that his body makes contact with two points of sufficient potential differences.
(b) The absence of sufficient body contact resistance to limit the current flow through the body to a safe value.
(c) The duration and path of the current flow.

It is difficult to determine what voltage, if any, is unconditionally safe. While it is generally recognised that shock hazards are negligible for voltages less than 25 V, a power source of 6 V or even less can be dangerous where there is sufficient capacity in the supply. Many people have received serious burns when personal metal objects, such as rings, have bridged across low voltage, high current leads to batteries or tube filament transformers.

The problem in determining a safe voltage arises from the variability of many factors. The most important factors which determine the seriousness of the shock may be categorised as follows:

(a) Resistance of the body.
The total body resistance is affected by the internal body resistance, the skin resistivity and the area of contact with the source. The internal body resistance is relatively low—about 500 ohm between hand and foot—because of the high salinity of the body fluids. Resistivity of the skin varies from about 100 ohm when wet, to about 100 000 ohm or more when dry. However, once the skin resistance is broken down, the current flows through the blood and body tissues and the resistance to the current is that offered by the body internal resistance. Even without skin breakdown or puncture, there are many situations encountered in radio work where environmental situations such as high humidity, perspiration, wet clothing and large areas of contact make it necessary to assume a skin resistance below a normal value. The 500 ohm figure is frequently adopted as the working figure for body resistance calculation purposes as most current paths in practice are between hand and foot. For a temple to temple path the body resistance may be as low as 100 ohm if the skin is broken.

(b) Current path and duration.
The injuries from an electric shock are likely to be much greater when the path of the current involves the heart and lungs than when the current does not pass through or near these vital organs and nerve centres.

The longer the period the current flows through the body the more serious the consequences. Large currents will cause burning of tissue and possibly haemorrhage even though fibrillation of the heart may not be present. Long term contact with low current flow will cause decrease of muscular strength because of pain and fatigue resulting from muscular contractions. Where the victim is unable to voluntarily let go, exhaustion, asphyxia and death may result.

(c) Current magnitude.
The accepted value of a safe current is one that can be applied to the subject for an indefinite period, causes no injury and allows the subject to voluntarily free himself, without assistance, from the source of the current. The threshold of perception is generally accepted as being of value about 1 mA, although this varies widely from person to person and the environmental conditions. As the current is increased to about 5 mA, many sensory nerves are stimulated and the sensation becomes painful. As the current increases above this value motor nerves are stimulated and muscles may contract. At about 9 mA, the victim lacks the ability to control his own muscles and therefore cannot voluntarily let go of the live conductor. Although painful injury may result from the violent contraction of the muscles, the heart and respiratory functions would under most conditions continue. Above about 100 mA, the situation is very serious because life-threatening physiological phenomena may occur. The most important is ventricular fibrillation which defeats the heart's ability to pump blood, and unless corrective action is taken quickly, the effect can be fatal. Currents above 5 A also cause extensive damage as a result of burns and heat.

As a result of findings by many research workers, engineers have in recent years tended to adopt three levels of potential shock hazards for design purposes. These are:

(a) Minor shock hazard.
This generally exists with voltages less than 25 V, although as mentioned previously, voltage very much lower than this level can be dangerous under some conditions.

(b) Shock hazard.
A shock is considered to exist with any circuit fed from a 50 Hz a.c. or a d.c. source capable of passing through a 500 ohm load an uninterrupted a.c. current in excess of 9 mA or an uninterrupted d.c. current in excess of 60 mA.

(c) Major shock hazard.
A major shock hazard is considered to exist with any circuit fed from a 50 Hz a.c. or a d.c. source capable of passing through a 500 ohm load an uninterrupted a.c. current in excess of 100 mA, or an uninterrupted d.c. current in excess of 500 mA, or a surge discharge in excess of 50 Ws.

If it is assumed that the body has a resistance of 500 ohm under the worst conditions, then 50 V a.c./r.m.s. and 250 V d.c. can be considered as extremely hazardous voltages. The reason why a higher d.c. potential can be tolerated is that it does not cause contraction of the muscles to the same extent as a.c. Tests have shown that a subject can withstand a decidedly higher value of d.c. and still maintain control of his muscles. The muscle contraction of d.c. occurs chiefly at the time of making and breaking contact with the source. Caution should be exercised against interpreting the differences between potential values as a true index of relative hazards between alternating and direct current. It is emphasised that current is the proper criterion of electric shock intensity.

Also, it must be remembered that while work with d.c. potentials is comparatively safer than with a.c., on a volt for volt basis, the uncontrollable and often violent muscular reactions, particularly when breaking contact, can result in accidents due to indirect causes to the victim, other workmen nearby or the equipment.

In order to prevent confusion, duplication of standards and because many radio circuits contain both a.c. and d.c. potentials, it is now common practice in radio specifications to call for all voltages in excess of 50 V r.m.s. or 70 V peak to be considered as 'dangerous' and require the provision of suitable safeguards, where these potentials exist.

A major problem at large broadcasting stations where a permanent linestaff is employed is that associated with radio frequency burns resulting from voltages induced in materials and equipment being handled by the staff in the field. Often the radio frequency burns are deep and besides being painful take a long time to heal. The damage is the result of heat flow through the skin at the point of contact.

The criteria used for defining electric shock from mains power alternating current and direct current are not applicable to the radio frequency burn situation. The specific radio frequency voltage considered to be a burn hazard has not been clearly established but it is generally agreed that a situation can be considered to be hazardous if contact with the source will result in visible damage to the skin, cause an involuntary reaction by the victim or will cause pain.

It is not uncommon for a radio frequency voltage of 1250 V to be found on the guy attached to the bottom insulator of a 50 kW medium frequency broadcasting station and protective guards are usually specified at these points. Unearthed standby masts and towers can have very high voltage levels induced in them and should be approached with caution. For the purpose of defining a hazardous situation on their station some engineers have adopted an open circuit radio frequency voltage level exceeding 140 V as being appropriate.

Radio frequency voltages induced in metal mast sections and wires being handled on site are anticipated by most field staff and rubber gloves are usually worn. However, some mechanical aids because of their large physical size can have high voltages induced in their metal work. At one 250 kW high frequency broadcasting station a jib crane was being employed to lift steel mast sections some distance behind an activated antenna when the petrol tank ignited and set fire to the machine. The combined length of the steel section, lifting wire rope, jib and tractor body passed through a half wavelength resonant condition just as the load was lifted a short distance from the ground. The operator heard a sound like an arc near the fuel tank and ignition occurred.

WORKING ON LIVE EQUIPMENT

The performance of work on live equipment should be restricted to an absolute minimum. It is not practicable to eliminate completely work on live equipment, as this is a requirement in many cases in order to locate a fault. Not all circuits are permanently metered and temporary access arrangements for purposes of determining voltage, current, etc., are often necessary. Most temporary metering arrangements can however be carried out in a safe manner if proper safety precautions are taken. Built-in devices, such as gate switches, should not be bypassed during the work.

Typical recommended precautions to be taken when working on high voltage live equipment include:

(a) The workman to be properly briefed as to the nature of the work to be performed and the hazards involved.
(b) All relevant safety precautions to be followed.
(c) The workman to exercise extreme care in carrying out the work.
(d) Test equipment, leads, tools and all other devices required for the work to be in first class condition.
(e) The area of the work to be well illuminated.
(f) The workman to remove metallic personal accessories, such as rings, before commencing work.
(g) Loose clothing to be secured.
(h) The workman to stand on an insulated mat and place insulated mats over metal work and equipment to prevent his body coming in contact with live conductors or earthed metalwork.
(i) A second workman to stand by in case assistance is needed.

It should be particularly noted that insulated mats, rubber gloves or insulated tools do not necessarily give adequate protection at high voltage radio frequencies because of capacitive coupling between an earthed object and the r.f. voltage via the dielectric material.

On some stations, safety rules permit the use of rubber gloves as a protection against electric shock when workmen are engaged on live work with voltages up to 400 V peak, at power frequency or direct current. Their use above 400 V is seldom permitted owing to the difficulty of ensuring their high reliability. Any glove suspected of having been damaged should not be used unless properly tested by a competent inspector. All gloves used for protection purposes should be stored under approved conditions and subjected to frequent and regular inspection.

LEVELS OF ILLUMINATION

Adequate illumination should be provided throughout all areas where operating equipment and plant is installed. All passageways should be sufficiently lit to enable staff to move about without danger.

Local lighting to permit reading of identification tags, the visual checking of fuses, circuit breakers, switches, meters, liquid levels and the like, should be provided where the general illumination level requires supplementation. General purpose outlets should be suitably located throughout the equipment cubicles and the area to facilitate the use of portable lights.

A separate emergency source of illumination from the station battery system should be provided at every station where an attendant is located. The switching circuit should be so tied with the normal mains supply, that on failure of this mains supply the emergency lighting system is automatically energised.

The levels of illumination in rooms and areas where radio and electrical equipment are installed has been the subject of lively disscussion among engineers for many years, and there seems to be many cases where individual preferences enter into the arguments rather than pure safety requirements. *Table 27.1* shows the recommended illumination intensities for artificial lighting adopted by one organisation for design of its radio installations. The illumination levels indicated, are intended to be read in the horizontal plane at 1 m above floor level, except at the rear of power switchboards where it is read in the vertical plane.

Table 27.1 RECOMMENDED ILLUMINATION INTENSITIES

Location	*Intensity* (lx)
Control rooms	200
Transmitter equipment areas including vaults	200
Equipment rooms, including programme input, frequency generating, radio link rooms and receiving station halls	200
Battery and water distillation rooms	100
Power house, switchboards and generating areas	200
Mechanical equipment rooms	400
Store rooms	100
Workship areas	400
Antenna switchrooms and matching huts	100
External transmitter power equipment areas and switchyards	200
High density component repair benches	1000

BONDING, EARTHING AND SHIELDING IN BUILDINGS

To be effective all electrical bonding and earthing should be complete and continuous within a given structure, so that no significant difference of potential will be developed between metallic items or surfaces when subjected to intense radio fields. This is necessary to secure personnel protection from electric shock and burn hazard to prevent arcing and consequent fire and to prevent the generation and radiation of spurious and harmonic frequencies in metal structures. Poorly bonded joints can create the non-linear conduction characteristics needed for such generation.

To meet this requirement it is essential that each building or structure or metallic element located in an intense radio field area be provided with a complete and continuous earthing system within itself and this system in turn be connected in numerous places to an overall external earth system. To further meet this earthing criteria, it is necessary that all metallic elements including concrete reinforcements, structural steel, metal roofing, walls or decks, ladders, crane rails, pipe railings, fuel and water tanks, piping and conduit systems, electrical equipment and enclosures, doors, window frames, bin storage shelving and all other special equipment of a conductive nature, should be bonded in an approved manner and in turn connected to the main station radio frequency earth system. It is important that these connections be made with low impedance straps.

Straps have an equivalent parallel circuit represented by capacitance due to residual capacitance of the strap and the mounting, and self inductance. The parallel combination of L and C forms an anti-resonant circuit and in order to provide a low impedance path at the ratio frequencies concerned, the self inductance and residual capacitance should be minimised. It is difficult to change C but the self-inductance can be kept to a minimum by using solid strap in lieu of braid and by keeping straps thin, wide and as short as possible. A typical strip 50 mm wide, 0.5 mm thick and 15 cm long has negligible d.c. resistance but has an impedance of about 0.2 ohm at 17 MHz and 16 ohm at 1 GHz.

Another factor is that the bond is always in parallel with members to be bonded and the total impedance includes the various paths over which radio frequency currents may flow. Thus a bond strap of low inductance may combine with the capacitance of the installation to form a high impedance anti-resonant circuit at some frequency in the critical band.

Generally there are four basic factors involved in the consideration of bonding, earthing and shielding:

(a) To secure personnel protection from electric shock hazard. The provision of a simple earthing connection to the case of each power component, the metal framework of component assemblies, metal equipment racks or cubicles, essentially eliminates the danger of personnel shock, due to accumulation of static charges or to internal failure of insulation, especially in power components.

(b) To prevent arcing between metal components or a metal component and earth. High voltages and high circulating currents can occur in conducting members in an environment where there is a high radio frequency field strength. Arcing between members may occur and may set fire to nearby combustible materials. Also, high circulating currents may cause a high temperature rise in metallic members.

(c) To obtain the correct technical operation of transmitting, receiving and testing equipment through the ability to control desired and undesired signals.

Generally this control of signals is achieved by the provision of a basic earthing system for the building to which all parts of the equipment are earthed. The transmitter output circuit is of particular concern, since very heavy radio frequency currents are encountered, requiring very good balance in the output line (where it is balanced to earth) and adequate earthing in the vicinity of the output circuit. Earthing and shielding of low level audio cabling is necessary, and shielding of audio equipment may be required. Where audio facilities include high impedance devices, special attention is needed in shielding and bonding details. Where radiation from antennas may be encountered, shielding of low level equipment rooms may be needed.

(d) To prevent the generation and radiation of spurious and harmonic frequencies in metal structures.

Moderately thorough attention to earth systems and earthing details, plus application of audio and power line radio frequency filtering techniques where needed, would be adequate if the only consideration were one of proper technical operation of the transmitter.

Where the station system involves sensitive receiving equipment as well as intersite radio channelling facilities, the additional consideration of spurious signal generation in metal structures, either in the basic transmitter housing itself, or external structures, due to poorly bonded metal joints must also be taken into consideration.

The factor of spurious signal generation will also be an important consideration where high power transmitting stations are located close to populous areas due to potential interference to medium frequency, high frequency and television reception. Spurious signal generation in exterior metal structures, causing sums, differences, products and combinations of transmitter frequencies, can cause signals to appear in widely separated parts of the spectrum, often at surprisingly high intensities. Such spurious signals could, in fact, be radiated in such intensity as to exceed government regulations causing the transmitting equipment itself to be suspected of not operating within its specifications.

To minimise the possibility of such spurious signal generation, all metal used in building construction should be earthed or bonded to a properly earthed member. This includes all reinforcement steel in concrete structures, all plumbing and metal conduit installations, as well as metal roof, ceiling, wall and windows panels. Security fencing around the building area also requires earthing. Experience has shown that in a properly designed and supervised installation, this source of spurious signal generation will not usually occur in a new installation, but as corrosion develops after a period of time, non-linear conduction paths develop and spurious generation increases. Particular attention is therefore necessary in jointing dissimilar metals or where joints and earth straps are exposed to a damp environment.

Providing a good basic building earth system, including the bonding and earthing of all metal structures and installations within the building, plus shielded control and test rooms, will of course add an item of considerable expense to the building construction and it is important to ensure that the work is properly carried out in accordance with the specifications.

However, all these special measures cannot in themselves guarantee complete freedom from undesired signal pick-up in critical circuitry. These measures do nevertheless minimise the amount of trouble shooting needed to obtain clean operation of the station and expenditure, invested for this purpose during construction of the building, may very well be much less than the cost of overcoming pick-up problems encountered after the station has been placed in full operation. This is especially so if it is found after all construction work has been completed, that interior shielding or complex bonding must be installed in order to achieve satisfactory spurious signal control.

Obviously, a basic building earth system properly installed and adequately bonded to minimise spurious signal generation will also go a long way towards achieving correct technical operation of the radio equipment itself as well as providing adequate personnel protection.

The design of the earthing system for a high power station, particularly for high frequency, is complex engineering exercise requiring considerable investigation of soil conditions and a great deal of experience. In a typical installation, the earthing facilities consist of interior and exterior busbars. The exterior busbar consists of a 50 mm by 3 mm copper bar extending around the periphery of the transmitter building attached to a network of copper stranded conductors in grid formation of 1.8 m to 2.4 m squares, with copper or copper clad earth rods attached at the grid wire intersections. The depth to which the earth rods are driven depends upon the soil resistivity, but it is general practice to drive, where practicable, for an overall direct current resistance of about 0.5 ohm. The area occupied by the grid is dictated by the electrical constants of the soil and the location of the radio equipment within the building. The transmitter building external bus and its associated earth grid is tied to every grid system on the site complex, including those associated with power house, fuel tanks, switchyards and other buildings.

The inside busbar of the transmitter building is provided around the inside walls of the building and connected to the exterior bus at intervals of about 3 m with a wide low impedance copper sheet. There are many forms of earth arrangements within buildings, but the most preferred methods for high power installations consist of:

(a) Expanded copper mesh under all floor surfacing or covering of all equipment areas, with the mesh joined directly to the internal busbar. Connection with equipment is made by bringing up straps from the mesh at suitable locations.
(b) Fifteen centimetre wide copper straps forming a criss-cross grid on the slab floor, bonded at points of intersection and connected to internal busbar.

Within the main radio frequency and modulator cubicles of the transmitter, it is usual practice to provide 30 cm wide copper straps to bond the transmitter to a common earth connection. The frame of each component and rack assembly in the power supply is separately earthed.

Fully shielded, transmission lines from transmitter to antenna switching matrix as in *Figure 27.2* generally present no special problem of bonding, since earth currents are readily controlled. Normal bolted surfaces with bolted connection to earthed structures are generally sufficient. If a transition from transmitter

Figure 27.2 Shielded transmission line and switching matrix (Courtesy Continental Electronics)

coaxial lines to an open wire transmission line occurs quite close to the transmitter building, a good connection to earth at the point of transition should be provided. A copper sheet strap 45 cm wide has been found adequate for the purpose. *Figure 27.3* shows such a bonding and earthing strap near the transition section of a 250 kW high frequency transmitter. Good balance in the open wire line will minimise earth currents. However, some earth currents may flow in building structures where this transition is nearby, and greater attention to bonding of building metal work on the sides nearest the point of transition to open wire lines may be necessary.

In the case of earth tracking stations where signals of very low power levels are handled, the earthing system can be a major source of spurious noise generation and distribution. Great care is necessary in the design, layout and installation of the system to provide an equipotential source for the electronic equipment of the station as noise free as economically practicable.

For many of these stations it is practice to split the earth system into two sections with the two sections electrically connected at a single earth point. One system known as the quiet or signal earth is provided exclusively for the electronic equipment which is insulated from adjacent racks and other structural work. The other system known as the safety earth is used for personnel and equipment protection purposes.

The two earth systems are usually of the rod electrode types with sufficient rods to give a system resistance of 0.5 to 1 ohm. The earth electrodes are

Figure 27.3 Bonding and earthing strap for transmission line

connected to a copper place in a manhole and cables run from the plate to the required distribution points. The signal and safety earth systems are similar, with the earth electrodes interspaced, but whereas the safety earth uses all bare cables, the signal earth has all cables and terminal blocks insulated. Greater care is taken to prevent looping feeds during the installation. All feeds are radial.

Where the site is extensive and several buildings require both signal and safety earths, the practice is to install a satellite earth system identical to the main system and to interconnect all signal earth plates with insulated cables and safety earth plates with bare cables.

All electrical building wiring at transmitting stations should be encased in metal covering. Screwed galvanised conduit or integral copper coating such as pyrotenax are acceptable.

Cabling used for external services need not be run in metal conduit if steel armouring, properly earthed in accordance with design drawings, is provided.

In the case of overhead electrically driven cranes or gantries, flexible control leads and bare power pick up wires need not be shielded, provided that adequate insulation and suitable r.f. bypassing equipment are provided between all conductors and earth.

Shielding in the form of expanded copper or aluminium mesh should be provided over fluorescent light fixtures in strong r.f. field areas, Metal window frames should preferably be all welded construction of metal of high electrical conductivity to prevent heat losses damaging the enclosed glass. Aluminium alloy material is acceptable but heavily galvanised steel may also be acceptable in some situations owing to the high conductivity of the surface zinc coating.

Opening sections of the window should make positive connection of low resistance with the fixed frame. Where this cannot be maintained, a strap should be provided to bypass the hinge.

Metal reinforced glass should not be used in any window of the transmitter building or other buildings and huts where high radio frequency fields exist. Where used in other buildings, the wires at the perimeters of sheets of wire should be connected to metal frames at 70 cm spacing.

Where windows are used as lead-outs from matching hut equipment to antennas, considerable care is necessary to ensure a properly engineered arrangement.

Because of the thickness of the glass—sometimes up to 25 mm plate— it is usual to mount the glass in a wooden frame. However, this is a high fire risk, and the woodwork should be completely covered with sheet copper solidly bonded to the hut screening or earthed with a low impedance strap if no hut shielding is provided. In the finished installation the glass should fit tightly into a copper channel. Roofing material covering the transmitter building and in particular areas over which open wire transmission lines may pass should be of high electrical conductivity. Copper, aluminium and zinc have proved satisfactory but are expensive. Galvanised iron with a thick zinc coating has also been found satisfactory in many installations.

Individual sheets should be of maximum available width and length in order to reduce bonding problems.

Where the roof is isolated from ground, for example when only brick walls are used, low impedance straps should be provided to connect the roof to the building earth grid system.

Any wire mesh used in the ceiling to support insulating material, such as insulwool, should be of a type which is welded or similarly fixed at all crossover points. Overlapping sheets should be bonded as 70 cm spacing and the whole of the mesh securely bonded to supporting steelwork at 1.37 m spacing.

Heat reflecting material, such as sisalation foil, should be bonded and earthed similar to mesh.

Owing to the possibility of arcing between inadequately bonded conductors in the ceiling all heat insulation and acoustic materials should be of non-flammable types.

Overhead gantry rails supporting the traversing mechanism should be securely bonded to the piers by welding at the plate or bridging with a bond strap. All piers should be electrically continuous to one another through the metal work of the structure. Continuity via metal wheels of the traversing mechanism is acceptable. Care should be taken to ensure wire ropes and chains are adequately earthed through the systems. Nylon bearings or roller wheels should be bridged by suitable slip ring type devices.

SHIELDED MATCHING AND COMBINING HUTS

Antenna matching and combining huts provided at the base of high power antenna systems may require shielding to prevent the generation of eddy currents in building structural steelwork including concrete reinforcement steelwork.

Shielding of the internal walls, floor and ceiling in a typical hut is provided by using cold rolled sheets of 0.6 mm copper which is fixed in position with a power driven fastener applied through a copper disc or other mechanical fixing device.

To eliminate corona flash-over, insofar as is possible, the interior copper finish of the building shield should be entirely devoid of sharp corners. That is, re-entrant corners should have 15 cm radius copper fillets and all exterior corners rounded to a 15 cm radius.

Personnel doors, equipment doors and louvred vents should be all copper or steel frame with copper sheet covering, as conditions of use dictate. Each door leaf should be grounded to the copper building skins by means of flexible jumpers.

All joints should be continuously soldered or brazed and wiring chases within the hut copper lined and soldered for continuous electrical bonding.

Coaxial transmission lines should be terminated in a properly engineered arrangement and the outer bonded to the copper shielding at the entrance point to the hut by flexible copper straps properly bonded to the line flange and the copper sheet.

All metal components going into construction of the hut should be electrically bonded together, and connected to the earth system. Electrical bonding should be complete and continuous extending between all metallic elements of the

Figure 27.4 Room shielding at 2 MW VLF station (Courtesy US Navy)

structure, including concrete reinforcement and other structural elements, the copper wall panelling, equipment frames and bases, electrical equipment apparatus enclosures, lighting transformer neutrals and coaxial transmission line outer conductors. R.f. shielding in the form of expanded copper mesh should be provided over fluorescent light fixtures.

If building wall panels are to be used in the hut construction, the panels should be faced with a copper sheet skin both inside and outside, soldered or brazed to provide continuity of electrical shielding, and good conductance properties.

The copper shielding should be connected at intervals to the interior earth busbar in accordance with the design drawings. An exterior 50 mm by 3 mm copper bar placed around the periphery of the hut should form the external earth system and be connected to the interior earth busbar with wide copper straps located at frequent intervals in accordance with the design drawings. The exterior copper bus in turn should connect to the copper earth mat associated with the radiator at the intervals specified on the drawings.

Sheet aluminium has also been successfully used to shield huts but considerable expertise is necessary in the welding operation of joining the sheets.

Figure 27.4 indicates the extent of shielding provided at one high power very low frequency station. All the seams of the copper sheeting are soldered and fastened by blind rivets to brass furring. Anti-corona fittings applied to the high voltage trunk to prevent corona can be clearly seen.

SWITCHYARD AND MAST ENCLOSURES

Structures in power switchyards develop high radio frequency voltages because the size of the structures are such that they approach resonant conditions, particularly at high frequency broadcast stations. Care must therefore be exercised in the design of substation or switchyard earth systems to ensure they present a low impedance at the station operating radio frequencies.

All metal work in the switchyard with which maintenance staff could be expected to contact during their normal work, should be solidly connected to the earth system. The bonding and earthing of the fence and gate should be in accordance with the requirements for station security fencing.

Because of voltage considerations during a fault in the power supply system, there is a difference of opinion among engineers regarding the connection of the fence earth conductor to the switchyard earth system.

When there is a heavy flow of current through a connection to earth, due to an earth fault or a lightning discharge, the switchyard earth system is elevated above earth potential by a value equal to the voltage drop in the connection to earth. This voltage drop is equal to the product of the current and the impedance in the connection to earth. If the fence earth is connected directly to the main switchyard earth system, it will also be elevated above earth by the same amount. Because the potential gradient in the earth adjacent to the fence drops very abruptly within the first few metres away from the fence posts or other connections to earth, there may be a serious hazard to personnel standing on the earth and in contact with the fence.

On the other hand, if the fence earth is isolated from the switchyard earth, the potential difference will appear between the switchyard equipment and the fence.

Figure 27.5 Wire type security enclosure

Figure 27.6 All wood type security enclosure

When the fence is separated from the switchyard equipment or structure by a considerable distance there is little possibility of contacting both at the same time. Under this condition there is some merit in isolating the fence ground from the switchyard ground.

Enclosures are also provided around the bases of most medium frequency broadcast radiators for safety purposes. The majority of enclosure are of the chain wire manproof fence type and they should be properly installed with attention being given to bonding and earthing of all metal work with gate hinges being bridged with suitable straps. *Figure 27.5* indicates a typical security enclosure for a 10 kW transmitter but a major disadvantage with this type is that absorption power losses can be considerable. *Figure 27.6* shows an all wood type of enclosure at a dual frequency 55 kW station. No bonding or earthing problems are introduced and r.f. power losses are negligible. The timber used is well seasoned painted hardwood.

FURTHER READING

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Chapter 28

Installation of Equipment and Plant

SAFETY FEATURES IN TRANSMITTER DESIGN

Design simplicity is in itself a potent safety feature in radio transmitter construction. Errors by operational staff are compounded by complex transmitter system designs. Particularly in emergencies, it is necessary that the operator of the equipment clearly visualises at once how the various circuits, switching and interlocking devices are inter-related. At this time of stress, mistakes can be costly, if not disastrous. A well designed mimic diagram on the deck in the station control room with all indicating devices automatically set up, further unloads the operator's mind and contributes to improved safety.

Radio transmitting equipment, as a general rule, is designed and constructed to operate safely, as long as reasonable care and judgment are exercised. However, safety rules must be strictly observed, since high voltage on certain components is sufficient to endanger life.

Design aspects to be taken into account, to ensure a safe transmitter include the following:

(a) The overall design of the transmitter to be in compliance with current electrical codes of recognised authorities.

(b) All non-current carrying frames, panels, covers and the like to be suitably earthed so that potential differences above ground reference cannot exist. Proper system and equipment earthing is a most deserving area for improved safety. About one out of every four accidents involving electric shock occurred by contact with parts normally not energised. This means the equipment earthing had been inadequate. A continuous low impedance earthing system spreading from the station building earth grid and encompassing every separate item forming the transmitter installation is essential for safe operation.

(c) Full consideration of heat and fire producing characteristics to be given in the design, selection and location of materials used. Ventilation and location of equipment in relation to personnel, property and other equipment, are important factors. Non-combustible materials should be used where possible. Fire resistant materials are a second choice. If combustible materials are used, protection should be given from heat and arcing.

Properly engineered cooling and ventilation systems should be installed to remove heat and to provide air circulation throughout cubicles and equipment areas.

(d) Dielectrics to be of types which will prevent or minimise arcovers and tracking at the operating voltages and frequencies applicable.

(e) Large transmitters have the potential of destroying themselves and entire buildings. Consequently, they should have a built-in protective system that includes detection of over-heating, smoke and fire, with automatic power cut-off and ventilation system shut-down facilities. The provision of automatic fire extinguishing equipment may be considered desirable in some circumstances.

(f) The layout and design of equipment, and in particular, radio frequency and modulator cubicles, and power vault plant to be such that adequate working space is allowed around all units, components and machines requiring periodic maintenance or adjustment.

Normal working positions must provide safe distance from adjacent equipment, plant, hot water pipes etc., to prevent hazards or to keep them to a minimum. Equipment which requires regular checking or maintenance should be mounted at least 60 cm above floor level. In particular, ample room and handling facilities should be provided for the handling of large transmitting tubes and vacuum capacitors.

(g) The transmitter to be designed to ensure complete protection of operating personnel against contact with apparatus carrying dangerous voltages.

Access to the equipment should be available only after the main power supply circuit breaker has been operated to isolate the mains, the high voltage direct current supplies have been earthed by a mechanical device, and the gate and door interlock system has been operated. The measures should be such that they are not made ineffective without a deliberate action. Keys and/or special tools should be required to enable this operation to be performed.

(h) All capacitors which are accessible or connected to accessible conducting parts to be provided with bleeder resistors, shorting bars or other leakage paths to reduce capacitor potentials quickly to less than 72 V peak.

Where the capacitor is operated at peak voltages above 350 V the leakage path should cause the voltage to drop below 72 V within 4 s.

Where the capacitor is operated at peak voltages below 350 V the leakage path should cause the voltage to drop below 72 V within 2 s.

Where the energy stored in the capacitor exceeds 13.5 J and the voltage is 72 V peak or higher, a shorting bar should be provided so that a short circuit of the capacitor is achieved before the mechanical manual opening of an interlocked enclosure system can be effected.

(i) All equipment, terminals and conductors carrying voltages above 72 V peak to be completely enclosed with covers of either safe insulating material or earthed metal covers.

The cover should have printed thereon a warning notice, indicating the voltage and where applicable the location of the switch or circuit breaker controlling the power supply to the equipment.

(j) The doors or gates of enclosures surrounding live equipment to be fitted with safety switches that will remove dangerous voltages, including those due to charges on capacitors, before access to the enclosure can be obtained. While access to components, for examples tubes, are frequently necessary, safety arrangements must always ensure that access is possible only after all dangerous voltages have been removed, and hot water and steam circulating systems have been shut down. Door and gate switch interlocks which rely on the release of relays or springs are not considered to be sufficiently reliable for personnel protection. Positive directly acting mechanical systems are desirable for high power transmitters. Various systems are in use but one system consists of rods moved by rack and pinion action and arranged to engage with slotted discs associated with the power and earthing switches, in conjunction with a locking device to trap the door interlocks when the cubicle doors or gates are open.

Safety devices such as interlocks, warning lights and switches should not be taken for granted but should be subjected to regular tests and checks as part of normal transmitter maintenance.

(k) All equipment and plant forming part of the transmitter should be used to perform only the work and functions for which it was designed. Only equipment which has been, or would be approved by recognised authorities, and which has been designed and tested to known standards should be incorporated.

(l) Earthing wands, sticks or hooksticks to be provided at convenient points in or near the equipment to facilitate earthing of conductors and components prior to commencing work.
The earthing device should be solidly and permanently connected to a low impedance earth point. The normal home position of the earthing device should preferably be equipped with an interlocked switch, to prevent the application of power to the equipment until all earthing devices have been returned to their normal home positions.

(m) Overcurrent protection devices to be provided to open the supply circuits, for functional overloads, short circuits, temperature excess or any faults which tend to place a potential on the structural parts of earthed equipment.

Circuit breakers and similar circuit protectors are preferred to fuses as overcurrent devices, because ratings cannot be inadvertently changed and they can be reset without exposure of personnel to energised terminals. However, unless a premium circuit breaker with close tolerances is used, temperature sensitive fuses may also be required to prevent fires caused by long term faults that do not draw enough current to operate the breaker.

(n) A manually operated, non-fusible motor circuit switch or breaker, capable of interrupting the maximum overload current to be provided and mounted in a readily accessible and visible location. The switch or breaker should disconnect completely all lines of all power circuits to the equipment and be arranged so that it may be locked in the 'off' position. This provides the means to assure that any servicing, maintenance or other work in the transmitter and vault enclosures can be done without endangering personnel who have placed their lock on the switch.

General practice is to specify the circuit breaker breaking capacity in terms of the system voltage and the fault power to be interrupted under symmetrical fault conditions, namely a short circuit between all three phases. In addition to breaking fault current, a circuit breaker must be capable of withstanding closure on to a fault and will thus have a rated making capacity which should take into account the full initial transient current, since this is considerably more than the steady state value which is used when calculating symmetrical breaking capacities. Unless it is intended that the circuit breaker should operate immediately fault current passes, it will also have a short time current rating which specifies the length of time for which it is capable of carrying the fault current.

(o) A fast acting device which will give positive protection to high power tubes against damage caused by flash arcs, to be provided. During the initial ageing process, occasional internal arcing between the plate and the cathode or grid structures may be expected of many high power vacuum tubes. The result can be disastrous if the capacitor bank energy is dumped into the arc. Extensive damage can occur within a few milliseconds unless the circuit is suitably protected. Circuit breakers and fuses are too slow in operating to give sufficient protection, and devices which allow energy diversion are now widely used. The basic idea is to open a series switch connecting the load to the power supply. This energy diversion system, sometimes called an electronic crowbar, can be considered as a current diversion system in which the power supply is short circuited immediately after a load arc begins.

(p) A device to be provided for instantaneously removing the carrier power automatically, in the event of an arc being formed to earth or between balanced conductors at any part of the transmission line, antenna matching equipment or antenna system.

It is normal in most installations for the transmitter power to be reapplied after a short period by means of a recycling device.

(q) Provision to be made to protect personnel from injury due to moving parts such as gears, couplings, belt driven mechanisms, pneumatic and hydraulic systems. Where such protection is not practicable, warning signs should be prominently displayed.

(r) Circuit breakers, fuses and switches to be positioned so that there is no hazard to operators from burning or exploding parts should the device be operated during overload or fault conditions.

(s) Fan motors used for air scavenging in transmitter and vault areas, and which are not connected into the normal transmitter control circuit to be fitted with under voltage protection to prevent damage to machines or injury to personnel should machines start, following return of mains power.

(t) Air ducts associated with transmitter cooling systems to be constructed of non-combustible material.

Flexible woven asbestos, sleeve joints with rope asbestos packing or other approved non-combustible materials should be provided where flexible connections are desired to prevent transmission or vibrations. Non-combustible materials should also be used to seal the space around the duct where it passes through walls, floors or partitions. Combustible materials for coverings or exterior insulation must be avoided.

The passing of air ducts through vaults and other rooms with fire walls should be avoided, where practicable. When such an arrangement is necessary, the duct should be provided with approved automatic fire doors on both sides of the wall. The fire doors should be operated by a fusible link or other heat actuated device, so located as to be readily affected by an abnormal rise of temperature in the duct. The operation of the fire doors should bring about automatic shut-down of any transmitters or other equipment using the duct for air intake or exhaust.

All exhaust ducts should be fitted with fire detection equipment with suitable controls connected into the transmitter control circuit so that on the detection of smoke or flame the transmitter will be shut down, the station fire alarm system brought into operation, and any automatic extinguishing equipment which may be provided for the purpose, actuated.

(u) Where selenium rectifiers are used in transmitter power supplies, care should be taken to ensure they are not overstressed by high voltage or current loads.

The rupture or burning from an arc-over or a burnout produces toxic fumes. Fuses and breakers of correct size should be provided ahead of all selenium units.

(v) When using aluminium to support stud mounted solid state rectifiers, consideration to be given to the effects of galvanic action between the aluminium and the copper studs. Consideration must also be given to the thermal reaction resulting from the unequal temperature coefficients of aluminium and copper which in several installations has caused loosening of the assemblage, resulting in excessive thermal resistance.

(w) All wiring used throughout the transmitter to be identified by colour coding or marking with a legend on a wiring diagram.

(x) Precautions to be taken to ensure that the conditions of safety which are achieved under test will be maintained throughout the life of the transmitter, notwithstanding the possibility of wear, deterioration and predictable environmental changes.

(y) Careful attention to be paid to the floor layout of the equipment. Aisles of ample width should be provided in both the transmitter and vault areas without dead end spaces. An alternative escape route or exit must be available. The gates of enclosures, cubicles and rooms must be locked or fastened in such a way that they can be easily and immediately opened from the inside with facilities immediately available.

OIL FILLED EQUIPMENT

The number of oil filled units at a high power broadcasting complex may be considerable. The units may be broadly divided into two classes, (a) oil circuit breakers or switches and (b) transformers and reactors. Large oil filled capacitors may also be installed, but are mainly confined to special installations.

(a) Oil circuit breakers and oil switches as a rule may contain only about 40 litres per switch in a typical installation but with a complex using many units, an explosion or fire could cause considerable damage. These units should be separated from other plant and equipment by adequate fire resistant barriers or otherwise isolated. Where switches or switch compartments are constructed to prevent an appreciable amount of oil being thrown outside the compartment, exterior drainage or storage systems are not necessary.

If located outside in a transmitter high voltage unit they should be adequately isolated from other plant.

If installed near building walls, the walls should be of fire resistant construction and should have doors or windows so located and arranged that burning oil is not liable to pass through them to flammable material or equipment.

It should be recognised that oil circuit breaker or oil switch failure may depend upon the size and rupturing capacity of the circuit breaker or switch, and the short circuit duty that may be required of it. The rating of a breaker should be appropriate to the conditions which may arise in the apparatus.

(b) Where power transformers, regulators, modulation transformers, modulation reactors, oil filled capacitors and switches are located inside the transmitter building or any other building, floors and drains should be so arranged that oil will quickly collect in a suitable drainage or storage system provided for the purpose either inside or outside the building, as may be advisable. Sumps filled with crushed rock have been found suitable for this purpose. If the equipment contains large quantities of mineral oil—and it is not unusual for a single transmitter to contain 7700 litres of oil— local regulations may require that each unit or group be placed in a separate fireproof compartment or vault, suitably ventilated. Generally, access is restricted between fireproof vaults and the main transmitter area but cable ducts and other points of access should be sealed and rendered fireproof. It may also be desirable to equip the vault with thermally operated fire extinguishing apparatus which automatically discharges extinguishing material when a predetermined ambient temperature is exceeded. Similar type of treatment may be necessary for power equipment installed external to the building, but alongside the building wall. *Figure 28.1* is a typical vault installation of a 250 kW transmitter and indicates the capacities of the oil filled components while *Figure 28.2* shows the difference in floor level between cubicle and transformer areas in order to contain the oil in the event of the catastrophic failure of a tank. The floor is sloped towards a grated drain extending the full length of the room.

GUARDING EXPOSED LIVE PARTS

Where it is necessary and essential for staff to perform work on or close to live conductors or parts, the work should be done by workmen having the

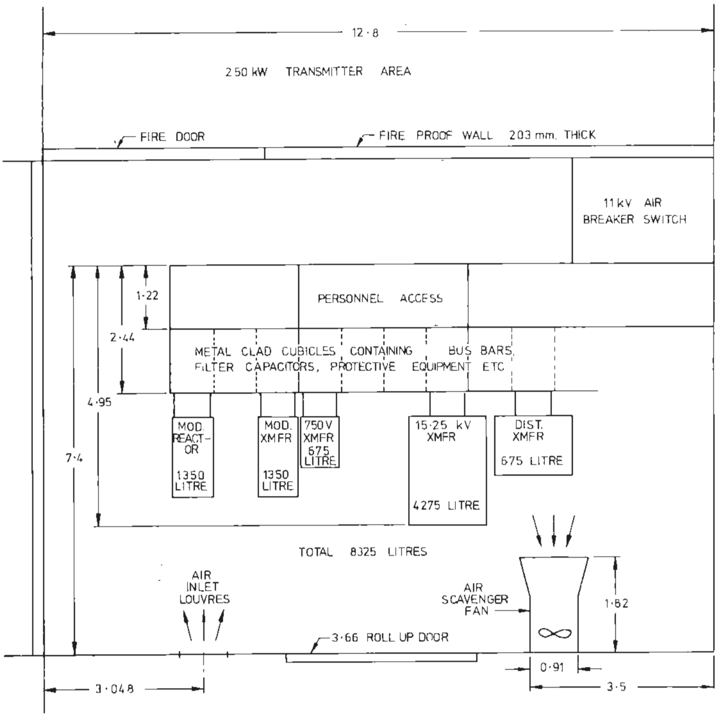

Figure 28.1 Typical vault installation of 250 kW transmitter showing transformer oil capacities

Figure 28.2 Stepped vault floor to contain oil spread

appropriate qualifications and taking appropriate safety precautions. This applies to conductors or equipment energised or considered to be available for service for intermittent periods such as standby equipment, transmission lines of a switching matrix or transmitter dummy loads. It should also apply to partially completed installation works which may be available for service or subject to energisation for test purposes.

It is necessary to guard against the accidental contact with parts carrying dangerous voltages and all uninsulated live parts of equipment such as conductors, switches, busbars, components, terminals and devices operating at more than 72 V peak to earth or between conductors, should be protected by one of the following means:

(a) An enclosure which gives access to live parts only through the opening of a door or removing a cover which should be appropriately marked. Where covers, housing or barriers must be removed as a regular occurrence from the current carrying parts which they guard, and while these parts are alive, the covers, housing or barriers should be of suitable insulating material, or so arranged that they cannot readily be brought in contact with live parts.

Where a cover has to be removed for a long period for maintenance or repair works or to admit temporary connections, a warning notice should be displayed close to the exposed equipment.

(b) A guard of suitable metal sheet, mesh, railing or other barrier which will remove the liability of contact or approach and at the same time provide a guard zone with adequate clearance between the guard and the live parts. Typical minimum clearances observed by many workmen are shown in *Table 28.1.* These clearances are not a requirement for definite engineering

Table 28.1 RECOMMENDED MINIMUM CLEARANCE BETWEEN GUARDS AND LIVE PARTS

Peak voltage (kV)	*Minimum clearance (cm)*
1	6
5	9
10	12
15	15
20	18
25	20
30	23

design of either apparatus or guards but are solely for the guidance of workmen installing guards without such design. For example, the minimum clearances in the Table are not intended to refer to the clearances between live conductors or parts and the walls of the cubicles, compartments or similar enclosing structures. Also, they do not apply to the clearances between busbars, line conductors and associated supporting structures nor to the clearances between the blades of a switch and its base.

(c) Isolation of the part or conductor by placing it at least 2.5 m above the floor or other permanent supporting surface used by workmen. Exposed conductors or parts over or near frequently travelled passageways should be properly guarded or given clearance in excess of those specified such as may be necessary to secure reasonable safety. The guards should be substantial and where practicable should completely shield or enclose the parts.

Exposed conductors or parts of indeterminate potential, such as communication and remote control equipment to antenna matching huts, and which may be exposed to conduction from high radio frequency fields, should be classified and where practicable guarded, on the basis of the maximum voltage which may be present.

(d) Adequate insulation on test leads.

Test leads or measuring circuits should not be taken out of transmitters or other high voltage equipment unless they are contained in an earthed metallic sheath and terminated in a protected test area. Meter connections and the deflection leads to cathode ray oscillographs fall into this category. Conductors and equipment carrying high voltage should not be brought out of a transmitter or other protected enclosure in such a manner that the interlocking switches or protection equipment will no longer serve as a safety guard.

HIGH CURRENT FILAMENT LEADS

Protection of filament leads and safe working habits near these leads is essential where high currents are involved. The filament voltage applied to the tubes of high power transmitters is low, usually within the range 5 to 25 V, and is not considered dangerous from an electric shock standpoint. However, currents can

Table 28.2 FILAMENT VOLTAGES AND CURRENTS OF TRANSMITTING TUBES

Tube	*Voltage (V)*	*Current (A)*
ATW 10-3	12.0	150
BR 128B	7.2	170
BW 161	9.0	175
7480	13.0	190-220
BTL 50-1	20.0	200
BR 189	9.0	240
BR 194	13.0	240
3Q-293E	25.0	250
4CV100, 000C	10.0	300
BTL-25-1	10.0	320
BTS-150-2	20.0	570
4CV250, 000A	12.0	640

be very high, with 640 A being required for at least one high power tube. *Table 28.2* indicates filament voltages and currents of some typical transmitting tubes in service.

The filament busbars are necessarily run close together and the accidental short circuiting of these busbars by a metallic watch band or ring or a tool in the hand can result in a serious burn because of the heavy current which the filament transformer is capable of delivering into such a short circuit. It is therefore advisable for workmen not to wear wrist watches or rings, and to be extremely careful with tools when working around these filament connectors while the connectors are energised.

It is usual practice with many transmitter installations for filament circuits to be isolated from normal gate switch control circuits and so allowing filament voltage to be applied even during maintenance periods. To prevent accidental contact with the leads or busbars during these periods the conductors in some transmitters are provided with guards or are insulated.

SAFE DISTANCES

Installation practices should ensure that adequate and readily accessible working space with secure footing is provided about all equipment and live conductors which may require adjustment or examination while in operation. If it is not practicable to properly guard live components or conductors, sufficient space should be provided to ensure minimum clearance between the workman and high voltage points in accordance with *Table 28.3*.

Working spaces adjacent to exposed live parts should not be used as passageways. Clearance above normally elevated or isolated parts requiring occasional adjustment or attention should be provided so that workmen need not come within the danger zone around adjacent energised parts, unless properly guarded.

The distances set down do not apply to work on antenna systems or other devices where high r.f. fields exist. High intensity r.f. fields may cause considerable voltages to occur on metal work, tools and plant, and although in many cases a shock from an induced voltage may not be injurious, it can cause an

Table 28.3 RECOMMENDED SAFE WORKING DISTANCE FROM HIGH VOLTAGES

Peak volts	*Minimun distance (m)*
750–3500	0.6
up to 10 000	1.0
up to 50 000	2
up to 100 000	3

accident of a secondary nature, such as loss of balance or dropping of tools etc. Also, since a solid insulator does not necessarily guarantee high impedance isolation, because of the capacitance of the device, it is accepted practice at many stations to prohibit work on live antenna systems. Biological hazards from intense radio frequency radiation are further reasons for restricting work under live conditions.

CLEARANCE OF CONDUCTORS ABOVE GROUND

The maintenance of adequate clearance of open wire transmission lines and antenna feeders above site roadways, footpaths and other areas is an important safety requirement. In consideration of accidents which have been caused due to insufficient conductor clearance above the ground level, and also to allow plant and materials to be safely transported around the site during construction and maintenance works, many engineers have adopted the minimum clearances shown in *Table 28.4.*

Table 28.4 MINIMUM CONDUCTOR CLEARANCE ABOVE GROUND

Location	*Transmitter carrier power*		
	less than 500 W (m)	*500 W–50 kW (m)*	*above 50 kW (m)*
Above main station site roads where high loaded commercial vehicles may pass	5	5.3	5.6
Above station site roads used for maintenance access purposes only	4	4.3	4.6
Above areas normally accessible to pedestrians only	2.8	3	3.5
Above guys and metal fences	1	1.5	2

Figure 28.3 shows the arrangement adopted at one medium frequency broadcasting station with two 50 kW transmitters to maintain the clearance across the roadway used by station maintenance vehicles. The heights of the six wire transmission lines are gradually decreased as they approach the antenna matching building to minimise the introduction of impedance discontinuities due to sudden changes in height of line above ground.

It is necessary that some uniform basis be established as the determining condition of the wire in the crossing span from which the required clearance

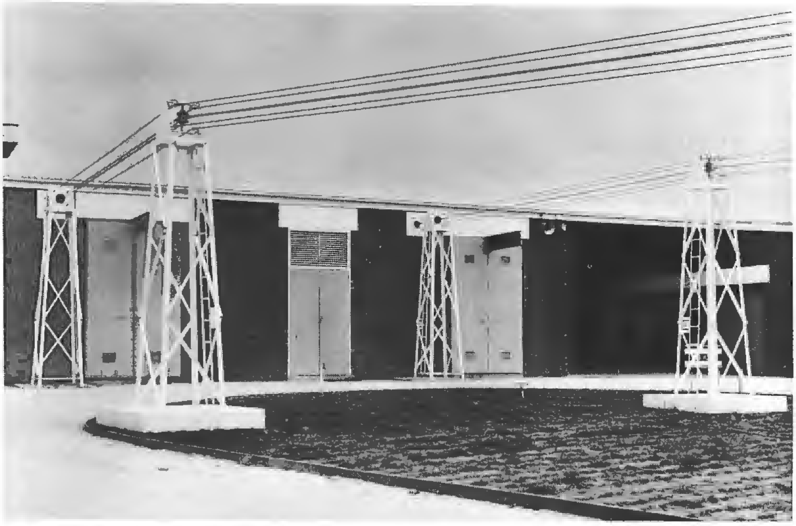

Figure 28.3 Transmission lines crossing site road

should be measured. Otherwise, there may be confusion as to whether the minimum clearance applies with the wire in its initial unloaded, or in its final unloaded condition at a particular temperature, usually 20 °C. As the prescribed clearances were determined on the basis of conductor sag increases from the final unloaded to the full load condition, it is obvious that, if the clearance were measured from the wire in its initial unloaded condition, there might subsequently develop an unsafe clearance reduction. It is the usual practice to design lines on the final unloaded condition of the conductors, the conductors being strung to initial tension and then allowed to stretch to the predetermined final unloaded tension, or the wires prestressed and then slackened off to this latter tension. Consequently, the final unloaded condition of the wire is generally used as the basis for determining clearances, except in those cases where engineers maintain the wires approximately at initial sags, by pulling out slack as it develops.

The height of vehicle loads above ground exceeding 4 m will be very rare and it is quite practicable to restrict ordinary traffic on the station site and in particular, those areas where crossings under overhead lines are involved, to vehicles not exceeding such height. Those responsible for the safe passage of vehicles with loads more than 4 m high can reasonably be expected to know that there exists along the site roadways, obstructions, and to know also that contact with overhead wires is frequently dangerous to men or to the wires and should always be avoided.

The movement of such mechanical aids as cranes and pole hole borers over the site must always be considered as extraordinary traffic and subject to the necessity of observing special precautions against contacts with overhead lines of all kinds. It is frequently practicable to reduce the height of such vehicles, but this is sometimes neglected, and the low wire clearance blamed for avoidable accidents, arising out of culpable negligence of the operator.

Notwithstanding the clearances shown in the Table there may be some stations where the traffic of vehicles of extraordinary height will warrant an increase of the minimum requirements given. On the other hand, there may be some stations where the vehicles used on the property are so closely limited that less wire clearances can be justified.

The requirement for ground clearance of conductors may be summarised as follows:

(a) Open wire transmission lines and antenna feeders on station property should have minimum clearances above ground level, not less than those given in *Table 28.4*. The clearances are applicable under the following conditions:
  (i) Temperature of 20 °C, no wind, with final unloaded sag in the wire or with initial unloaded sag in cases where wires are maintained approximately at initial unloaded sag.
  (ii) Unmodulated radio frequency carrier power.
(b) Conductors should be anchored to fixed supports.

These clearance values do not apply to vertical antennas or vertical lead-ins to transmitters, or to lead-ins (horizontal or vertical) between antenna and matching hut, where the antenna and lead are not readily accessible.

CLEARANCE OF CONDUCTORS FROM WALLS

The method of lead-out of a transmission line from a building can be an extremely difficult problem where high powers are concerned. In addition to the high voltage on the conductors there is the problem of anchorage for the line. A typical 500 kW open wire balanced line may exert a pull of 5 tonnes on the anchorage and this usually requires special consideration during the design of the building.

For safety reasons high voltage transmission lines within the building are invariably installed with earthed metal guards. These may be standard rigid or flexible tubes or cables, and in some cases fabricated square or rectangular box configuration. Sometimes these lines may be extended to the line matrix switch before changing to open wire, and in others the change to open wire may take place directly at the building with a specially designed transition section to minimise the discontinuity problem.

In order to meet safety requirements, the following conditions are considered to be necessary:

(a) High voltage lines or antenna lead-out conductors located inside transmitter buildings and other buildings where staff would be expected to work when voltage is applied, should be installed inside an earthed metallic sheath, in an inaccesible area of behind a locked enclosure.
(b) High voltage lines should enter a building through a rigid, non-combustible, non-hygroscopic, lead-through insulator or bushing properly engineered for the purpose.
(c) Where lead-through insulators or bushings are not practicable, conductors should pass through an opening, specially provided for the purpose.

FURTHER READING

British Standard 3192, 1968, *Specification for Safety Requirement for Radio Transmitting Apparatus*

Chapter 29

Protection

EQUIPMENT PROTECTION

All radio equipment should be provided with protective circuits. Two main reasons for providing protection are to prevent a component or equipment assembly reaching a temperature that may result in fire, and to minimise hazards to staff in the event of an unsafe condition developing.

In a well engineered design, several degrees of protection are provided. Circuit breakers, relays and fuses are used as well as electronic dissipation protection and crowbar energy diverters. Those circuits that are subject to frequent transient overloads, such as occur in tubes, are provided with overload relays and automatic recycling. The circuits are further protected by fuses and devices that will not trip out under normal overload relay recycling, but will provide carefully co-ordinated time delay protection of critical components, equipment and wiring.

Power tubes require mechanical protective devices such as interlocks, relays, and circuit breakers. Circuit breakers alone may not provide adequate protection in certain high power tube circuits when the power supply filter, modulator, or pulse-forming network stores considerable energy. Additional protection may be provided by the use of high-speed electronic circuits to bypass the fault current, until mechanical circuit breakers can be opened.

The handling of very high power requires particular attention to the removal of power under fault conditions since the large amount of energy involved can cause severe damage to equipment if not properly controlled. The earth lead of the plate circuit of each tube should be connected in series with the coil of a quick-acting overload relay, adjusted to open the circuit breakers in the primary of the rectifier transformer at slightly higher than normal plate current. The total time required for the operation of the relay and circuit breakers should be 1/10 second or less. The grid circuit should be equipped with similar overload relays which will likewise remove all grid power within 1/10 second.

To protect the tube until the relay and circuit breakers act, the installation of a device which will short-circuit the rectifier output to earth in the order of microseconds during the fault is recommended. For this purpose an electronic device called a 'crowbar circuit', as in *Figure 29.1*, is often provided for high power tubes. In practice, a gaseous conductive device is connected at the output of the plate supply filter to dissipate the filter circuit energy as well as the rectifier output. In some applications, depending on the size of the filter capacitor or speed of the relays, sufficient protection may be obtained by connecting a resistor in series with the plate lead of each tube. The criterion is the total energy to which the tube can be subjected.

Great care should be taken during the adjustment of tube circuits. The tube and its associated apparatus, especially all parts which may be at high potential above ground, should be housed in a protective enclosure. The tube protective housing should be designed with interlocks so that personnel cannot possibly come in contact with any high potential point in the electrical system. The interlock devices should function to break the primary circuit of the high voltage supplies and discharge high voltage capacitors when any gate or door on the protective housing is opened, and should prevent the closing of this primary circuit until the door is again locked.

A specification for protection of a high power transmitter should include the following:

(a) All electrical components, including power tubes, shall be conservatively rated to ensure a high factor of reliability and safety.
(b) The cooling system, the power supplies and the overload protective system shall be properly interlocked to prevent damage to the tubes and equipment during starting, shut-down and fault condition.
(c) The transmitter shall contain such features as r.f. drive control to limit final tube screen dissipation, a final amplifier plate dissipation limit control which prevents excessive plate dissipation when being tuned and r.f. arc sensors for the final amplifier tubes and vacuum capacitors.
(d) High power tubes shall be protected against flasharcs by an electronic crowbar

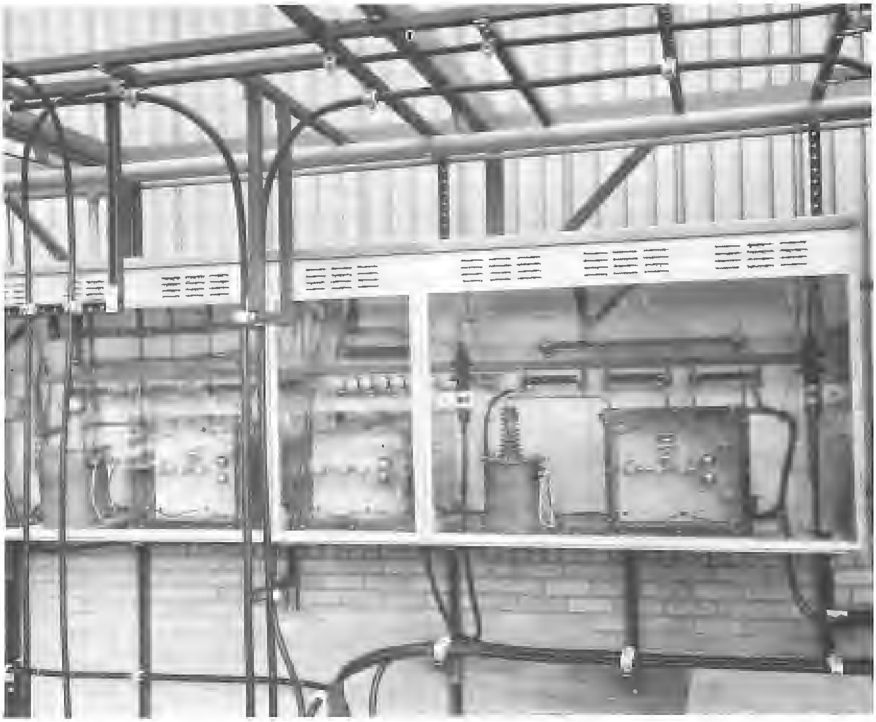

Figure 29.1 Rockwell-Collins Crowbar assembly (Courtesy Rockwell International)

or dump circuit to divert energy from the tubes, and to automatically interrupt primary power.

(e) A device which is capable of detecting an r.f. arc within the equipment cubicle shall be provided to automatically remove r.f. drive upon detection of the arc.

(f) Interlocking facilities shall be provided to allow the transmitter to be interlocked with external antenna or transmission line switches.

(g) A device shall be provided which will shut down the transmitter on the detection of excessive v.s.w.r. on the r.f. output due to a fault in the transmission line or antenna system. The restoration time of the trip should be adjustable to suit local conditions.

(h) The equipment shall be protected against the effects of over modulation.

(i) The overload protection system for radio frequency stages delivering an output power exceeding 100 W shall be provided with a three shot device to switch off the equipment or parts of it, if a fault persists after completion of three restoration attempts. For faults in the main high tension transformer, the main h.t. circuit breaker shall lock out, after the first shot.

(k) The equipment shall be designed with sufficient operating margin to minimise unintended tripping.

(l) The design of safety devices shall be such that if a fault occurs, the result shall not reduce the safety of the equipment.

(m) A tube lift or hoist facility shall be provided as an integral part of the permanent installation for handling and changing each high power tube.

(n) The larger power components, including e.h.t. transformer, screen voltage transformer, distribution transformer, modulation transformer and modulation reactor, shall have temperature sensing devices that shut down the transmitter if the oil temperature exceeds a preset value. All transformers with an oil capacity exceeding 2250 litres shall also be fitted with a device that detects a pressure surge in the transformer oil due to violent internal arcing and wired into the control equipment to immediately shut down the transmitter upon detection of the surge. These protection features shall be carefully co-ordinated with overload relays and fuses.

Figure 29.2 shows the e.h.t. transformer of a 250 kW transmitter fitted with these features. The transformer also houses the main rectifier diodes and has an oil capacity of 4275 litres. Forced air cooling is automatically cut into service should the oil temperature exceed a pre-set limit as may occur during extended periods of testing at high levels of trapezoidal modulation.

(o) Rectifiers in d.c. power supplies shall have peak inverse ratings at least twice the working voltage and be fitted with transient suppression resistors and capacitors on the primary a.c. input as well as the d.c. output circuit.

Circuit parameters shall be carefully selected to minimise starting voltage overshoot even under lightly loaded conditions. In high voltage supplies where many diodes may be cascaded, individual resistors and capacitors shall be shunted across each diode to ensure equal voltage distribution across all series diodes.

(p) Adequate consideration shall be given to the protection of equipment against damage from lightning surges on the power line. Some of these surges may be of sufficient magnitude to cause transformer, switchgear and rectifier troubles, and relay contact burning. Burn-out of equipment lamps and tower aircraft warning lamps have also been experienced. Rectifiers using

Figure 29.2 E.H.T. transformer of high power transmitter

semiconductor diodes may be more vulnerable to power line surges than thermionic rectifiers, and this aspect should be adequately considered during the equipment design stage.

(q) Cabinets housing equipment shall consist of a well engineered structure which will safely support components and be free from vibration or movement when fixed in position. A strong steel base to which a steel framework is attached is the usual form of construction. Panels and doors should not be required to contribute to the strength of the structure.

To enable cabinets, and other heavy items comprising the transmitter, to be easily moved into position during installation and for any future maintenance requirement, provision should be made for the attachment of multi-roller dolleys or other similar type device.

EARTHING OF EQUIPMENT

The main reasons for earthing equipment may be summarised as follows:

(a) To secure personnel protection from electric shock hazard.
(b) To obtain the correct technical operation of equipment through the ability to control desired and undesired signals.

(c) To prevent the generation and radiation of spurious and harmonic frequencies by metalwork.
(d) To stabilise circuit potentials.
(e) To provide protection against lightning.
(f) To provide protection against mains power surge effects.
(g) To provide return lead for earth return circuits.

In order to meet the requirements of the manufacture and fabrication, maintenance accessibility and mounting or fixing arrangements, discontinuities in electrical conductivity between equipment chassis or structure to earth are often created. To provide stable electrical conductivity which can be considered favourable for bonding or earthing, suitable means must be provided to bridge these discontinuities. For removable equipment it may be in the form of spring type wipers, metal rollers, or flexible leads. For fixed equipment and plant, flexible bonding straps in the form of metal strip, braid or standard cable may be provided.

In order to meet the requirements of effective and safe earthing at a transmitting station the following must be satisfied:

(a) The metal case of each power component, the metal framework of component assemblies, metal equipment racks, panels, cubicles and racks should be effectively earthed by a low impedance connection to the station earth grid system.

(b) To minimise the possibility of spurious signal generation in metalwork housing and supporting equipment, particular attention should be given to the proper bonding and earthing of all the metalwork which does not carry current. This includes all racks, cubicle framework, doors, cable racking, water and steam pipes, ductwork, conduits, transformers and other power units, and any other metalwork forming part of the installation.

Any bonding system should be considered as an extension of one conducting body to another. The metal mating areas of the bonding material and the body or structure should be as large as practicable and electrically clean.

(c) Particular attention should be paid to the protection of joints of dissimilar metals, and also to joints in earth straps which are exposed to a damp environment.

(d) Components which are sensitive to extraneous fields, for example feedback circuits, should be properly shielded and earthed to prevent pick-up from other nearby equipment.

(e) A properly engineered earthing arrangement must be provided to ensure the complete safety of personnel, equipment and the proper operation of transmitters. Within the main radio frequency and modulator units, a well engineered high power installation will have wide low impedance straps within the cubicles to bond these cubicles to a common earth point of the station earth grid. The frame of each component and rack assembly in the power supply vault is as a general rule separately earthed to tails of the grid system brought up through the building floor.

(f) Where a transition section is necessary in order to connect a pair of coaxial lines to an open wire line, a low impedance earth connection should be provided at the termination point of the coaxial tubes.

For a 250 kW installation an earth strap 37 cm wide connected directly to the common ground point of the transmitter has been found suitable for the purpose where the transition is about 7 m above floor level.

(g) All mobile and portable test equipment and associated flexible leads should be thoroughly inspected and tested by an experienced and competent officer at regular intervals, to ensure that the equipment is functioning correctly and the flexible leads are sound, securely anchored, conductors are continuous and the earth wire is in sound connection with all exposed metalwork.

It is very important to keep in mind that a low impedance earth system is essential for all radio frequency earthing purposes. Earth connection leads are often a considerable fraction of a wavelength long, and may act as shorted transmission lines with voltage standing waves. An earth lead a quarter of a wavelength long may have a very high input impedance at the resonant frequency. To minimise this problem many installations take advantage of the low reactive characteristics of wide sheets or mesh to give an effective low impedance r.f. earth. Where a high power transmitter is many metres from the main grid earth connection point, an earth sheet strap up to 100 cm wide has often been necessary to obtain a good earth at high frequencies.

PROTECTION BY DISCONNECTION

Radio equipment which will require maintenance work upon it should have approved means of disconnecting it from all unearthed conductors of its supply circuit. Care must be taken in the design of the control circuit or mechanism that power cannot be inadvertently restored while work is in progress.

Where it is necessary to isolate a section of a power distribution system on the station, the power must be removed by circuit breakers before the isolators are opened, unless the isolators are of a type designed for on-load operation. Where equipment is operated by remote control, facilities should be provided to allow the remote control mechanism to be locked-out or otherwise suitably guarded, to prevent inadvertent operation.

The need for definite procedures to protect men working on radio and electrical equipment is as a general rule appreciated by all station staff. The procedures developed by the various broadcasting organisations to protect workmen vary in detail from one organisation to another, but there are certain basic requirements common to all. These are:

(a) At least one visible break between each power source and equipment upon which work is to be done.
(b) A visible notice, either a lock, a flag and/or a tag to show that status is not to be changed.
(c) Control of the person authorised to remove the visible notice and close the break.
(d) A communication system that prevents misunderstandings in instructions.
(e) A knowledge of the lock, flag and/or tag rule by every employee on the station.
(f) An understanding by every member of the station staff that failure to follow the established procedures will result in disciplinary action being taken.

A single break in a conductor is usually sufficient to ensure adequate isolation from the power source. However, a particular problem is encountered in the case of a high power multi-transmitter complex. Very high r.f. voltages are picked up by non-working antennas and transmission lines as a result of radiation from working systems and can be hazardous to maintenance staff should these voltages find their way into a closed down transmitter tank circuit. Although the line matrix switch may disconnect the antenna, a remaining section of open wire line between the switch and transmitter can still have considerable voltage induced in the conductors. This is not usually a great problem where the lines to the switch are shielded but open wire lines often require additional isolators close to the transmitter building preferably at the transmitter.

Figure 29.3 shows a system installed at one station using remotely controlled vacuum switches directly in each line conductor. The switches were activated by compressed air through insulated tubing but they did not prove suitable as line disconnection devices because the relatively high capacity between the large surface contacts allowed considerable r.f. voltage to pass into the transmitter output network.

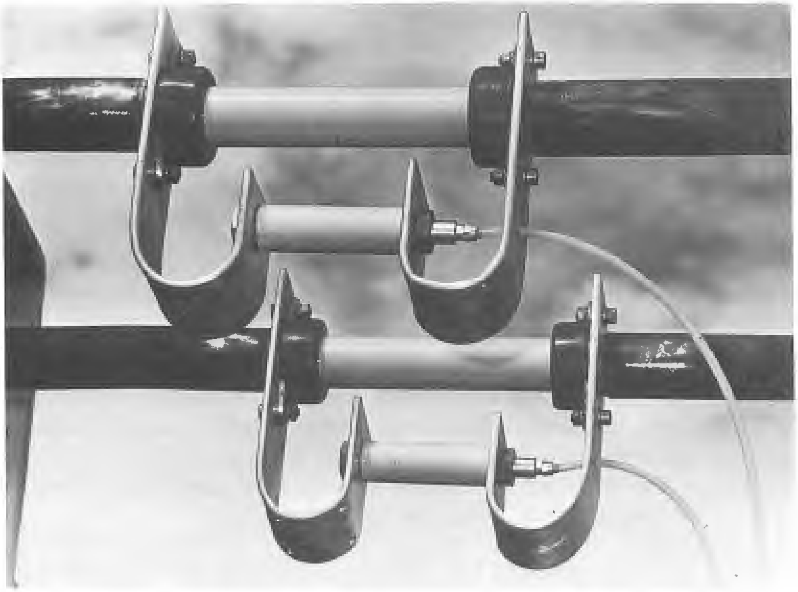

Figure 29.3 Transmission line isolating switches

PROTECTION AGAINST LIGHTNING

To provide adequate protection for staff, equipment and plant against lightning, it is necessary to install facilities by which a discharge is not required to pass through a path of high impedance.

The presence of a charged storm cloud may affect radio station equipment in the following ways:

(a) Direct strokes.
Lightning may discharge directly from the cloud to masts, towers, antenna systems, power mains and power substations. The incidence of direct

strokes on tall structures, in particular, may be considerable and special measures may be necessary to deal with this problem.

(b) Electrostatic induction.
Voltages may be induced in insulated tall structures and antenna systems by electrostatic induction when charged clouds or air masses move into the vicinity of these systems. The current discharged to earth will often be quite small but on a well insulated system voltage build-up can occur which may have some secondary effects on equipment operation. Static bleed chokes or shorted-end earthed transmission line sections are generally installed to minimise problems from these voltages.

(c) Electromagnetic induction.
Cloud-to-cloud, and cloud-to-ground lightning strokes in the vicinity of antenna and power systems will induce high voltages into circuits, the values of which will depend on the separation between the systems and the lightning strokes. This is probably the major cause of excess voltages on systems and necessitates the provision of effective protection equipment.

(d) Rise of earth potential.
A lightning stroke to earth will raise the earth's potential considerably at that point, and set up a potential gradient in all directions along the surface moving away from the point of the stroke. In areas of high earth resistivity where the mast or tower has been struck, a supported antenna system will seldom be damaged due to the cone of protection offered by the structure, but the rise in potential of the earth may be sufficiently high to damage buried coaxial cable feeders, lighting cables or communication cables in the vicinity.

Basic requirements to ensure the safety of installation and operations staff, together with protection of equipment and plant from lightning hazards may be summarised as follows:

(a) Lead-out conductors of transmission lines or antenna feeders to be equipped with a horn gap, lightning surge diverter, earthing switch or other suitable device for lightning protection purposes. The horn gap, surge diverter or other device should be set at a peak flashover value that is co-ordinated correctly with the peak level of the operating r.f. voltage.

A considerable amount of damage caused by lightning to matching equipment is brought about by too wide a spacing of the mast base lightning protective gap. When this condition prevails, a direct stroke on the mast or even a stroke in the immediate vicinity may cause a voltage to be induced in the mast of sufficient magnitude to seriously damage equipment in the antenna matching unit. For this reason it is essential that the mast gap spacing be sufficiently close to provide effective lightning protection taking into account the peak modulation voltage at the gap.

Surge diverters composed of non-linear resistance elements have been used with success on some medium frequency mast radiators. However, other station engineers have reported that the diverters were not successful due to overheating of the elements as a result of r.f. losses in the material. If no conducting path is provided between the antenna and earth through the connected equipment, means should be provided to drain static charges from the antenna system.

(b) In the areas of high lightning incidence, arresters to be installed on the incoming power main feeds, and low voltage protectors to be installed on branch circuits feeding radio equipment.

A direct stroke on a power line will often result in damage to the line and equipment connected to it. However, even a lightning stroke on a supporting tower or nearby building can induce very high voltages and currents in the line.

(c) Control and communication circuits on the station site to be fitted with a properly engineered system of surge suppression inductances and heavy duty gas arresters to minimise danger to equipment and staff during times of lightning discharge.

To protect staff using a telephone during a storm, the potential between body and earth must not rise to a dangerous level. Also, the potential difference between equipment connected to incoming cable pairs and the frame or shields of equipment must not be allowed to rise above the insulation breakdown point.

A protective system for communication and control circuits has several basic requirements. It must be inexpensive because protection must often be provided to a large number of circuits, the devices used must be physically small because space for them is usually limited, and they must be simple to install and require little or no servicing.

On sites where lightning conditions are severe, additional protection may be secured for the cable, through the use of high dielectric strength insulation or by bare conductors buried in the ground parallel with the cable.

(d) In areas of high soil resistivity, guard wires to be installed to minimise damage to buried coaxial transmission lines.

Earthed masts and towers when struck by lightning will cause the ground potential to rise steeply and set up a potential gradient in all directions from the base of the structure. This could cause damage to buried coaxial transmission lines. However, the effect can be minimised by the installation of guard wires in the ground adjacent to the coaxial line. The guard wires conduct away part of the lightning surge and reduce the amount of current flowing along the outer conductor. The percentage of current carried by the wires depends on their inductance relative to that of the outer coaxial line conductor and it is common practice to use two or three wires in parallel to reduce the inductance.

(e) A device which can detect the presence of an arc across a horn or ball gap, and which will disconnect the r.f. power when an arc is formed, to be fitted to the transmitter.

If the power output of the transmitter is sufficiently high, an arc once established across a gap by a lightning discharge, or other disturbance, will be sustained by the r.f. transmitter power and will continue to burn until the r.f. power is cut off, or until the arc burns itself clear. Standing waves may also be set up along the transmission line if the resonance of the tuned circuits is destroyed by the arc. This may result in a flashover at a voltage maximum point along the line, with consequent damage to the hardware.

(f) During the erection of a mast or tower, the structure to be solidly connected to earth as soon as possible after erection of the first section.

Where practicable, the permanent earth system should be installed at the same time as the foundation work is being carried out. This will allow the structure to be bonded to a good earth immediately erection work starts. If the earth system is not to be laid until after the structure is erected, then an adequate temporary earth system should be installed to provide safe protection in the event of a storm occurring during the erection work.

Work on the erection and also on maintenance of masts and towers should cease during periods of electrical storm activity. If the structure is struck by lightning the workman would be subjected to a potential difference across his body determined by the current flowing and the impedance of the steelwork between the point where it is touched by his hands and feet. In most cases the impedance would be very low and the potential would not be very high even for a discharge current of 100 kA. If it is assumed that the current is divided uniformly down the four legs of the structure and the workman is contacting one of these, the potential difference would be about 3000 V in a typical situation. Although this would be unlikely to cause death, the shock effect may be sufficient for the workman to lose his grip and even fall.

(g) All metal work associated with incoming services such as water pipes, electricity and telephone cable sheaths be bonded to the station earth system.

If these services are not tied to the earth grid then a high potential difference could exist between station equipment and these services during periods of lightning contact with the tower. A workman touching the metalwork of one of these services or even standing nearby can provide an easy path for a side flash within the building. At one station a member of the staff was thrown to the floor while using the telephone during a period when the tower carried a heavy lightning discharge current. The incoming lead telephone cable sheath had not been properly bonded to the station earth grid system and the potential to which the radio equipment was raised above true earth caused a side flash to the telephone earpiece which was at earth potential.

EMERGENCY SHUT-DOWN SWITCHES

In a large transmitting station, transmitters may be controlled from a remote location and, during normal test procedures or during fault finding operations, defective equipment may cause a fire or cause an operator to be the victim of a severe shock. In either case, immediate action is required by the nearest workman on the spot to shut down the equipment. To fulfill this need, emergency shut-down switches are often provided.

At least one switch should be provided to shut the transmitter down from a position conveniently accessible. Where the power vault is separated from the transmitter proper, experience has shown the need for an emergency shut-down switch in the vault area, also.

This switch should be of a different colour from any other switch on the equipment and be clearly marked in bold lettering ‘Emergency Shut-down’. Such switch should not be dependent upon the action of springs for opening but be positively opened by the movement of the operating member itself. Springs may however be used to accelerate the separation of current carrying parts. The circuit should be so arranged that it operates the main circuit breaker supplying power to the transmitter. It should also be so arranged that when the emergency switch has been operated, the transmitter cannot be automatically restarted without going through the normal starting sequence.

Emergency shut-down switches should also be provided on any other station equipment or plant where the failure of any part of the operating or control circuits may create a life hazard, and on equipment where there is possibility of the workman being caught or injured in the normal operation of the machine, such as a workshop lathe.

In these situations the shut-down switch should be installed in a position accessible to the workman in his normal operating position.

CIRCUIT BREAKERS, SWITCHES AND FUSES

The safety requirements in connection with circuit breakers, switches and fuses used with high voltage and medium voltage circuits, including power and radio frequencies may be summarised as follows:

(a) All circuit breakers, switches, fuses and other control devices should be readily and safely accessible to authorised persons, unless they are intended to be remotely controlled.

They should be so marked or arranged as to clearly identify the equipment or plant controlled by them and (except for fuses) should indicate whether they are in the open or the closed position. Markings on circuit breakers and switches are sometimes confusing as they are often intended to inform the regular operator of an operational feature rather than to denote the switching on or off of a circuit. Workmen should therefore ensure that they have carefully studied and understood handbook literature and wiring diagrams, before working on equipment and plant.

(b) Circuit breakers and switches used for isolation purposes should where practicable be located in a position where they are readily visible from the equipment or plant which they isolate.

(c) Circuit breakers and switches used otherwise than as disconnectors should have a capacity sufficient to ensure safe interruption, at the working voltage, of the greatest current which they will be required to carry continuously and should be marked with the current and voltage for which they are rated.

Circumstances could arise where a circuit breaker might be closed on to a fault and this condition imposes very severe mechanical stresses. The maximum mechanical forces will be proportional to the square of the peak current and may produce stresses on conductors etc. of several hundred newtons. As far as the ‘making’ capacity of the breaker is concerned it is rated in accordance with the maximum peak symmetrical current. This maximum peak current is important because the breaker must be able to perform the function of closing against this without damage in order that it may be in a fit condition to reopen and clear the fault. When selecting a breaker for a transmitter, therefore, the making current rating should be at least equal to the peak asymmetrical current which can appear in the station system.

(d) Disconnectors which include transmission line or antenna switches should be of suitable voltage and current rating for the circuit in which they are installed, and be accessible only to properly qualified persons. They should also be protected by signs warning against opening them while they are carrying currents in excess of safe opening limits.

Even though a transmission line or antenna may not be connected to an energised transmitter, high voltages can be induced from adjacent powered lines and antennas, and consequently a routine switching operation can involve the interruption of considerable radio frequency voltage.

(e) Remotely controlled circuit breakers, power switches, transmission line switches, antenna earthing switches and isolators should be so arranged that they can be secured in the proper position to prevent inadvertent operation while work is being done on equipment and plant, controlled by them.

It is important that the control circuit be provided with a positive disconnecting or isolating means near the apparatus, such as removal of a key to prevent accidental operation of the mechanism. For switches and disconnectors, the accidental opening of which may cause a hazard, similar arrangements are desirable for retaining them in the closed position.

(f) Power operated circuit breakers, transmission line matrix switches and the like, excepting magnetic contactors, should be provided with means for readily closing and opening them manually.

(g) Circuit breakers and switches should be so constructed and installed as to minimise the danger of accidental operation, and where practicable so that gravity or vibration cannot operate them. Such switches as may tend to close or open by gravity or vibration or the slamming of equipment cubicle doors, should be provided with a proper latch or stop block to prevent accidental operation.

As circuit breakers are capable of making, carrying and breaking normal load currents and also making and automatically breaking abnormal currents such as short circuits extreme care should be taken when opening and closing these devices, particularly with high power transmitters.

(h) Switches are not required in the transformer vault to control individual transformers except as may be deemed necessary by the design engineer to meet a special operating requirement.

(i) Switches are not required in leads to transformers measuring radio frequency currents in transmitters and antenna matching huts, or mains currents.

Care should be taken to ensure that the secondary circuit of a current transformer, whether at r.f. or a.c., is never left open circuit. Should it become necessary to remove a meter or overcurrent relay actuated by a current transformer, the current transformer secondary winding should be short circuited until the unit has been replaced and permanently connected in circuit. The reason for this is that if no secondary current is flowing, all the primary ampere turns become exciting. This is usually sufficient to saturate the core, and a high peaked voltage is induced in the secondary winding each half cycle as the flux is changed rapidly from saturation value in one direction to saturation value in the opposite direction. This takes place as the primary current passes through zero. The induced voltage on the secondary may be sufficiently high to endanger personnel and will almost certainly break down the insulation of the low voltage secondary winding. Peak voltages in excess of 2000 V have been measured across some secondary windings.

(j) Switching gear and other apparatus belonging to the local electrical supply authority should not be operated by station staff except on the instructions of the station manager and with the agreement of the supply authority.

(k) No workman should be permitted to operate, adjust or carry out any maintenance work on high voltage switchgear unless suitably qualified to do so.

At a typical high power transmitting station installation, incoming mains to the power sub-station may be 110 kV or 66 kV with distribution to transmitters at 11 kV. Before staff are permitted to work on the distribution equipment it is the practice in many organisations to have the electrical staff trained in high voltage work.

The main circuit breakers used for high power transmitter installations are generally of the air or oil types. Both types are widely used and in some installations it is not unusual to see an oil breaker at the station switchboard and an air breaker at the transmitter on the same feeder. Many engineers however, prefer air type breakers, particularly for high frequency transmitters for the following reasons:

(a) Freedom from explosion due to oil.
This results in freedom of choice of location, as isolation prohibitions are unnecessary.

(b) Elimination of oil fire hazard.
The number of oil fires at radio stations resulting from the use of oil circuit breakers has been very small compared with the number of breakers in service but the complete absence of this hazard is a welcome reassurance to operating organisations.

(c) Mechanical simplicity.
The mechanism of an air breaker is not as complex as the oil breaker owing to the absence of toggles and catches required to provide a mechanical reduction in load to permit tripping from the comparatively small effort usually derived from trip coils. Also the power necessary to open or close is considerably reduced.

(d) Suitability for duties requiring frequent operation.
High power transmitters, particularly those used for high frequency broadcasting, where several frequency changes and transient fault conditions may occur daily, require breakers capable of handling a large number of on-off operations. The air breaker is much superior to the oil breaker in this regard.

(e) Cleanliness of maintenance and operation.
This elimination of the need for changing oil is welcomed by maintenance staff.

(f) Reduced maintenance.
Making contacts are exposed for ease of inspection. Clear and speedy inspection of arcing contacts is possible.

STATION SITE ENCLOSURE

The station property should be enclosed by a fence of proper height and construction which will prevent access to the property by persons and grazing animals where not normally permitted on the site. All entrance gates to the property should be fitted with reliable locks, and appropriate warning signs should be erected, inside the fence line at all gates and at suitable intervals around the boundary fence.

The station building complex, line switching matrix, vertical transmitting antenna masts and other hazardous plant and equipment should be fully enclosed by walls or fences, of appropriate height and construction, which will prevent access to high voltage equipment and structures by unauthorised persons, particularly children. Where animals are allowed to graze on the site, appropriate protection should be provided to prevent injury to the animal and damage to plant. Stays and guys of structures should receive particular attention.

Fences which have been found suitable for this purpose consist of standard industrial chain wire construction with a barbed wire off-set along the top. Normal height is approximately 2.2 m and is so constructed that it goes fully to ground level at all points. This type of construction is, however, not normally provided around the base of high power antenna masts because of the danger of high induced voltages and excessive power absorption. Wooden picket fences are preferred for enclosing masts operating at 50 kW and above. Fences should be constructed at safe distances from live equipment, particularly masts and towers which often are an attraction for small boys residing near the station. A recommended minimum distance is 3.3 m between the fence and the structure.

All metal fences and gates throughout the property of a transmitting station should be bonded and earthed in accordance with a properly engineered arrangement to eliminate the presence of dangerous voltages which may result from the presence of high electromagnetic fields.

All enclosures and fences should also meet the requirements of any local authority with regard to safety and structural aspects.

The question of the responsibility of broadcast organisations in connection with facilities which they own has been the subject of examination by the Courts in recent years. The law with regard to liability for injury or death to trespassers, and especially child trespassers, has undergone radical development over the past twenty years in some countries. The early view was that there had to be some act done with a deliberate intention of doing harm to the trespasser or at least some act done with reckless disregard of his presence. The requirements have gradually been eased in favour of the trespasser and in the Australian scene the High Court has introduced the concept of a general duty of care, and in regard to children, the concept of 'allurement'.

A broadcast installation and in particular mast and towers are now considered to constitute an attraction or allurement to children with the danger constituted by the installation not being easily and instantly recognisable by a child trespasser. It is therefore necessary for the installation to be rendered as innocuous to trespassers, especially child trespassers, as is reasonably possible. In practice, this means the enclosure of the installation with a suitable manproof fence and the provision of signs which will impress instantly upon the minds of any trespassers the dangers involved in the installation.

The protection of facilities from the action of rifle fire by vandals is a difficult problem and does not always lend itself to easy solution. One station engineer who had been plagued by repeated vandalism had hoped to spur increased police patrols to the isolated mountain top where his transmitter and antenna were located by inviting the police department to instal their communications antenna on his tower. However, vandals continued to use the tower as a rifle target and on one occasion tore off the heating unit cables to the antenna and punctured the coaxial feeder to the police antenna. Eventually, he had to abandon the concept of unattended operation and erected a residence on the site.

FURTHER READING

NATIONAL BUREAU OF STANDARDS, *National Electrical Safety Code*, US Government Printing Office, Washington, 1948

PANNETT, W. E., *Radio Installations, Their Design and Maintenance*, Chapman and Hall, London, 1951

Chapter 30

Installation and Construction Hazards

MATERIALS AND EQUIPMENT HANDLING

The installation of a large radio station requires the assembly of a series of very large shipping packages, and considerable care must be exercised by workmen during handling operations. The main radio frequency unit of a typical 250 kW transmitter may measure 6.5 m by 3.2 m by 3 m in its shipping crate and weigh 6400 kg. A single oil filled transformer may weigh 8400 kg. A typical three transmitter installation with spare parts may comprise more than 210 crates with an aggregate weight exceeding 170 tonnes. Steel associated with antenna masts and towers and other facilities could be very much greater.

In many cases special facilities and planning are required to cope with transport and on-site handling problems. Advance traffic negotiations and pre-planning of route may be essential, particularly where the station is located in an isolated area with poor roads and light traffic bridges, or in some cases with the complete absence of bridges at creek and river crossings. The successful delivery of all equipment and plant may mean involvement in roadbed reinforcing operations in some cases.

Arrival of the crated equipment and plant at the nearest port or railroad siding generally involves transfer to a truck trailer. This truck trailer is frequently required to transport the load to the station site, often over rough and uneven terrain. In some cases it may even be taken by barge to an appropriate shore landing point near the station or a suitable access point.

Transfer of the crated items from a ship to truck trailer is usually no great problem, but where the material arrives by rail, at a siding, problems often occur owing to the absence or limitation of off-loading facilities. To transfer very heavy and bulky items, hydraulic jacks are used to raise the crate from the floor of the rail car. Greased planks or lubricated rails are then placed beneath the base of the crate. Timber cribbing or blocking is erected on the side of the railroad bed, underneath the skid members and extending to the truck trailer. Cables are attached to pulling devices fixed around the crate or unit, and a winch or tractor used to slide the load on to the truck trailer. In some cases hard wood or steel rollers may be used between timber blocking and the crate base to accomplish the same lateral movement.

A well designed station should have fork lift trucks, gantries and cranes of adequate capacity to handle off-loading from the truck trailer when the truck arrives on site. *Figure 30.1* shows a six tonne overhead gantry provided at one station for handling materials and supplies. A truck can stop anywhere along the unloading platform and all materials can be cleared from the truck and placed at any point on the platform or transferred to some other vehicle. A much larger electrically driven gantry is provided in the power house on this station to

Figure 30.1 Gantry for material handling

handle very heavy or tall items, such as large transformers.

Positioning of the major units, such as radio frequency unit, audio frequency unit and the vault unit, usually solves the major *in situ* handling problems. However, large units may be divided into several sections for transport and many fragile parts such as vacuum tubes and capacitors and oil filled components may be removed and crated separately. Multi-tonne steel rollers and hydraulic jacks find extensive application in moving large units into their correct position inside the transmitter and vault enclosures.

Although some transformers in high power radio transmitters contain up to 4500 litres of oil, the units are nearly always transported to the site filled with oil. Only in very few cases has the oil been removed and added on site. Some damage has occurred to filled units as a result of slapping of the oil against flexible leads and inside conservator tanks. During the transportation of the e.h.t. and modulator transformers for one 50 kW station, both conservator tanks fractured at the welds of the standoff pipes as a result of slapping of the oil during a 1600 km rail journey. Broken flexible tin foil straps of large oil filled capacitors were also broken during the same journey.

While it is expected that, in handling material, a workman will carry a reasonable load, supervisors should ensure that where awkward or heavy material and plant is being handled and the risk of injury exists, adequate staff is provided to carry out the work safely. Where suitable mechanical aids are available, these should be used for heavy lifts. All lifting gear should be in good condition and of sufficient strength to handle the load.

Care is required to prevent personal injury which can follow when a heavy lift has been thoughtlessly applied. It is a well known fact that workmen engaged in hazardous occupations sometimes become contemptuous of hazards, and supervisors must be on the alert to guard against this human failing. A common result of this attitude is in the overloading of materials handling plant, and ignoring or failing to determine ultimate strength of materials.

Chains used on overhead gantries and other hoisting devices for handling heavy radio and power house plant should be inspected at regular intervals. They are less reliable than wire rope used for the same purpose and they may break without warning. Small cracks and flaws are not easily seen and the chain should be carefully examined by an experienced inspector.

The handling of materials during construction of some radio engineering works, such as mast erection, may require the provision of special built-in facilities to ensure safe execution of the work. The provision of temporary guys, permanent guys, tensioning devices and other facilities require considerable detailed planning during the design stage of the work to ensure that all facilities are available when required. *Figure 30.2* indicates the extent to which special anchor points may be

Figure 30.2 Typical anchorages required for safe mast erection

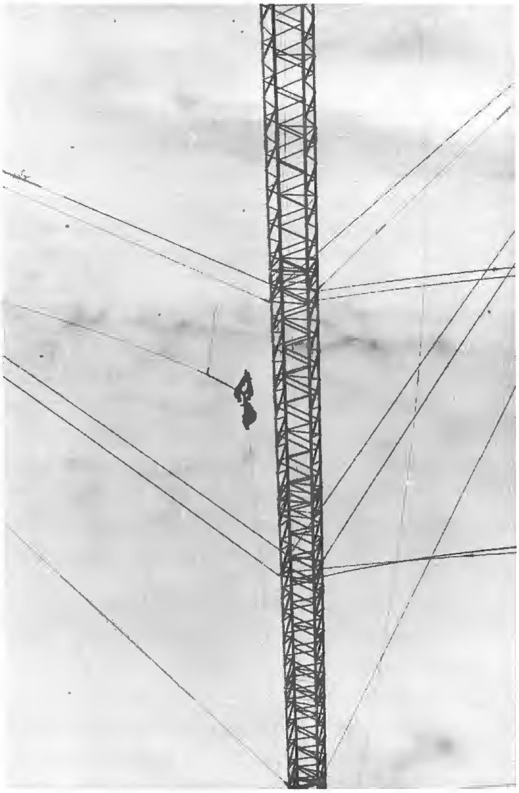

Figure 30.3 An unsafe practice during mast erection

required for the safe erection of a tall mast to support television antennas.

Lifting gear set up for hauling materials aloft to workmen on masts and towers should be laid out in the most convenient position but not where it will interfere with the operations. The ground in the vicinity of the gear and the structure must be cleared except for the lifting gear. Lifting gear used for hauling materials during erection of structures should not be used for transportation of staff. *Figure 30.3* shows a group of workmen being hauled aloft during the erection of a 200 m mast and it is evident that the men were exposed to a hazardous situation.

Cylinders which contain compressed gases should not be subjected to dragging, rolling or sliding. They should be moved from one work point to another by using the proper hand truck, cart or other transport vehicle to which the cylinders can be securely fastened in a vertical position. Where it is necessary to hoist a cylinder aloft for work on a mast or tower, the cylinder should be fitted into a safe cradle or platform, provided for the purpose.

Materials, tools and equipment should not be left in passageways, driveways, against switchboards, fire hydrants or fire alarms or in any position which is likely to endanger the safety of workmen and visitors to site works. They should be adequately protected by barriers and warning signs. First class housekeeping and preventative maintenance, plus constant supervision of all the requirements of both, are important specifications for the effective control and safe movement of materials during installation and construction works.

Antenna materials, transmission line poles and other external plant materials must be placed in positions where they can be readily seen. Where material may be hidden in grass, special care should be taken to ensure that it is not left in such a position that it could be a hazard to man or vehicle. Excavations associated with external plant works should be properly guarded. This applies particularly to holes for transmissions line poles as they are not easily seen. Where animals graze on the site, workmen should ensure that all excavation guards are secured before leaving the area.

When working with stacked transmission line poles, staff should be careful of stack movements. When poles have to be handled on such stacks, measures should be taken to wedge-up or otherwise secure the poles on which the men have to work so that accidents may not be caused by the poles moving. This applies particularly in the case of tubular steel or wooden transmission line poles.

The handling of large drums of coaxial cable and flexible waveguide can also be hazardous because of the problem of rolling. Some drums are very large in diameter as well as being heavy, and this further aggravates the handling problem particularly at the base of the structure which may pose many restrictions on the type of aid which can be employed.

Too much emphasis cannot be placed on orderliness and cleanliness in regard to safe materials handling. The consciousness of the need for safe working practice will not be aroused unless the station environment is such as will cultivate it. Orderliness and cleanliness are just as important to accident prevention as personal protection equipment. The approach should be 'a place for everything, and everything in its place'. It is the experience and influence of supervisors and their capacity for organised effort which must be used to ensure that these conditions prevail. On them depends, more than anything else, the rapid, easy and safe movement and handling of materials to and from any part of the work. The problem of handling materials safely, i.e. protection of the product, contains basically the same factors needed to protect the individuals who do the handling.

HANDLING HARMFUL SUBSTANCES

Many poisonous, corrosive, flammable, asphyxiating, explosive and otherwise harmful substances are used in both radio installation and maintenance activities. The storage and handling of these substances should be such as will prevent harmful exposure of workmen to the effects of such substances. Wherever harmful substances are proposed or are being used, the possibility of the substitution by less harmful substances should be examined.

Typical harmful substances encountered in radio engineering works include:

(a) Sulphuric acid for battery systems.
(b) Hydrochloric acid for deionized water supplies for transmitter cooling systems.
(c) Sodium hydroxide also sometimes used with deionizing equipment.
(d) Acetylene for welding and brazing.
(e) Cadmium plating of chassis and components.
(f) Polyurethane enamelled wire which gives off toxic gas when soldered.

(g) Carbon tetrachloride in fire extinguishers and cleaning fluids.
(h) Methyl chloroform as a cleaning agent.
(i) Resins and hardeners as bonding agents for insulators and fibre glass.

Many others can be added to this list which can also be injurious if improperly handled, and safety rules should be observed at all times. Some substances, for example resins and hardeners, may cause negligible effect when handled by some workmen but extreme irritation when handled by others. The development of safety hardeners may eventually make these materials safe for everybody. Methyl ethyl ketone peroxide (MEKP) presently widely used as a hardener is very dangerous. A drop in the eye may result in blindness as it will destroy the tissue of the eye.

Special storage cupboards or buildings may be provided as a permanent safety control measure for an operational station, but particular care is necessary during installation works when proper storage and handling facilities may not be readily available. Although all harmful substances are not combustible it is usual practice with many safety conscious organisations to prohibit smoking or lighted matches in areas where harmful substances are stored.

Where harmful gases, such as those in battery rooms, are given off into open space, the accumulation of unsafe concentrations should be prevented by means of a local exhaust ventilation system. At one station with a large battery installation, the batteries were inadvertently left on a high charge rate for an extended period without supervision, and the room became filled with a high concentration of highly explosive gas. It was detected as a result of leakage of the gas into the adjacent control room through the floor duct carrying the battery cables. To minimise the effect of a reoccurrence, the engineer fitted a motor driven exhaust fan controlled by the battery charger switch.

Materials used for the storage of harmful substances should be such that they will prevent leakage or escape of the substance and retain it in a safe condition under the reasonable hazards involved in transport, handling and storage. The containers should be appropriately marked and labelled in a manner consisting of colours, numerals and shapes to identify the hazards of the material with respect to health, reactivity and flammability, and the severity of these hazards. The labelling should also indicate procedures for safe handling of the substance and action to be taken should personal contact be made with the substance.

Another harmful substance which has received considerable publicity in recent years is the beryllium oxide (BeO) ceramic used in the construction of some electron tubes and accessories. Compounds of beryllium are very poisonous. Even the dust of the powdered metal or its oxide may cause very serious illness or death, when inhaled. Fumes also are highly toxic. Workmen should therefore be extremely careful not to disassemble, grind, pulverise, chemically clean or perform any other operation on ceramic parts of electron tubes or accessories which may cause the generation of dust or fumes.

Because of their extremely high thermal conductivity the main uses of beryllium oxide ceramics are to conduct heat from power tubes, usually directly from the plate of types using external plate construction, as socket insulating material for base cooling of tubes, in Gunn and IMPATT oscillators and amplifiers to mount semiconductor devices. Although it is normal practice for tube manufacturers to label beryllium oxide ceramic parts and components, sometimes the label becomes detached or obliterated and it is consequently unwise to carry out any work on the ceramic parts of power tubes without first checking with the manufacturer.

Because of the hazards involved with this material, the disposal should be carefully controlled when the material is no longer required. Some manufacturers recommend that tubes or accessories containing beryllium oxide ceramics be returned to their works for disposal at the end of their useful life.

The following safety precautions are appropriate:

(a) Do not attempt to file, drill, grind, polish, cut, break, etch or otherwise work a piece of beryllium oxide material.
(b) Ensure that manufacturers warning labels are always attached and store beryllium oxide insulators in such a way that they cannot be mistaken for any other substance.
(c) When a tube or piece of equipment using beryllium oxide is scrapped it should be returned to the manufacturer with written authorisation for disposal.
(d) If a tube or piece of equipment using beryllium oxide is to be transferred to another station or sold ensure that the person taking charge of it is aware of the hazards and which parts contain beryllium oxide.

CONSTRUCTION SITE WORKSHOP

Nearly all radio installation and construction works will require some on-site workshop facilities to allow the work to be carried out properly and safely. The extent of the facilities provided will depend upon the nature and size of the project being undertaken and also on the remoteness of the site from permanent commercial engineering workshops. When justified, an on-site construction workshop would generally be equipped with such basic items as bench drill, grinder, mechanical hacksaw, electric and acetylene welder, workbench and a comprehensive set of installation and construction tools. Additional equipment would vary with the nature of the work to be undertaken.

For a large project involving the construction of masts, transmission lines, matrix switch, transmitters and associated equipment, it will often be desirable to establish the station permanent workshop as soon as access is given to the main building, and before the commencement of the construction work proper. This workshop may contain such major items as lathe, sheet metal bender, pipe benders, guillotine etc. together with a mobile gantry system to assist in handling heavy materials in the workshops. Where a large transport and mechanical aid fleet is involved, facilities such as ramp, greasing equipment, battery charger, tyre repair outfit, fuel handling and fuel supply equipment may also be necessary. A temporary construction and installation tool and instrument store would also form part of the overall facilities.

Where a field workshop has to be established, it would generally be of simple prefabricated construction with adequate protection for the plant, plenty of work room, good lighting and ventilation. A large temporary covered workshop area is often a sound investment as it will allow much work, such as assembly, to be carried out in the event of wet weather affecting outside works. The area in which the workshop would be erected would be governed by the site layout of the plant to be erected, the location of proposed buildings and the topography of the site.

In the establishment of temporary workshop site facilities there is too frequently a tendency to skimp on facilities such as machine foundations, solid flooring, adequate lighting, proper electrical wiring, leakproof roofing, good housekeeping and store areas. However, it is important that proper consideration be given to all aspects affecting safety.

HAZARDS IN THE USE OF MECHANICAL AIDS

The use of mechanical aids, such as pole hole borers, cranes, work baskets, hoists etc. during radio station construction and maintenance works, gives rise to special hazards owing to the danger of contact with high voltage antenna systems, transmission lines and power lines. The special nature of some works, such as the erection of masts and towers, introduces another hazard, and that is the safety of the work crew on the structure during operation of these aids. A typical situation encountered in practice is illustrated in *Figure 30.4* which shows a crane being used for the erection of the supporting structure for antennas associated with a television relay system. Inattention by the crane operator could pose a serious threat to the safety of the workmen on the structure.

When mechanical aids are to be used near high voltage lines precautionary measures should be taken to ensure no contact takes place. The supervisor in

Figure 30.4 Use of crane for tower erection

charge of the work should ensure that the necessary precautions are known by and strictly observed by the operator. The satisfactory earthing of mobile mechanical aids and vehicles working in the field near high voltage conductors has generally been impracticable because of the difficulty in obtaining and maintaining a low impedance earth connection to provide a significant measure of protection. Practice adopted by many engineers is to instruct the operators in alternatives precautions for their protection.

The field supervisor should constantly consider the risk of line or antenna contact, with the object of anticipating hazardous situations, and suitably alert the operator and other staff. Where the supervisor believes the circumstances are such that safety would be improved by a clearance observer, such help should be provided. During the erection of one high power broadcast station a crane operator allowed the jib to come in contact with the incoming 66 kV mains feeder, and he was extremely fortunate in escaping without serious injury. The supervisor had failed to properly appreciate the hazard and provide a clearance observer. In a large crane it is difficult for the operator to accurately gauge the clearance between the jib and conductors, from his position in the cabin. One safety device which is available to alert the operator of close power mains can be mounted on the jib. It consists of a bare metal antenna fastened lengthwise to the jib, a screened electronic detector unit and visual and audible warning devices for warning the crane operator when the jib approaches within a fixed distance from the power line.

No safety precautions are adequate without the co-operation of operators and other staff. They should remain alert to the possible hazardous situations which exist in many operations in which mechanical aids are used. Some typical safety precautions applicable to the use of these aids are:

(a) Mechanical aids to be operated only by authorised and qualified persons.
(b) The operator to wear a safety helmet. Persons assisting in the operation of the aid to wear a helmet, safety shoes and also gloves where wire ropes and slings are being handled.
(c) The operator to be responsible for ensuring that to the best of his knowledge the aid is in sound condition, and has been properly serviced in accordance with the supplier's manual.
(d) The safe working limitations of each aid to be clearly marked on the machine, and the operator to be responsible for ensuring that these limitations are not exceeded.
(e) No special attachments to be fitted without the approval of the appropriate engineer.
(f) At the conclusion of each day's work and at other times when the aid is to be left unattended, it is the operator's responsibility to ensure that the aid is parked in a clear area and left in a safe condition with all controls in the 'off' position. Braking devices should be securely applied and wheels chocked.

EXPLOSIVE POWERED TOOLS

Explosive powered tools are finding wide application in installation work at radio stations. They find application in the fixing of copper sheet or mesh to floors of transmitter rooms and in the complete shielding of antenna matching huts, test rooms, link rooms and control rooms. They are also used for fixing attachments to walls for equipment supports, runways etc.

Several deaths and many injuries have resulted from the use of these power tools and extreme care is necessary in their use. Deaths and injuries have also occurred to on-site workmen not directly associated with the operation of the tool.

Recorded accidents which have resulted from the use of these tools include the following:

(a) A workman, fixing copper bonding straps to steel roof members in the ceiling of a transmitter building, was struck on the cheek by a small piece of hard blistered paint when the pin pierced the steel work, but his reaction was sufficient for him to lose his balance and fall backwards. He was fortunate in not falling through the ceiling.
(b) A workman whilst fixing 'danger' signs to round steel transmission line poles was badly injured when the steel pin was deflected by the curved pole surface and cut his wrist. The normal blast shield does not cover a curved surface and the tool should not be used for this type of work.
(c) A workman picked up a tool to explain its use to an electrician, and during the demonstration the gun was accidently fired, killing the electrician. The person who had previously used the gun had loaded it for further work but left it unattended.
(d) A workman fixing a cable tray to a wall, fired the stud just off line of the desired position and broke it off flush with the surface. A second stud was then fired alongside the remainder of the first but contacted the edge of it and shattered, causing a piece of steel to fly into the operator's eye.
(e) A workman attempting to fix a projectile to a wall stud, missed the target, and the projectile travelled completely through the wall killing a workman on the other side.

Power driven tools are very versatile and are great labour savers. However, there are certain materials, encountered in the construction of radio stations, that are not suitable for these tools. In fact, some materials can be extremely hazardous to the operator, and a thorough examination of the material should be made before attempting to drive a projectile into it. Experience has shown that it is dangerous to attempt to use a power driven tool to drive a projectile into:

(a) Hardened steel, high tensile steel, cast iron and other hard and unyielding materials.
(b) Shatterable substances, such as cut building stone, glass, tile, glazed or clinker brick.
(c) Positions close to the edge of materials where there is a danger that the material might crack or break, or the projectile escape and continue to travel.
(d) Positions within 1 cm of the edge of steel plate.
(e) Positions within 7.5 cm of the edge of a brick or concrete block.
(f) Concrete with large hard aggregate.
(g) Material where it is intended to fix the projectile to its full depth and where it may foul an imbedded object, such as a round concrete reinforcement bar that would deflect the projectile from a straight path.

(h) Material of such strength that the projectile may pass completely through with the charge being used, unless the material is backed by a protective material capable of fully absorbing the energy of the projectile.

Because of damage which can occur to materials and plant, and the hazards to which workmen may be exposed by improper use of explosive powered tools, many safety precaution instructions have been issued on their use and care. In view of the similarity with firearms, some government authorities have also been active in controlling their use, by bringing down appropriate legislation. The following guidelines issued by one organisation to its staff covers most of the issues outlined above:

(a) Only operators who have been suitably trained to be allowed to use the tool.
(b) The operator to wear suitable eye and ear protective devices, in addition to his safety helmet.
(c) The tool to be loaded only at the point where firing is to take place. Tools not to be loaded on the ground and hauled aloft to workers. Loaded tools should not be left unattended.
(d) A warning notice to be displayed at or near the place where the tool is being used to bring to the notice of other workmen and visitors that such tool is in use.
(e) The gun to be retained in position for at least 30 s, if the cartridge fails to detonate.
(f) The tool not to be fired intentionally or for test purposes in such a manner as to cause a projectile to fly free.
(g) The tool not to be used in an area where there is a risk of fire or explosion from sparks or the discharge action of the projectile.
(h) The tool not to be used for any purpose other than that for it was designed.
(i) Pins not to be fired into very soft or brittle materials, holes made from attempts of previous firings, or near corners of materials which may break away.
(j) All safety requirements of local authorities and standards organisations applicable to these tools to be followed.

WELDING HAZARDS

In a large radio station construction project, the amount of welding and brazing work is generally considerable. Many accidents have occurred in this type of work and it is essential that workmen be familiar with the potential hazards of the various processes, and also means of controlling the hazards. A survey indicated that 2% of injuries on radio stations resulted from welding operations. Aspects of welding work requiring particular attention are:

(a) Compressed Gases.
All cylinders are generally well marked and usually colour coded. The primary hazard of compressed gas cylinders is the possibility of sudden release of the gas by removal, or breaking off, of the valves. At least one accident is known to have occurred in a transmitter hall when a small cylinder fell from a work platform during welding operations to a transmission line outlet, causing the valve to break off and the cylinder to act as a jet propelled object and crash into the side of a transmitter cubicle. Also, escaping gas may provide an explosion hazard.

Oxygen is one of the best known of the compressed gases used in welding work. It is perhaps the most hazardous due to its ability to accelerate the combustion of normally combustible materials, and it is especially important that oxygen be treated with respect. The pressure of oxygen in a full cylinder is approximately 280 kPa. Oxygen should in no case be substituted for 'air'. It should not be used in any operation or equipment requiring compressed air. Pure oxygen, or oxygen enriched air, will accelerate burning.

Safety and capacity of acetylene cylinders is obtained by packing the cylinder with a porous material, the fine pores being filled with acetone, a liquid chemical having the property of dissolving or absorbing many times its own volume of acetylene. In such cylinders, acetylene is perfectly safe and will not change its nature. However, cylinders should not be subjected to rough handling, dropping or knocking. The fusible safety plug with which an acetylene cylinder is provided acts as a safety release should the cylinder be exposed to excessive temperature. The plug will melt at about the temperature of boiling water and release acetylene from the cylinder. Rough treatment might damage the fuse plug, the cylinder or the valve.

Another gas which is used extensively on radio construction work, particularly on external plant such as brazing of antenna earth mat wires and stakes, is liquefied petroleum gas. It is a petrol by-product and is sold under various trade names. Liquefied petroleum gases liquefy at relatively low pressures and normal temperatures and can be stored in steel cylinders which are easily handled and transported. The gases are non-corrosive and non-toxic and are normally odourless, but to comply with some government regulations, an added odorant gives the gases a distinctive smell to assist in detecting leaks.

Because very small lightweight cylinders are available for this type of gas it is used almost exclusively when repair work must be carried out aloft on antenna systems. The small cylinders can be filled locally from a large cylinder held on the station, but care should be exercised during the filling operation. If a cylinder is overfilled, liquid expansion as a result of rise in temperature can cause high hydrostatic pressures to be developed and the safety valve may operate, allowing liquid to escape. This could create a dangerous fire or explosion risk.

There are special precautions which should always be taken with compressed gas cylinders. They should be properly stored in an upright position in approved safe places. They should be kept away from the hot places and away from the direct rays of the sun, particularly in locations where high temperatures prevail. Cylinders containing oxygen should be stored well away from cylinders containing combustible gases. Workmen should be instructed to treat compressed gas cylinders with respect at all times.

(b) Electric Shock.

Any source of electricity provides the hazard of electric shock and it is important that electric welding apparatus be periodically inspected and properly maintained by qualified electrical staff. Mobile generator welders are frequently provided on large stations for work on the external plant and care is necessary by operators when working in damp or wet locations in the field. Moisture reduces the electrical resistance, and increases the likelihood of a good contact should the operator become involved in the current path. This of course increases the hazard.

(c) Electric Arc Radiation.

The rays emitted by an electric arc in welding operations contain ultra-violet rays which can be painful to the eyes. This discomfort is caused by the extreme intensity of the rays, and in the fact that the eye cannot withstand exposure to them without having its delicate nerves and membranes injured. Only glasses or helmets specially designed and approved for the purpose should be used during welding operations. The filter glass has to perform two important functions. It must render the operator immune from the effects of ultra-violet rays and it must reduce the glare from the arc and make the work distinguishable. Smoked or tinted glass should not be used as a substitute, as they do not give sufficient absorption of the rays.

It also is important that the operator wears appropriate clothing to prevent arc rays from contacting the skin. This can result in painful 'sun burn'.

(d) Air Contamination.

Welding, along with many other processes, produces contamination of the air. It is important to recognise the different types of contamination produced by welding and brazing operations, and to take necessary steps to reduce their potential hazards. The concentration of toxic gases and dust can be measured, and threshold values for different materials have been established by standards organisations. These gases and dust may come from the base metal being welded, the electrodes, or shielding gases. Many of the base metals used in radio engineering work produce toxic gases. These include lead, zinc, cadmium, beryllium and many others. Adequate ventilation is essential for all welding operations and respirators may be required during some work.

(e) Fire and Explosion.

The three elements of the fire triangle, fuel, heat and oxygen, are normally present during welding operations. The level of each of these elements should be kept to a minimum and under control to avoid fires and explosions. The heat involved comes from the torch of the arc or from the base metal being welded. Sparks which fly from welding or cutting work are really little balls of glowing metal oxides. They can travel a long distance from the point of origin and may stay hot for a considerable time after landing. Fuel for the fire may come from the gas employed or from combustibles in the welding area. The oxygen, of course, is present in the air and may be enriched by pure oxygen available from the welding equipment. Each of these elements should be kept under strict control.

Accident free welding operations can be maintained, provided that station supervisors take the proper steps to ensure that precautionary measures are continually observed. Staff required to use welding equipment in the course of their work should be informed of the hazards through continual re-education. Protective glasses, helmets and clothing should be readily available with the plant.

An example of the need for re-education was high-lighted by a case at one station during the brazing of an earth mat associated with a mast radiator. A large busbar had been installed around the perimeter of the mast concrete thrust block and a workman was engaged on brazing the copper radials on to the busbar. In order to cut a wire he put the brazing torch, still alight, on the edge of the concrete block. The heat from the flame caused the block to crack and a small stone in the aggregate to shatter. A piece of the stone fragment entered the workman's eye. The workman was a very experienced operator, but had become lax in his safety practices.

At another station, lengths of 7.5 cm diameter rigid coaxial line, mounted on posts about 45 cm above ground, were being silver soldered with a brazing outfit when the flame set fire to dry grass. A hot wind was blowing at the time and a large area of the paddock was burnt out before the fire could be brought under control. The two workmen responsible had failed to clear away combustible materials from the work area and had also neglected to keep a water spray and beater handy, even though their supervisor had instructed them to do so at the commencement of the project.

BLASTING OPERATIONS

Blasting operations using explosives are carried out in connection with excavations for foundations associated with masts, towers, transmission lines and other facilities, in areas of hard rock where mechanical methods are impracticable or uneconomical. They have also been used for speed and economy in soft water logged areas where specially designed 'floating' type foundations were provided for broadcast mast radiators.

The object of blasting is simply to shatter the rock or loosen up the ground, thereby permitting easy removal of the spoil by mechanical means. On mountain tops, which are invariably of rocky foundation where excavations are carried out for television and link structures, care is necessary to ensure that walls close to cliff faces are not fractured. Many engineers will not permit blasting on hill tops for mast foundation purposes unless the work is carried out by an operator experienced in such site activities and the hole is examined and passed as safe for foundation purposes by an engineer experienced in foundation practice.

The use of explosives is also sometimes necessary to remove old foundations of dismantled masts and towers, particularly the anchor blocks which may protrude above ground level and be dangerous. Also, it may be necessary to remove a new foundation where the strength of the concrete fails to meet the specified strength. Few problems are usually encountered where the foundations are isolated, but where located near a building or near another structural foundation, great care should be exercised, and only small charges employed. General practice in these instances is to employ vertical drill holes to break down the foundation block. Experience has shown that holes should be spaced 45 to 60 cm apart and with similar burden distance to the free face. The charge per hole should be small and be distributed along the drill hole. A charge of 60 g/m^3 is generally sufficient to break a foundation block into a suitable condition for removal.

Extreme care must always be exercised in the use of explosives because of the serious nature of the injuries. Some causes of accidents have been attributed to the following:

(a) Smoking or the use of naked light when handling explosives.
(b) Premature firing of electric detonators from induced earth currents and electromagnetic currents from radio transmitters.
(c) Returning to the area too soon after firing.
(d) The absence of, or improper use of, blasting mats.

(e) Improper use of tamping rod when charging holes.
(f) Use of safety fuse too short in length.

The use, storage, carriage and destruction of explosives is generally covered by regulations of local authorities, and in all cases the requirements of these should be rigidly observed.

The following safety rules are appropriate, in the use of explosives:

(a) No workman who is not a current holder of a shotfirer certificate or other qualification required by the local authority, or the organisation, should handle uncased explosives, prepare a charge, charge a hole, fire a charge or investigate a misfire. Many organisations and local authorities require that persons registered as a shotfirer undergo a practical test every two years.
(b) Before the engineer or supervisor of the work permits a workman to handle explosives, he must inspect the shotfirers certificate and confirm that it is current, and satisfy himself that the shotfirer is registered for, and has sufficient experience, to carry out the particular work.
(c) The shotfirer should have full control of all blasting operations, and all persons in the area must obey his directions during the period in which charges are being prepared and fired, and until the 'all clear' signal is given.
(d) On completion of the work the engineer or supervisor should check the details recorded in the log-of-work which the shotfirer must keep, and sign in the appropriate column.
(e) Explosives must not be used in the vicinity of the station power plant fuel tanks or other restricted areas where underground construction exists and could be damaged.
(f) A vehicle in which electric detonators are being carried must not be taken on to premises on which radio transmitters are operated. Electric detonators must not be placed in a vehicle equipped with a radio transmitter unless the transmitter is made inoperative.
(g) When blasting close to a building, for example when providing for a television or microwave link tower after completion of the building, the building must be closely inspected immediately before and after blasting to ascertain the extent of any damage.
(h) Blasting mats must be placed over a hole whenever there is a possibility of damage from flying debris to buildings, plant or personnel. The blasting mat should have the following features:
    (i) It must be heavy enough to prevent it being blown away by the explosion.
    (ii) It must stand up to rough usage.
    (iii) It must stop the passage of small stones.
    (iv) It must allow gases liberated by the explosion to pass through it quickly and easily.
(i) No explosive should be conveyed to, or from a magazine, or about the works, except in unopened cases or standard explosive boxes.
(j) Explosives should not be taken to the site of operations until the holes are ready to be charged and fired. Immediately charging is completed and before firing, the explosive material and detonator boxes, with all unused gelinite and detonators respectively, must be removed to a safe distance from the charged hole.

(k) The carriage of explosives in vehicles must comply with the requirement of all laws and instructions applicable.

(l) Detonators in transit with leads which might pick up radio frequency energy from nearby broadcast, radio or radar transmitters should be carried in a closed metal container with no apertures and with low resistance contact between lid and the container.

(m) Explosives for destruction must be destroyed only by a qualified person and under the approved conditions set down for the procedure.

Great care is necessary in carrying out blasting operations at or near transmitting stations of all types. In recent years, transmitters have become more powerful and it has been established that under certain conditions in the vicinity of these transmitters, the wiring system of the electrical method of detonation can have current induced in it of sufficient amperage to fire the detonator. The detonator as supplied by the maker usually has the lead wires twisted and wrapped and is not likely to be affected by an electromagnetic field. The danger occurs when the leads are unwrapped. The leads can act as an antenna to pick up radio frequency voltages resulting in a current flow through the detonator.

The recommended minimum safe distances from medium frequency broadcast transmitters has been interpreted differently by many organisations with a result that there are wide variations in the figures. One drawing prepared for use by field staff when working in the vicinity of transmitters employing omnidirectional antenna systems is shown in *Figure 30.5.* The British Standards Institution in its BS4992:1974 suggests a distance of 1000 m from a 500 kW medium or high frequency broadcast transmitter.

Frequency modulation, television, radar and high frequency stations invariably employ directional antenna systems with various horizontal and vertical patterns and it is not possible to generalise on field strength levels. For instance a typical international high frequency broadcast station may have an antenna

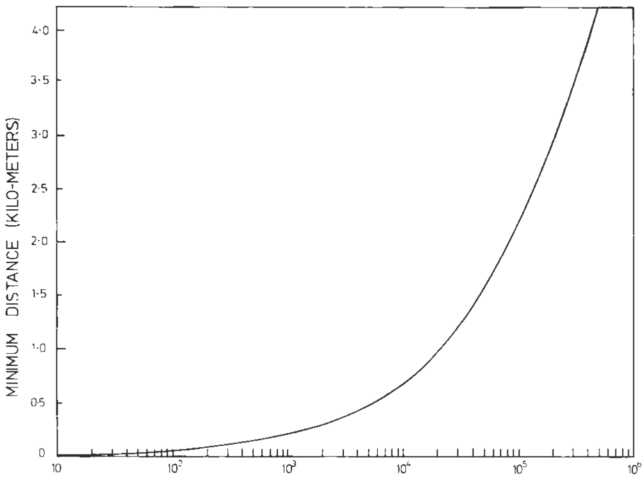

Figure 30.5 Recommended safe distances from transmitters with omnidirectional antenna systems

system with a beamwidth of about 20 degrees, a vertical angle for maximum intensity of 10 to 20 degrees and an effective radiated power towards the target area of up to 50 MW. However, as the energy is radiated towards the ionosphere the field strength at ground level would be relatively small at a distance of, say, 3000 m from the station. In directions away from the main lobe the signal strength may be very small indeed. Because of the difficulty of determining the field strength, many engineers insist that all circuits be subjected to test before connections are made to the firing circuit. Suitable tests devices include a pea lamp, a thermistor bead attached to a bridge wire or a thermal millianmeter of suitable sensitivity.

Detonating fuse or safety fuse and detonator are preferred for work in the vicinity of transmitting stations. However, on the site of all high power stations it is prudent to forbid all forms of blasting because the high field strengths may cause sparks to jump from such metal objects as workmen's tools, crowbars etc., resulting in possible firing of the charge.

ELECTRO-EXPLOSIVE DEVICES

Electromagnetic radiation is also considered to be a hazard under some conditions where particular items of military stores and equipment are involved. The use of electrically initiated explosive devices for booster rocket igniters and warhead detonators, and for reliable high speed operation of switches and valves has greatly increased in recent years. Some modern weapons contain more than 75 electro-explosive devices. Several instances involving ordnance items have been attributed to initiation of their electro-explosive devices by electromagnetic radiation from nearby radio transmitting equipment. Each incident occurred during operations while the ordnance item was being handled normally.

The basic problem in determining an ordnance system's susceptibility to electromagnetic radiation lies in the evaluation of the pick-up by the various electro-explosive devices utilised in the weapon system. The pick-up can be in the nature of antenna-like couplings or probes, radiation through slots or cracks in the weapon skin, or by conduction into the weapon via firing leads etc. entering the weapon enclosure.

The precise probabilities of actuation of an electro-explosive device are very difficult to predict because so many variables are involved. These include field strength of the radiation in the vicinity of the weapon, the frequency of the radiation, geometric orientation with relation to the radiated field, the extent of metallic contact of the weapon with other bodies and the environment.

The most likely effects of premature actuation are dudding, reduced reliability of the system or ignition of propellant. The probability of warhead detonation, although low, nevertheless exist.

WARNING SIGNS

Suitable signs to provide an effective means for directing attention to dangerous conditions or to places where caution should be exercised, and for indicating the location of safety and fire protection equipment, should be installed at appropriate locations throughout the station when installation and construction works are in progress. Signs must be clearly legible, concise, in the appropriate and simple language, and take the form of pictorial symbols and colours approved by recognised standards associations. The provision of warning signs is not however the ultimate in countering hazardous conditions. The aim of accident prevention should be the removal of hazards, and the use of warning signs can be no more than a contribution to such action.

The selection of locations for signs is important. Not only should the message that the sign carries be legible, but it should be clearly visible to all concerned. Sufficient warning signs should be provided to indicate places which are temporarily or permanently dangerous, where men are at work overhead, places where caution should be exercised, the location of emergency exits, fire extinguishing equipment, first aid and safety equipment. The appropriate international electrical danger symbol should appear adjacent to all key-locked covers and handles.

'Danger' and 'caution' signs should be placed sufficiently ahead of a particular hazard to allow a person ample time after first viewing the sign to heed the warning. This is particularly necessary in case of low level transmission lines, crossing roadways and paths used by vehicles. Signs should not be placed on movable objects such as the doors of antenna matching huts and other locations where a change in position would make void the purpose of the sign.

Radio and electrical equipment carrying high voltage, mechanical plant such as motors, fans, generators and engines, pneumatic equipment for transmitter or switch drive and similar type of plant undergoing test or modification, should be temporarily roped off, the area well illuminated and 'danger' signs conspiciously displayed. The signs should not be removed until all work has been completed and the equipment or plant accepted as safe by the station manager, in accordance with recognised procedures.

Permanent 'caution' signs should be attached to capacitor banks used for transmitter high voltage power supplies as soon as they are installed in position. Shorting bars or wires should be maintained across the terminals until all installation work has been completed. The modern power supply has become a considerable shock hazard not only because of increased quality built into capacitors, but also because of the greater value of capacitance required with resistance-capacitance filters compared with earlier inductance-capacitance networks. The time constant of the network is often such that considerable time may elapse before the capacitor has discharged sufficiently to allow safe handling. The capacitor bank connected across the rectifier output of a typical 250 kW transmitter has a capacity of 80 μF or more because of the requirement to provide a low impedance source at audio frequencies, and strict adherence to safety procedures is essential in handling these capacitors, as death or serious injury may result from unsafe practices.

The need for the installation of adequate 'caution' signs on large capacitors is evident from the case where a workman overlooked the potential danger associated with a high voltage filter capacitor which he had disconnected from circuit. In order to lift the capacitor away from the work, he grasped the two terminals of the unit, one in each hand, and was killed instantly. The current surge at the moment of contact was so great that the thread marks of the capacitor terminals were burned into the flesh of his hands.

Particular attention should be given to hazards during power failure when the building could be in complete darkness. Local lighting should be automatically provided from a station battery supply at sufficient intensity in hazardous areas to enable staff to safely bring into operation, emergency power generating plant.

Many different types of signs are used for warning purposes but the four main classifications are:

(a) Danger signs, to warn of an immediate hazard.
(b) Caution sign, to warn against unsafe practices.
(c) Safety instruction sign, to indicate location of first aid and safety equipment.
(d) Direction sign, to indicate emergency exits, direction of safety services and detours for traffic on the site.

In order to maintain respect for warning signs, all those which are temporary must be removed as soon as possible after completion of the work for which they were provided.

FAILURE OF STRUCTURES DURING ERECTION

The erection of tall masts and towers calls for much skill, experience and a head for heights. In the design and fabrication of these structures the special requirements and work hazards of the erection crew must always be kept in mind. The need to work at great heights, often under unfavourable weather conditions and with limited tools and devices, imposes limitations on the configuration, size and weight of individual sections and components which have to be hoisted into position to form the completed structure.

Erection of guyed masts, in particular, calls for special care and skill because of instability which may be introduced during temporary guying, and the attachment or replacement of the permanent guys. Many collapses have occurred during these critical phases of the work. In the case of structures used as medium frequency radiators, base and sectionalising insulators are particularly vulnerable to damage and extreme care is necessary in handling to ensure that unnecessary stresses are not applied during the structure erection process.

The erection invariably commences by lifting the bottom section which has been assembled on the ground into the vertical position with the aid of a mobile crane. Temporary guys are attached and the erection proceeds more or less piecemeal with individual members of the structure being hoisted aloft by a winch controlled rope. The winch rope passes over a sheave block, fitted at the base of the mast, up to the head of a derrick mounted at the top of the structure and thence down to the load to be lifted. Where site conditions are suitable and adequate space is available it is not unusual to have three such winches operating simultaneously, one for each leg of a three sided structure. This allows considerable speed in erection rate of members. The derrick used to assist with the erection is raised from time to time as the height of the structure increases.

During the erection of a guyed mast, temporary guys must be attached to maintain stability. The levels at which temporary guys are attached must be carefully calculated to ensure that excessive bending or deflection does not occur. The anchor blocks should have provision for attachment of these temporary guys. As each permanent guy level is reached the permanent guys are attached and tensioned. All temporary guys below this level are released and prepared for further use.

The fabrication, installation and tensioning of the permanent guys demand a well considered procedure, and very careful handling. The wire rope used for fabrication may be of several approved types but the bridge strand type is preferred by many engineers. Individual strands are generally specified as being the largest size consistent with reasonable handling qualities of the rope, thereby providing the maximum safeguard against damage to, or corrosion of, individual strands. The wire is, as a rule, galvanised and treated with an appropriate preservative during manufacture.

For large guy wires, terminations are of the socketed type with the socketing operation being performed carefully to avoid disturbance to the lay of the strands which may permit the entry of water to the core. Because of the special skill and control required in this operation, the work is regarded as a workshop function and not one for field staff. Tucked eye splices at guy terminations are not permitted on most installations.

When construction has reached a permanent guy level, the guys are hoisted in turn, fixed to the mast attachment fittings and left dangling, but clear of the structure. Extreme care should be taken during laying out and handling to ensure they are not dragged over rough surfaces or allowed to hit against the mast. The lower ends are pulled out together towards their respective anchorages as far as possible by manhandling. Further pulling into the anchor block fixing position is made with the aid of winches. The winch is sited behind each anchor block and the rate of pull for all guys kept uniform to avoid out-of-balance loading on the structure. The guys and insulators of a tall structure are very heavy and require careful handling. A guy for a typical 300 m mast may weigh up to 10 tonnes and be more than 300 m in length. Often additional lifting gear will be necessary to hoist the guy to its attachment point on the mast. Multi-drum winches may be required for simultaneous handling of guys.

After connection of the guys to the anchor block fittings, tensioning equipment is fitted and by manipulation as directed in the designer's instructions and drawings, initial tensions are induced in all guys together. This work is a critical operation and many structures have collapsed because of the lack of proper control and co-ordination at this stage.

Throughout the guy tensioning operation, and indeed throughout all phases of the mast erection, the mast should be kept under observation for verticality from two theodolite positions viewing in planes at right angles. Final guy tensioning and vertical alignment of the structure is carried out in still air conditions. It should be borne in mind that, with a properly designed and engineered mast and with the work adequately supervised, damage and danger to the structure will seldom occur, except if the structure is bent, due to uneven guy tensions at one level. This can be avoided by continually checking the mast for straightness.

Structures have failed dramatically and embarrassingly. The majority of failures should not have occurred. There are only a few examples where it can be said that the failure of the structure was due to sheer misfortune occurring in such circumstances that no blame could be attached to any of those associated with the design, fabrication or construction of the project. A study of many structural failures has shown that the majority of failures were caused by inherent defects, or inadequate control or supervision of the construction activities, rather than from the action of some natural force of unforeseen magnitude or other external factor.

A surprisingly large number of total or partial collapses have occurred during erection or adjustment to the structures. It is impossible to eliminate mistakes altogether in the type of structural work encountered in broadcast engineering because of the large content of human involvement in the work. However, many mistakes could be eliminated, or at least reduced, by closer liaison between the principal, the structural designer and the erection contractor, and by having adequate and proper checking and supervision of the work. Many cases have indicated that if more money had been invested in proper supervision of the fabrication and erection methods, it would have saved money in the end.

Following an investigation into the collapse of a mast which resulted in fatal injuries to seven erection personnel in the United States in 1971, the Department of Labor and Industry, Division of Occupational Safety and Health made a number of recommendations[1] to reduce the likelihood of a repetition. They are applicable to similar situations in many countries and include the following:

(a) Careful consideration should be made of the erection stresses during the design phase of the project, and critical areas documented.
(b) There should be a detailed written erection procedure and rigging specification agreed upon by the fabricator and the erector. There should be no change, unless agreed upon in writing by both parties. Structures should conform to the Uniform Building Code, wherever feasible, during all phases of construction.
(c) A qualified neutral third party should review the design, erection procedure, and rigging specifications prior to the start of the project. He should also review any changes prior to incorporation.
(d) A qualified engineer should be on the job site at all times with authority to enforce the agreed-upon erection procedures or to stop the project if there are any unauthorized deviations from agreed procedures, or any variation from specifications, or if any welding or material defects are noted.
(e) Fabrication should be done with certified welders and proper process control and quality control procedures to insure the integrity of the end product.
(f) The material should be clearly specified and defined both on the specifications and on the drawings for the project. The material ASTM or other means of identification should be marked thereon as specified in Chapter 27 of the Uniform Building Code (UBC).
(g) Plans and specifications should be signed and sealed by a qualified engineer as required by statute.
(h) The plans, specifications and construction procedures should be reviewed by the proper state or local authorities prior to the start of the project. The Department of Labor and Industry would review the plans with regard to the safety of the construction personnel and others in a hazardous area.
(i) In the event of a catastrophic accident with resultant loss of life or injury, the Department of Labor and Industry should be authorized to convene a public board of inquiry consisting of competent professional engineers or architects and persons experienced in the construction trades, to conduct a complete investigation. This board should be small, not more than five in number, and should be charged with determining the cause of the accident and with making constructive recommendations for changes in codes, standards and procedures to prevent re-occurence, in the interest of safety.

The following examples taken from available records on the failure of structures during erection illustrate typical troubles which have been experienced.

EXAMPLE 30.1

Collapse Candelabra Mast, Shoreview.

A few minutes before 10 a.m. on 7 September 1971, the 390 m mast being erected at Shoreview, Minneapolis, as a support structure for television antennas collapsed killing seven workmen and injuring two others. Six of the men were on the mast and the other, a supervisor, was on the ground. Three of the bodies were located near the fallen structure but the others were crushed beneath tonnes of steelwork. It was several hours before the twisted steelwork could be cut away and shifted by mobile crane to allow removal of the bodies. The injured workmen were in a single storey transmitter building near the base of the mast. The falling steelwork caused considerable damage to the building and also crushed four cars parked nearby.

A 50 tonne crane was required to remove the steelwork which fell onto the building. Some sections smashed through the prestressed roof, through the floor of the transmitter room and were embedded more than a metre into soil after penetrating the reinforced concrete basement floor.

The workmen at the top of the mast were preparing to lift an antenna base assembly weighting about 7700 kg by means of a hoisting derrick powered by winches on the ground. Shortly after one end of the load lifted off the ground the structure collapsed.

The structure was of a candelabra design with a triangular lattice steel platform mounted atop the guyed mast. An antenna of 30 m height was to be placed at each corner of the platform giving an overall design height above ground of 419 m.

The mast was of triangular section with legs fabricated from solid steel bars on 3.6 m centres. The diameter of the bars varied from 16.8 cm at the base to 7.5 cm at the top. The legs were braced with horizontal and diagonal members bolted to pairs of gussets welded onto the legs. A total of 43 sections bolted together through flanges were used to form the mast. Guys were attached at the 77 m, 164 m, 251 m, 342 m and the 383 m levels. The guys were spaced at 120 degrees and the sets of the first two levels were tied to large anchor blocks 128 m out from the base while the top three levels were fixed to blocks 305 m out. The thrust block consisted of a reinforced concrete pad of triangular shape with 4.3 m sides and 1.8 m thickness mounted on top of a hexagonal reinforced pad 9.5 m across the sides and 1 m thick.

The platform atop the mast was 32 m along each face and about 4.9 m in depth. Each corner of the platform was designed to be supported by a knee-brace which connected on to the mast face. In the completed form, permanent guy ropes were to be attached to the outside corners of the platform but at the time of collapse temporary guys of 31 mm diameter were attached to the tower just below the platform.

A hoisting derrick had been installed atop the platform for erection of the antennas and their base sections. It comprised a vertical mast 36 m high and a 33.5 m boom. The vertical member was mounted on a base plate and held in position by three sets of twin guy ropes anchored to the platform. The platform was in turn stayed to the mast by six pendant guys. The boom was controlled by a 12 mm line which passed down the mast to ground to a motor driven winch

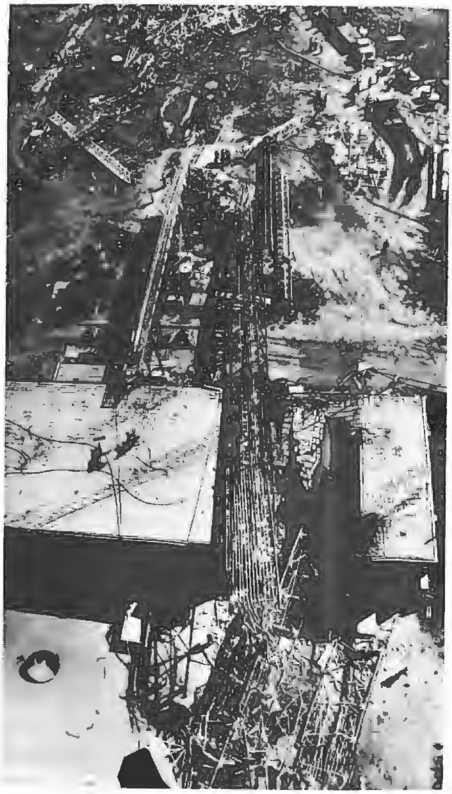

Figure 30.6 Aerial view of mast debris (Courtesy The Minneapolis Star/Tribune)

situated about 115 m from the base. The line used to lift the load was a 19 mm steel rope also powered by a winch on the ground.

The section to be lifted was one of the antenna bases which also formed the platform deck corner section. It was assembled with part of the knee brace fittings and total length was about 9 m. One end of the 7700 kg section had been lifted off the ground about 3 m when the 500 tonne mast collapsed.

Figure 30.6 shows the extent of the damage caused by the collapse. The debris from the top platform where the men were working can be seen at the top of the photograph. Just below in the light area is the base of the mast. The bottom third of the structure sliced through the transmitter building.

The Minnesota Department of Labor and Industry which carried out an investigation into the collapse commented as follows:

"Based upon the physical evidence, metallographic tests and structural analysis, the following conclusions can be drawn:

(a) The structural analysis has demonstrated that the 7.5 cm diameter southeast tower leg in Sections 2 or 3 (upper part of tower) failed by local buckling between the girts or cross bracing. The combined effects of direct compressive loads and bending moments caused a condition where the total stresses in the southeast leg columns were just under the critical buckling stress prior to the attempt to raise the antenna socket or 'lift'. As the lift progressed, additional stress was applied, until the total load exceeded the critical buckling stress, causing local buckling of the southeast leg column, and subsequent destruction of the entire tower.

(b) Based upon the metallographic tests, the following observations are noted:
   (i) There is evidence that there was no post welding heat treatment of the fillet welds, which causes a brittle condition between the weld deposited metal and the leg material.
   (ii) The welding procedures caused circumferential cracking of several leg columns due to the residual stresses of the weld fillet. Zinc from the hot zinc coating had penetrated some of these cracks. There have been discussions about the effects these circumferential cracks may have had on long term structural stability if the tower had been completed, but a thorough analysis regarding this matter was beyond the scope of this study.
   (iii) The cracks in leg columns occurred most frequently at the juncture of legs and heavy gusset welds, guy pull-off plates and the knee brace weldment.
   (iv) The chemical and mechanical properties of the material tested met the specifications or had no significant variations from the specifications limits.

Although the analysis and tests have eliminated the welds and cracks as the prime cause of the tower failure, these faults cannot be condoned or allowed in any structure.

(c) In making the structural analysis, it was determined that the temporary guy cables and other rigging cables were sized with appropriate safety factors and were adequate for the project. One area of concern was the apparent splicing of the northeast pendant stay from C face lower left on the platform to the northeast knee leg weldment of tower Section 6. This stay terminated in an open loop with a thimble and a factory installed compression ring. The mating turnbuckle attached to Section 6, had clevis pin, with cotter key, through the 'upper' jaw end. A short piece of choker cable was attached to the upper jaw end. The stay had two 'loose' cable clamps near the loop end, as if another cable had been pulled through them.

In the structural analyses, the case with both backstays, or pendant stays was considered, and it was determined that 38 % of the moment loading was restrained by the stays. In the case of only one backstay, 26 % was restrained. In either case, the greater part of the moment load was resisted by the upper tower section.

(d) The specifications for the steel in the tower legs were conflicting. On page 6 of 32777 specification T-5265-F, Rev. 3, 2-27-70, fifth paragraph quote: 'All steel members are solid and tubing will not be used. The tower leg members will be high strength steel, the type such as USS 'T-1.' All bolts will have positive locking nuts'.

Then in the material list on drawing 32777-D1J, quote:

'Tower Sections 1, 2, 3, and 4 to be 36 000 psi min. yield strength.'

'Tower Section 5 to be 50 000 psi min. yield strength. Tower Section 6–43 to be 95 00 psi min. yield strength. All steel not noted to be 36 000 psi min. yield strength.'

From the test results, it was concluded that those values on drawing 32777-D1J were the actual case in the tower design and fabrication."

EXAMPLE 30.2

Collapse of Television Mast, Cedar Rapids.

Gusty winds at Cedar Rapids, Iowa, on 10 December 1956, caused what would have been the world's fourth highest mast at the time to collapse during construction. The construction had reached the 381 m level of its intended 414 m when 85 km/h wind gusts twisted and dislodged the unguyed section at the top. The falling section hit guy ropes at lower levels, bringing about the complete collapse of the structure.

The triangular steel structure was a 15 point guyed system designed for permanent guys at the 70 m, 143 m, 221 m, 300 m and the 381 m levels. The first two guys of each leg were connected to a common foundation block and the upper three were connected to another common block located further out from the mast. Guy number one anchorage had a designed breaking strain of 41 800 kg, numbers two and three a breaking strain of 55 500 kg while four and five had a breaking strain of 70 000 kg. All temporary guys had a breaking strain of 36 400 kg.

The day prior to the collapse, the permanent guys had been fixed and tensioned

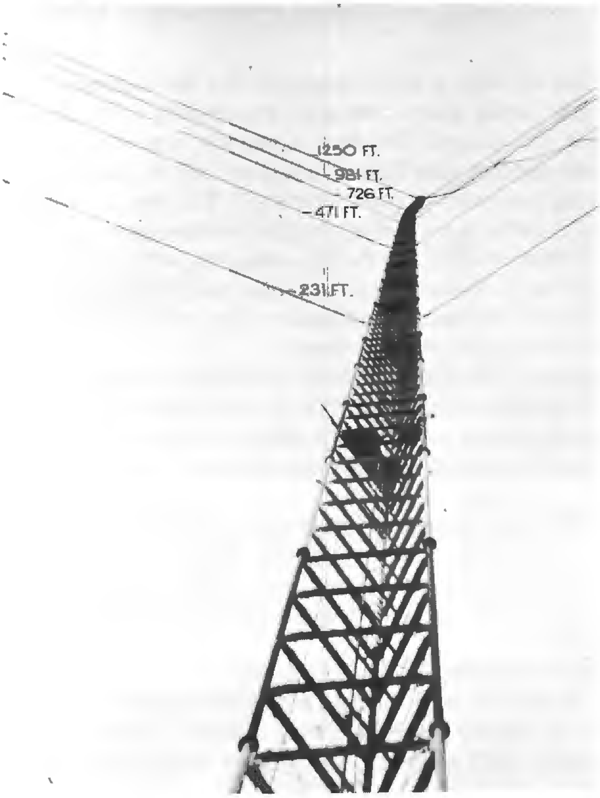

Figure 30.7 Displacement of top section of mast (Courtesy WMT)

up to the 300 m level and a temporary guy attached at about the 340 m level in accordance with the erection procedure set down. Two permanent guys of the 381 m level, numbers 57 and 55 on the erection schedule were in position at the top of the mast and anchor ends were fitted on the foundation blocks. A wind came up from the south west and the erection crew were unable to fasten these two guys to their respective anchor blocks. They were tied temporarily to the inner anchor blocks for the night.

The following morning, the third guy, number 53 was hoisted in position and fixed to the mast at its 381 m leg points. There was very little wind at the time. However, when the erection crew were in the process of pulling out guys 55 and 57 to their anchor blocks, wind gusts of 85 km/h came up from the south south west. Even though the guys were being pulled out by trucks, the crew could not get the guys to the anchor points. The more they tried, the more the top unguyed section moved about. Eventually the bending caused failure of the steel at the leg which was facing into the wind.

Just prior to the collapse, the station engineer who was standing about 80 m from the base of the mast and about midway between the anchor blocks of guys 55 and 57, observed that the mast was vertical to the fourth permanent guy, i.e., the 300 m (981 ft) level. From the fourth permanent guy to the fifth temporary guy which was attached at the 340 m (1116 ft) level, the structure was bending about half its width to the north north east. From the fifth temporary set of

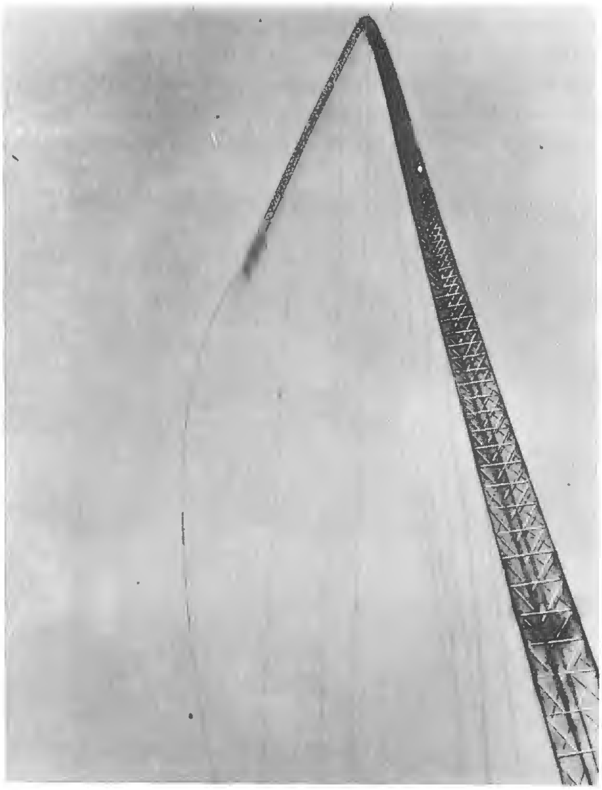

Figure 30.8 Top section falling (Courtesy WMT)

guys to the tower top the remaining portion was bending north north east, about the width of the mast. These points can be clearly seen in *Figure 30.7* in which the permanent guys have been marked-in on the photograph. The communication line to ground can be seen draped across some of the guy ropes.

During the observation period the top section maintained the off-set position, always leaning north eastward. At no time did it straighten up plumb. At times it appeared to oscillate slowly through a small arc.

From his vantage point, the engineer saw the top unguyed portion lean very far to the north north east, then begin what appeared to be a slow descent, all in one piece, seeming to be held to the mast by the leg on which temporary guy 57 was attached. This is well displayed in the touched-up photograph of *Figure 30.8*. The whole piece still attached to the mast at one point then doubled back on the face of the structure and appeared to hang there for a brief period. The mast then began to crumple in two places and seemed to fall north eastward, then the section between the third and second guys fell eastward, the second and first guy section fell eastward also, and the remaining parts fell to the north west. *Figure 30.9* is an aerial photograph of the site following the collapse, and shows the wide distribution of the damaged steelwork.

The collapse appeared to follow a pattern. The mast remained vertical until the section between guys above it fell, then the next would buckle and fall. No part of the steelwork fell a distance of more than half the mast's original height, from the base.

The falling mast severed power lines which were not restored until two days later. The building erected near the base of the mast was not damaged.

A most important lesson which one observer considers was learned from this collapse is that all guy ropes or cables, whether permanent or temporary, should be pulled out simultaneously for fastening to anchor blocks. The replacement

Figure 30.9 Mast wreckage on the site (Courtesy WMT)

mast which was identical with the one which collapsed was erected in this manner. The foreman stood beneath the mast signalling the winch operator as to tension, keeping the structure plumb throughout the guy pullout period. The erection winch had drums all powered from a single engine. Each drum could be independently controlled or any or all operated together. There were six drums altogether, being used for load lines, tag lines, ginpole and three guy drums.

A further point of interest is that the collapse of this 381 m mast was the fifth structural failure which had occurred at the station since its establishment. Two 130 m selfsupporting towers of 10 m sides at the base were blown over by a strong wind which passed through the district. They both pivoted over in one piece. Two 130 m guyed masts erected at the same location did not solve the problem. Strong winds caused the anchor points to be pulled out of the ground and the structures fell as broken sections.

In October 1973, a 600 m mast belonging to another station in Cedar Rapids collapsed while being modified for the Iowa Educational Broadcasting organisation. It was one of the tallest in the United States at the time. Five people were killed and three injured as a result of the collapse.

EXAMPLE 30.3

Collapse of 153 m Television Mast, Mt. Burr.

A 153 m guyed television mast collapsed on 4 October 1965, at Mt. Burr, South Australia, when an inner guy anchor failed during guy tensioning adjustment. The structure which cost about $90 000 had been erected to its full designed height and some of the television antenna panels had been fitted. Two transmitters were to be installed at the station and the mast was to carry two separate antenna systems. The wind velocity at the time of the collapse was estimated to be less than 16 km/h.

The falling structure caused damage to the following:

(a) Part of one of the antenna systems which had been installed above the 134 m point.
(b) Two motor vehicles.
(c) Engine generating equipment and the station building.

At the time of the collapse there were 26 people working on the site, six of whom were working inside the station transmitter building situated about 30 m from the base of the mast. The only injury sustained was by one of the erection crew who injured his ankle as he ran to safety from the falling steelwork.

The structure was a lattice steel mast with two parallel sections. The lower 130 m was a 3.8 m square cross section and the upper 19 m was 1.2 m square with a tapered section between the two parallel sections. The mast was supported by two sets of guys spaced at 120 degree intervals and attached at the 68 m and 131 m levels.

Investigations showed that the anchor failed in a brittle manner at a low nominal stress due to a combination of four factors[2].

(a) A rolling seam at the critical location of minimum cross section between the pin hole and the end of the plate.

Figure 30.10 Fractured guy anchor strap

Figure 30.11 Damaged antenna panels and steelwork

(b) The loss of ductility of the end of the plate due to the combination of shearing, pickling and galvanising.
(c) The pin hole geometry in the strap.
(d) The low notch ductility of the steel used.

If any one of these had been absent it is unlikely that the anchor straps would have failed although there is still the uncertainty as to whether the desired factor of safety on yield of the steelwork for the guy ropes would have been achieved.

Figure 30.10 shows the fractured guy anchorage which allowed release of the pin and subsequently the guy rope. The two straps were 225 mm wide by 22 mm thick, the pinhole diameter 112 mm and the centre hole 103 mm from the end of the strap.

As the mast collapsed the restraining influence of the top guys caused the structure to double back on itself at the lower guy point level. *Figure 30.11* shows the top section almost over the top of the base thrust block. The block is located immediately in front of the workmen shown in the photograph. The damaged antenna panels which had been fitted to the section above the top guy point can also be seen. The lattice steel sections lying beneath the antenna panels were used in connection with the erection of the mast.

In order to remove the inelastic stretch of the guy ropes due to the bedding down of individual wires, pretensioning was required and this was to be carried out after erection of the mast. The erector was required to raise the tension of all guys to their maximum working load, hold this tension for not less than 30 minutes, release the tension and then re-load to the maximum tension again for a further period greater than 30 minutes before setting the guy tensions to their normal design figures.

The initial and maximum tensions were:

	Initial working tension (tonf)	*Maximum working tension* (tonf)
First Level Guy	24.2	70.5
Second Level Guy	22.6	55.0

The maximum working tension of the first level guy which failed was 70.5 tonf and with the designed factor of safety of 1.5 on yield, the anchorage should have been capable of satisfactorily holding a load of 105.75 tonf. It failed when the tension in the guy reached 64 tonf.

The guy tensioning operations commenced by raising the tension in the first level guy ropes to 47 tonf per guy after which the mast was plumb. This was the maximum tension achievable with the hydraulic jacks alone. The tension in the guy ropes was then increased beyond the 47 tonf by plucking the rope in the centre through a winch and pulley system. All guy ropes were then plucked together to 64 tonf tension and as the mast was being plumbed at this tension, the support straps for the guy anchor pin carried away on one of the guys, and under the tension of the other two first level guys, the structure folded about this guy point and crashed to the ground.

In the erection of a new mast, the same anchor blocks were used and modifications carried out to all straps. The complete work was later proof tested by applying tension loads through a framework super-imposed above the concrete foundations.

EXAMPLE 30.4

Collapse of 186 m Broadcast Radiator, Spokane.

A guyed mast designed as a broadcast radiator to reach a height of 252 m collapsed at Spokane, Washington, when the structure had reached the 186 m level.

Figure 30.12 Wreckage of mast top sections (Courtesy KHQ)

The guyed mast which was being erected to replace an angle iron selfsupporting tower because it was damaged was a three sided pylon type structure constructed of round steel members, 100 mm diameter at the base. The structure was erected by bolting together 6 m lengths of all-welded section hoisted aloft by a floating jury mast.

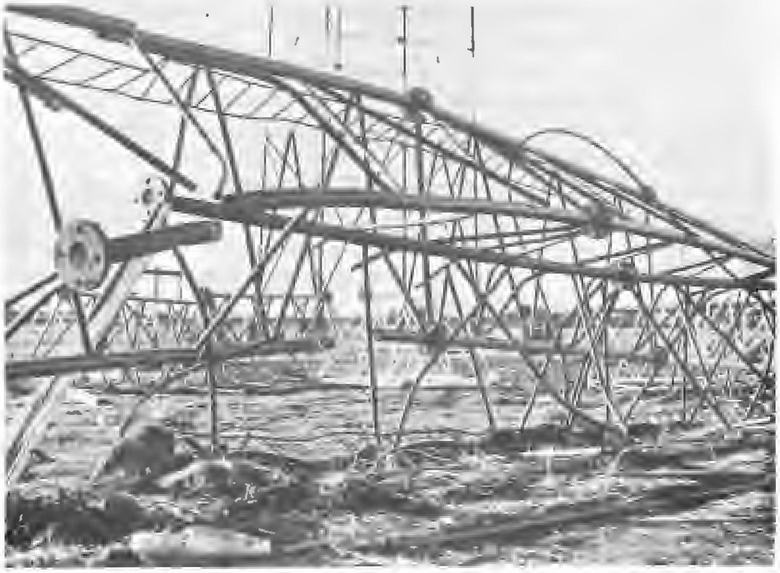

Figure 30.13 Broken solid members and tower in background (Courtesy KHQ)

When the construction had reached the 186 m level and the permanent guy ropes were being fitted, the mast crashed to the ground. Observers said that the top of the mast appeared to be pulled out of plumb by a metre or more to a point where it reached an out-of-balance condition, and fell. *Figure 30.12* shows part of the damaged steelwork on the ground after the collapse. The erection jury mast, although damaged, was thrown clear of the main wreckage and can be seen at the end of the mast top and at right angles to it.

Figure 30.13 shows the twisted wreckage near the base of the mast and alongside sections which had been laid out and ready for erection. It is interesting to observe in this, and the other photograph, that all breakages of solid members occurred at the weld points.

The large double conical base insulator assembly and its rain shield escaped major damage in the collapse. One of the 6 m sections which was standing vertically near the base ready for hauling aloft was cut through by the falling mast and every brace on one leg was sheared off at the weld.

The original radiator at the station was an 252 m insulated selfsupporting tower and was one of the tallest selfsupporting radiators in the world. The top half crashed to the ground during a severe wind storm.

Pending the installation of the new guyed mast, also 252 m in height, but which collapsed as outlined above, the bottom section of the original tower was operated as a quarter wave antenna. Fortunately, during the collapse of the mast the falling steelwork narrowly missed the tower.

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Section 4

Fires in Radio Installations

Introduction

The highest standards of reliability are required for most types of modern radio equipment and both design and operations engineers place considerable emphasis on reducing to the lowest possible level the risk of failure due to fire.

Fire hazards in radio installations arise from the use of various flammable organic materials as insulation, dielectrics and in the supporting and housing of all forms of radio and electronic equipment. Even in a well designed facility, fault conditions and environmental factors may cause the overheating of wires and cables and may result in very high temperatures. Alternatively, the breakdown of insulation material due to aging, physical damage, lightning or other factors may cause an electric arc. Any of these conditions may result in the ignition of flammable materials or the generation of explosive gases. Many fires have struck unexpectedly and with dramatic suddenness.

In considering the protection of radio equipment against fire, the nature of the materials likely to become involved has to be taken into account. The ignition of insulating material, transformer oil, capacitor wax, rubber, pitch, wooden coil formers, cotton fibre and printed circuit boards is a common occurrence. Of particular concern with radio station installations with tall masts and towers is the protection of equipment during periods of lightning strokes on or near the structures.

Some radio stations, for example multi-bearer repeater stations in a broadband microwave radio relay link carrying telephone and data traffic and television programmes, may not be of great value in isolation and it may therefore not be easy to justify a full scale fire protection system. However, linked with major trunk telephone exchanges or national broadcasting and television networks, the station assumes a value well in excess of the cost of replacing it were fire to destroy it. The community-wide repercussions which would follow its loss and the time needed to effect its replacement are factors which contribute to its true value..

Despite the care taken by staff to avoid fires, the occurrence of an actual fire can highlight the importance of care with a new realism. It is profitable to analyse some cases of fire which have occurred under the broad categories of transmitting stations, studios and fires caused by lightning.

Chapter 31

Fire Hazards

The number of fires which have occurred throughout the world at broadcast and television transmitters, studios, radiocommunication and radar stations, together with the associated financial loss, is staggering. This highlights the great need to develop sound and continuing educational programmes of fire protection and prevention.

In the United States alone, during one recent five year period which has been examined in some detail, more than 24 stations and studios were destroyed or severely damaged with loss of assets exceeding US $21 million. The situation in many other countries is of similar concern and it is evident that a great deal has yet to be done with regard to the protection of radio installations of all kinds.

Fire strikes unexpectedly and with dramatic suddenness. A radio station is no exception. In fact, large transmitters are potentially self-destructing. A great amount of radio and electrical equipment installed at transmitting stations and studios is potentially selfigniting, whether through the heating of conductors which are overloaded beyond their safe design working capacity, by arcing at contact surfaces or through insulation, or by excessive heat loss in a dielectric.

Interconnection wiring and cabling between transmitter units, control rooms, studios and rack equipment is generally installed in ducts or chases set in the floor or in overhead troughs. At many stations the ceiling space has been used for this purpose while at some television transmitting stations the wiring and cabling between units has been installed in troughs or runways suspended in crawl space beneath the floor. Because of the wide range of frequencies, signal levels and voltages necessary in most radio installations, many different types of cables are employed. They range from shielded low level studio microphone cables feeding programme input equipment to transmitter power cables which may carry megawatts at mains frequency.

The majority of interunit wiring cables have a rubber or thermoplastic insulation protected with a thermoplastic jacket, in most cases polyvinyl chloride, and because of circuit requirements, may be grouped in very large numbers. Being grouped together in a confined space, cables can present a considerable fire hazard. Although so-called selfextinguishing insulations help to retard burning, they are still a fire hazard because of the manner in which large numbers of the cables are frequently laced together.

It is interesting to observe from Fire Department reports that the causes of fire at radio installations are of common or ordinary nature. They can be grouped into electrical faults, lightning storms, heating systems, hot devices, arson or human carelessness. Combustible construction, lack of automatic fire detection devices and lack of automatic fire extinguishing facilities are responsible for a great number of heavy losses. Unfortunately, many transmitting, communications and radar stations are located in remote areas where water supplies and fire fighting facilities are often inadequate to deal with a fire.

Equipment design and environmental conditions are significant factors. Due to circuit arrangements in some installations, unlikely fault conditions caused by the fires are able to aggravate considerably the damage caused by fires. For example, in one case, fire in a cable form caused an earth to be placed on the start lead of the cubicle blower motor which started up and acted on the fire like a blacksmith's forge.

Environmental conditions due to both installation and maintenance features appear to have been major contributory factors to several fires, probably causing the equipment to be operated outside the specified limits. Some unattended transmitters involved in fires contained overload protection circuits which would normally be adequate under a staffed situation but the fires which occurred showed that a new approach is necessary in the design of protective circuits for unattended stations.

In a normal office situation, fire protection facilities are aimed at limiting the fire to a single area to give sufficient time for evacuation of personnel. This would also apply to broadcast studios located in single or multi-story buildings. For buildings containing the technical plant and equipment, the facilities are arranged to prevent fire damage to the technical installation which, because of its construction, cannot be easily removed.

Many factors determine the severity of a fire but the amount of combustible material and the areas open to the atmosphere have considerable influence. The fire load, which is the expected maximum amount of combustible material in a single fire area, varies widely with the equipment installed. In an administrative room such as the office for the Officer-in-Charge of a station or for a studio programme supervisor, the fire load would average about 20 kg/m^2. In a studio control room it would be of the order of 10 kg/m^2 but in the studio with tape cartridges, spools etc., records, programme paper material, drapes etc., it would be much higher, probably twice as much. Fire loads for transmitters, particularly large high power units with printed circuit boards, plastic cables, wax filled capacitors and oil filled chokes and transformers, can be very high.

In a typical radiocommunication repeater station, where the fire load may be about 12 kg/m^2 or less, the high ceiling height and restricted external openings will usually result in a relatively low temperature rise and a smoldering type of fire. The equipment will probably be damaged by smoke and injurious gases issuing from burning components and wire insulation materials.

Deaths caused by gas and smoke inhalation are increasing. Many of the modern synthetic polymeric materials used in radio installations produce toxic gases when burning that are not generally evolved by the more conventional cellulose type materials.

SPREAD OF FIRE

It is not easy to predict where a fire may start or the circumstances by which it may spread. However, the broad pattern which the fire will follow in its early development will be determined largely by whether the equipment, the building itself, or both, become involved initially.

Since many of the materials used in radio equipment, including incidentally paper and other stationery type documents, can be readily ignited, they can be set alight by a small high temperature source such as a relay or core winding, arcing etc. and even careless disposal of cigarette butts. In favourable circumstances and in the presence of fast air movement from air cooling blower systems, rapid flaming can be induced. Unless blowers are shut down immediately a fire commences, the effect can be disastrous. This may produce heat sufficient to lead to the ignition of building materials and other items which may not have been ignited directly.

With rack and cubicle type equipment, heat can usually rise freely and flames will tend to spread vertically in the equipment rather than horizontally. Hence if a cable form is ignited at a low level, burning will progress upwards. In the case of an enclosed cubicle the fire may be reasonably contained, except that it may spread through ductwork if there is sufficient air flow. With rack type equipment, the fire will progress towards the ceiling and may ignite overhead cabling or building ceiling materials.

The use of cubicles with equipment mounted on horizontal shelves at various levels has introduced an unusual hazardous situation. In one known case, involving a transmitter, a fire started amongst transformers, capacitors, a blower motor and miscellaneous equipment mounted in the bottom compartment. The fire burnt slowly for a considerable time, consuming a large quantity of insulation materials but the flames did not spread to the top compartment housing the radio and audio frequency units of the system. An intense layer of very hot combustible distillate accumulated in the top compartment and when the flames ultimately entered the compartment, they ignited the distillate. The result was the very fast ignition of all of the combustible contents in the top compartment.

Fire will spread at a violent rate when fed by oil or other flammable liquids from exploding capacitors, reactors, transformers and engine fuel tanks. Where a large quantity of the substance is involved, the consequences can be disastrous.

In a fire at a US Air Force radar station in Oregon in 1964, a short circuit in an oil filled transformer resulted in an explosion spreading burning oil over a large area. Excessive heat warped steel decking, cable troughs and damaged electrical equipment. The estimated damage was US $2.5 million.

FIRE PREVENTION

As always, prevention must be considered before protection. Apart from the elimination of combustibles from the immediate area, smoking should be prohibited within certain specified equipment rooms. Flammable liquids should not be allowed in rooms with operational equipment. Some organisations have a rule which even prohibits the use of any floor cleaning substances which contains flammable materials.

At practically any large radio station complex, there is seldom a time when new installation, construction, major alterations or repairs are not in progress. Many fires in these work areas have been caused by workmen igniting combustible materials with acetylene welding equipment, sparks from arc welding equipment and grinders and careless disposal of cigarettes and matches. A continuous fire watch should be maintained during all these works. At the completion of the day's work on large and small jobs, a delegated fire watcher should make a tour of the work area.

Given certain conditions of faulty wiring, flammable materials etc., potential equipment fires can be anticipated. However, real danger lies in the apathetic attitude of many workmen towards what can be predicted about fires and what can be done about fires once started.

MATERIALS

Nearly all inorganic materials used for radio engineering, such as porcelain, glass and mica, are non-combustible. Organic materials which are widely used vary in combustibility properties. Most of the organic materials, particularly those used as conductor insulation, are combustible to some degree but whether or not they produce a selfpropagating fire depends on environmental conditions, such as air supply to the equipment, temperature, the rate at which heat is lost, shape of the wiring form and several other factors.

The use of modern insulating materials, such as epoxide and polyester resins and polyvinyl chloride (p.v.c.), has enabled many components, fittings and supporting devices to be made more compact, thus saving valuable space and increasing the reliability and safety of the equipment. However, these insulators are to some extent flammable and their decomposition temperatures are not very high.

Components and materials under normal operating conditions should not emit free silicone or other deleterious materials or any other toxic or corrosive fumes, liquids or solids which could be detrimental to personnel or the operation of other plant. Any component when subject to overload current, due to circuit fault conditions, should neither interefere with the operation of, nor cause damage to, adjacent components or materials. Component construction should be of such design that they will fail-safe by not causing excessive heat or flaming.

In recent times oxygen index tests have been introduced in connection with quality control of insulation materials. Flammability test apparatus which can measure the critical oxygen index of materials to 0.1% is in use by several organisations with a special interest in this field. Some specifications for radio equipment restrict the use of materials whose oxygen indices are below a certain percentage. In the specification, the critical oxygen index is defined as the volume percentage of oxygen in a mixture of oxygen and nitrogen in which a given substance will just continue to burn.

There are many flammable substances in use on radio stations which will burn in gas mixtures with less oxygen than that normally found in air. Other substances, for example polytetrafluoroethylene (PTFE), have high oxygen indices.

Some experiences with various materials by transmitter and studio engineers are summarised as follows:

(a) With high power stations the voltage at the lead-out point to the antenna from the transmitter building or the matching hut can be very high, sometimes of the order of 200 000 V, and this can be a serious fire hazard in many situations where combustible materials are used.

At one very low frequency station, the feeder tube was taken through the centre of a 2 m square plate glass window with the glass fixed into a solid wooden framework. A short time after switching on the transmitter, the wooden framework caught fire and was badly charred at several points. To cure the trouble, the woodwork was completely covered with copper sheet and earthed with a low impedance strap. New difficulties then arose during wet weather with flashover across the surface of the glass but this trouble was cured by fitting a large copper cowl over the lead-out. The r.f. current in the conductor at this point was 465 A.

A similar problem has been experienced at some stations where mounting frames in antenna matching huts have been constructed of wood in an attempt to minimise circulating currents and coupling between coils. Although great care had been taken in the selection of well seasoned timber and the use of non-conducting fixing devices, such as permali nuts and bolts, several instances of charred timber have been reported. In some cases the problem was rectified by covering the effected woodwork with earthed copper sheet and in others by placing an earthed metal screen between the live component and the wooden support member.

Fifty years ago, when tall wooden towers were in service, one such tower was used to support a steel wire halyard at one station. A few days after commissioning, sparks from the halyard set fire to the top of the tower. Two firemen took nearly an hour to climb the structure by means of the diagonal braces and with axes they cut away the burning top to prevent the fire spreading.

(b) A television interference filter in a 250 kW high-frequency transmitter caught fire as a result of overheating of insulating materials in the unit. Because the unit was mounted within an enclosed section of a 20 cm diameter transmission line, considerable difficulty was experienced in getting to the seat of the fire. The insulating materials used in the filter were polypropylene and fibreglass.

(c) Much concern has been expressed with the use of p.v.c. by operators who have experienced fire in radio equipment. In two separate cases in one network, fire started in equipment and quickly spread to overhead and underfloor chases and to equipment in other areas via the p.v.c. cabling.

When fire does occur with p.v.c. covered cables the combined effects of hydrocholoric acid and smoke constitute a serious hazard. The decomposition of the p.v.c. goes through two stages. Gaseous hydrogen chloride is released when the temperature rises above about 200 °C and this in turn reacts with the moisture in the air or applied water to form a hydrochloric acid mist. Unfortunately the mist can be mistaken for steam by staff or fire fighters but if inhaled it acts as a severe irritant and corrosive agent to the respiratory system. At higher temperatures carbonaceous degradation of the material takes place forming dense black smoke and the p.v.c. can burst into flame.

The hydrochloric acid mist as well as being of concern to the fire fighters has a very damaging effect on equipment and components. Examinations of several cases have shown: heavily corroded transistor cans and leads, attacks on printed circuit tracks, heavily corroded aluminium fittings, and zinc plated surfaces converted to solutions of zinc chloride.

Figure 31.1 shows p.v.c. insulation burnt off the conductors during a fire in a transmitter whilst fire resistant jacketing on one cable withstood the flames, even though the inner p.v.c. insulation had been consumed.

In 1965 a US $15 million loss occurred at a space tracking station in Florida when fire resulted from breakdown in the insulation of the wiring system of the large dish antenna. The building was of fire resistant construc-

Figure 31.1 Polyvinyl chloride insulation burnt out in transmitter fire

tion but without sprinkler protection. The combustible contents were mostly the cable insulation of the 1500 or more electrical or electronic systems. Exposed steel members were so badly damaged that the building was torn down and a new structure erected.

(d) A fire occurred at one transmitting station destroying 20 cells of a 50 V battery installation. The system was used to power microwave terminal equipment, control room switching equipment and the station alarm system.

The cells in polystyrene cases ignited and burnt out during the night after shut-down of the station, when no staff were on duty. The explosion proof vents on the cells had completely disappeared but their ceramic inserts were found in the debris on top of each cell and many of the battery terminal posts and interconnecting straps had melted in the fire. There was no evidence of an internal explosion having occurred, as the polystyrene cases had not cracked, neither had the contents been violently ejected as has happened in such occurrences.

While it is desirable to keep separation between cells to an absolute minimum, in order to ensure a low impedance source, it is nevertheless undesirable to have the cell cases hard up against each other as existed in this particular installation as an acid spill can provide all the conditions necessary for a fire. Subsequent tests showed that the most probable cause of the fire was an external short circuit between terminals on top of the polystyrene cases.

Adequate separation should be provided between the cases, and maintenance procedures should stress the need to keep outsides of cases, the stands and cabinets free of acid, and dry at all times to avoid external short circuits, as well as corrosion problems.

(e) Materials used for recording tapes and polystyrene cassettes or spools are highly flammable and many cases of fire are known. The extinguishment of fire in these materials is not an easy matter because of the problem of re-ignition. Tests with several extinguishing media have led to the following conclusions:

(i) Both CO_2 and bromochlorodifluoromethane (b.c.f.) are capable of extinguishing a fire involving tapes and spools in the very early stages of the fire. However, a considerable amount of CO_2 is required on account of the re-ignition problem.

(ii) When the tape burns it leaves a residue to red hot iron oxide. The polystyrene spool decomposes to give off flammable vapours which are readily re-ignited by the hot ash of the burned tape.

(iii) When carbon tetrachloride is used, heavy brown vapours are given off. Chloride is liberated and persists for a long time. This type of extinguisher should therefore not be used for tape fires.

(iv) Water spray is effective in extinguishing tape and spool fires. It is interesting to note that where the spool or cassette material is involved in fire, it is sometimes possible, by speedy extinguishment of the fire, to salvage the tape. The reason being that the polystyrene material absorbs the heat and frequently burns with very little damage to the tape inside.

(v) High expansion foam is a very efficient type of extinguishing media for this type of fire. It causes very little damage of the tape, the residue is quickly cooled and re-ignition seldom occurs. With the very great expansion rate, water damage is negligible.

Heat of combustion figures for insulating materials commonly used in radio equipment are for some materials very high. Typical values shown in *Table 31.1* indicate the wide range of heat levels which can be generated by various materials.

Table 31.1 TYPICAL HEAT OF COMBUSTION VALUES FOR INSULATING MATERIALS

Material	*Heat of combustion (BtU/lb)*
Cotton fibre	7 200
Natural rubber	10 000
Nylon	8 750
Pitch	15 000
Polyethylene	20 500
Polystyrene	18 000
Polytetrafluoroethylene	2 200
Polyvinylchloride	9 500
Printed circuit board	18 000
Silk fibre	9 300
Transformer oil	19 350
Wooden former (pine)	8 000

It is important that equipment designers and installers be aware of the fire characteristics of the insulating materials being built into equipment. The operators should also appreciate this factor and in addition should be familiar with the flammability, flash points, vapour density and other fire characteristics of solvents and materials associated with the running and operation of station facilities. If these are not readily known, they are usually available from the manufacturer of the particular product concerned.

FURNISHINGS

As part of the general problem of materials it is common practice at many stations to ensure that furnishing do not present a hazard. Cupboards made from combustible materials for any purpose are usually not permitted. Where shift staff sleep on the premises and bunk rooms are provided, steel lockers are provided for the storage of bedding material not in use and kitchen and dining room furnishings use a maximum amount of metal equipment to reduce the fire load.

Fabrics are particular potential fire hazards at television studios and many major fires have resulted from drapes etc. coming in contact with hot lighting equipment. Typical of many in the USA, was the outbreak in studios in Southfield where US $60 000 damage occurred in 1971 when special decoration material on the stage came in contact with a hot lamp. At New Orleans, heat from an unguarded 1500 W lamp ignited cotton drapes in a local television studio. The drapes had been flame proofed less than a year prior to the fire. Damage exceeded US $40 000. A much greater loss occurred as a result of fire at Dewitt when damage exceeded US $505 000. Combustible prop materials in the studio ignited and the fire spread to the film processing room and then to other areas.

Lamps should be screened with a wire grill and kept well clear of flammable materials. Where performances call for the use of smoke bombs, fireworks, flares and the like, special precautions are necessary to protect staff, artists, the audience and the furnishings.

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Chapter 32

Organisation

MANAGEMENT INVOLVEMENT

Many radio installations have suffered heavy fire losses because management have not developed their fire protection arrangements sufficiently enough to match technical advances that have been taking place with their radio equipment. There are many recorded instances of fire losses amounting to millions of pounds of equipment and building, because inadequate fire protection had been provided. With the ever increasing range of hazardous materials continually being introduced into the radio industry by manufacturers all with varying degrees of flammability and toxicity, management must make a positive approach to deal with the problem. Certainly in the larger organisations with high capital investment, management must ensure the appointment of responsible people in the organisation to coordinate and supervise an effective fire prevention and protection programme. Management has a responsibility to ensure that there are sufficient staff adequately instructed and supported to effectively control and extinguish the types of fires which could reasonably be expected within the technical plant and buildings under their control. Also, management must be willing to consult with and accept recommendations from various authorities and organisations who have the technical knowledge and expertise.

It is of course not possible to set down a standard fire protection plan to which every administration can work. However, guide lines can be developed which, if followed, could bring the organisation into a much stronger position in the event of threat from fire. Typical guide lines include the following:

(a) There must be a direct line of responsibility for fire prevention from top station management down to the basic technician level.

(b) The organisational structure should cater for a fire executive whose task is to examine and report on planning, installation, construction, service or operation activities from the fire point of view. In many cases, the delegated fire executive is the senior or chief engineer of the station or network.

(c) A properly engineered fire protection system should be installed as part of the engineering services during construction or alterations to station buildings. This would allow full facilities to be available before staff and equipment are moved in.

Special fire protection systems for the radio equipment, such as smoke detectors in ducts, built-in CO_2 systems etc., would be installed during the course of the equipment installation.

(d) The installed fire protection system should provide education and training to alert management and staff to everyday potential hazards and a better general understanding of fire.

(e) A well prepared programme should be implemented to ensure regular checking, not only of the physical protection facilities, but also of such matters as housekeeping, because it is well known that human carelessness is one of the greatest causes of fire. The person in charge of fire control should have a complete list of all the items that should be inspected at regular intervals.

At many large stations, fire drills involving actual operation of some parts of the facilities are held on a regular basis with everybody participating. One of the major advantages of this is that both management and staff are involved, and experience has shown that keen team spirit is developed. As a consequence, individual indifference to fire hazard seldom occurs.

FIRE FIGHTING ORGANISATION

Nearly every fire begins as a small one that can generally be extinguished readily if the station staff on the spot are trained and equipped to handle it early enough. Because of the isolation of many transmitting stations from town or city centres, the early arrival of the public fire brigade is often not possible and full facilities should be provided on the station to cater for an outbreak. The public fire brigade should be relied upon only to provide back up.

At a transmitting station in Indiana, USA, damage to the extent of US $250 000 was caused in 1964 before the fire brigade brought a fire under control. The alarm was delayed because there was no telephone in the building and when the brigade did arrive water had to be pumped from a creek 400 m away.

It is generally conceded by many fire authorities that if an outbreak cannot be controlled within 20 minutes, little can be saved. There have been, of course, many situations where fire has burnt for much greater periods than 20 minutes in radio equipment without getting out of hand. For example, in an enclosed cubicle or cabinet with no forced draught, the heavy dense smoke inside and the heat radiating properties of the metal enclosures have a damping effect on the spread but in this type of smouldering situation it could hardly be considered that the fire was out of control. Many have in fact been self-extinguishing.

Even the quick arrival on the scene by experienced fire brigades is no guarantee that immediate control can be assured. The fire which destroyed the computer area of the Pentagon in 1959 was fought by 31 fire companies involving 71 applianced and 300 men and yet damage of nearly US $7 million was incurred. The cost of replacing the records destroyed could not be estimated. The area where the computers were installed was unprotected and it took the firemen more than 4 hours to bring the fire under control. The vapours produced by the burning material were so strong that cannister type masks were ineffective. Only oxygen masks were effective. Forty firemen collapsed during the battle. The cause of the fire was classified as unknown but an electrical short circuit in the equipment was given as a suspected cause.

In a large continuously staffed radio station complex, it is necessary to develop a first line of defence against fire, consisting of a selected group of workers on each shift, trained in the use of the fire extinguishing equipment provided on the station. As soon as a fire occurs, these men will immediately implement a prearranged procedure to attack the flames. Others, in the meantime, will close down plant, vacate the area and assist as directed by the fire team leader.

Fundamental considerations in a fire fighting organisation are:

(a) Immediate indication and location of a fire outbreak.
(b) Prompt initiation of action to deal with the outbreak by the rapid concentration of fire duty personnel on the scene.
(c) Efficient and effective application of appropriate measures.
(d) Evacuation from the building of those personnel not required to assist.
(e) Prompt restoration of service after the outbreak has been subdued.

It is not enough merely to install fire extinguishing devices. Such apparatus must be suitable and adequate for the hazards present, it must be properly installed and conscientiously maintained in first class working order, and responsible persons must be thoroughly educated in its underlying principles and uses. To fail to provide devices for fire control is bad enough, but it is tantamount to negligence to provide devices for fire control which cannot be used in a time of emergency because of improper maintenance or because of the ignorance of a workman in their application.

There is also the problem of unattended radio stations. Considerable progress has been made towards providing highly reliable equipment and it is now unusual for television or broadcasting stations, operating on relatively high powers to be staffed. In the event of any malfunction of equipment which may result in fire, no one is likely to be present to see this happen. A system of accurate monitoring must therefore be provided. Another point is that even though the fault may be detected, staff will not be available to implement 'first-aid' fire fighting operations, pending the arrival of the fire brigade. Consequently more attention must bc paid not only to the automatic detection of fire or smoke but to its automatic control and extinguishment.

STAFF TRAINING

As part of the normal station or studio safety training programme, attention should be given to aspects of fire protection and extinguishment. While it is highly desirable that all personnel be instructed in the practical use of fire fighting equipment, in some cases, this may not be practicable. The feasibility of this is largely dependent on the number of staff engaged. In a large studio complex, for example, staff numbers may be of the order of several hundred with many being in part time or freelance employment.

In this situation it is advisable to fully train selected permanent staff personnel in the use of all fire fighting equipment available to them and in the most expedient and efficient manner to control and extinguish the type of fire that may be experienced on the premises. In the smaller studios and at all transmitting stations, regular training programmes for all staff should be implemented.

Points to be taken into consideration in developing a training programme for transmitting stations should include the following:

(a) Every workman on the station should know the location of extinguishers and all associated equipment.

(b) All staff should know how to operate properly each of the common types of extinguishers.
(c) Every workman should know the proper extinguisher to use on each class of fire and the limitations for each type.
(d) Everybody should be thoroughly familiar with the procedure to be followed in the event of fire.
(e) Every workman employed in a particular area, whether a member of the technical, cleaning, labouring or office staff, should be knowledgable in the emergency methods required to shut down plant or disconnect power to the area should fire occur.
(f) Personnel should be trained in the use of the extinguishers by a competent Fire Officer. The annual recharge and inspection time is often taken as a suitable period when this instruction is given with individual workmen participating in the extinguishment of practice fires.

BOMB THREAT

Explosive and incendiary devices have recently become powerful weapons in the hands of terrorists and have been of considerable concern to radio station managers. Studios in particular have been prime targets resulting in extensive damage from explosion or fire. Antennas have also been targets with high explosives being attached to base insulators and guy anchors.

Critical bomb locations in buildings used for studio purposes include:

(a) Air conditioning ducts
(b) Cable ducts and chases
(c) Announcers control desk
(d) Switch room
(e) Speaker cabinets
(f) Closets and storerooms
(g) Behind studio drapes
(h) Cable distribution room
(i) Tape and record libraries
(j) Foyer

At transmitting stations explosives and incendiary devices have been placed:

(a) Alongside the electric power sub station.
(b) Inside the transmitter cubicle by inserting the device through the air exhaust duct.
(c) In the power house near the switchboard.
(d) Inside the manhole through which cable carrying the programme entered the building.
(e) On or near the base insulator and guy anchors of lattice steel radiators.
(f) Near the antenna matching hut at the base of the mast.

Staff should be suitably instructed in the bomb threat situation so that they are fully prepared to meet all eventualities. An Emergency Control Officer should be nominated to provide co-ordination and decision making for all emergency situations where large numbers of staff are employed.

The Emergency Control Officer's primary responsibility should be to effectively control and direct all phases of activity relating to a bomb threat and subsequent search, evaluation and decision on the course of action in consultation with organisations or experts as considered appropriate to the circumstances.

Typical of bomb threat situations is that experienced by the British Post Office in control of the London Post Office Tower, a nerve centre for national and international communications.

The main engineering function of the 176 m high tower is to handle 28 television links and 40 000 telephone channels which pass through its equipment. The Television Network Centre performs an important function. It acts as the point of control for the extensive line and radio transmission network which serves the requirements of the British Broadcasting Corporation and the Independant Broadcasting Authority throughout the country. It also serves these organisations when overseas television transmissions are fed into the country via Eurovision or satellite. The building is a great tourist attraction. In the first five and a half years some 4.6 million visitors were taken to observation galleries and the Tower restaurant.

On 31 October 1971, a bomb blast removed one section of the outer wall of floor 31 and severed domestic water supplies to the upper floors. Within minutes of the explosion police and fire brigade services were on the scene. One television link and an international telephony link of 1800 channels were put out of service for about six hours.

Security at the Tower has been tightened and observation galleries have been closed to the public. Stringent checking is carried out of people in and out of the building, including patrons of the restaurant as well as dealing with bomb threats. In the five year period 1971-1976, security staff had to deal with more than 2000 bomb threats. Four had been received in one day. The bomb incident, as might be expected, has had a very real effect on the administration of the whole Tower complex.

In a further example of the detonation of an explosive device on premises used for radio purposes, an intruder fired a charge of high explosives at the base of a 230 m high dual frequency broadcast radiator at Preston, New South Wales, at 1.30 a.m. on 12 November 1969 destroying the main base insulator and causing the 50 tonne mast to drop about 60 cm.

The explosion resulted in considerable damage including the following:

(a) The large porcelain base insulator was completely demolished and very little of the porcelain remained near the base area.
(b) Part of the 45 cm diameter 5 cm thick steel jacking plate was hurled a distance of 50 m from the mast after punching a hole through the safety fence.
(c) The mast, in dropping 60 cm, caused severe distortion of the steel members of the lower section of the structure.
(d) Seventeen guy insulators were damaged by shock impulses transmitted by the structure when it dropped.
(e) The antenna matching equipment building was extensively damaged. Part of the roof was blown off and a section of the wall demolished. The dual frequency matching equipment inside the building was also damaged. No fire resulted. The two 50 kW transmitters were off-air at the time of the explosion.

EQUIPMENT REQUIRED

Two types of equipment are used to extinguish and control fires. There is the fixed type which includes automatic sprinklers, hydrants, hoses and special pipe systems for carbon dioxide, foam or dry chemicals and the portable equipment which often supplements the fixed equipment.

Fire extinguishing facilities should meet the following conditions:

(a) They should be reliable and efficient in operation.
(b) The operation of the facility should not be a danger to human life.
(c) The extinguishing medium should be suitable for the type of fire likely to occur in the area protected taking into account the nature of the equipment (for example, high voltage apparatus).
(d) There should be minimum damage to the equipment being protected following operation of the extinguishing device.
(e) It should require minimum space in equipment areas.
(f) There should be local and remote warning signals that the protection system has operated.

The selection of the equipment for adequate fire protection depends wholly on the local conditions involved. For a small radio station, hand extinguishers may be sufficient. Larger stations may require a standpipe or sprinkler system in addition to many portable extinguishers. Hazardous locations, such as transformer vaults of high power transmitting stations, may require the installation of elaborate and specialised extinguishing systems. Even with such systems, however, hand extinguishers should also be provided. Hand extinguishers may often quench

Figure 32.1 Forest fire approaching three television stations (Courtesy The Advertiser)

Figure 32.2 Typical fire fighting unit for dealing with station grass fires

a small fire in its initial stages without having to utilise the resources of the larger apparatus.

It is not unusual for a large high frequency broadcasting station to be erected on a site comprising 250 ha or more and the control of grass fires is often a problem, particularly during hot dry weather. Television, frequency modulation and radio relay stations are in many cases erected on mountain tops surrounded by large areas of forest. When fire breaks out it may be a difficult problem to control it. The station site should be cleared of uncontrolled vegetation for a distance of at least 30 m from buildings and any vegetation planted for beautification purposes should be kept under control with all shrubs being located well clear of the building, towers and tanks. Trees on the station property should be kept to a minimum and those left standing should be located in such a position that should they fall towards the building there will remain a clear space of at least 5m between the tree and the building. *Figure 32.1* shows a forest fire burning on a wide front and approaching three television stations. A well equipped emergency fire service is essential to cater with this situation.

Not only do grass and forest fires often cause damage to plant and buildings but at high power installations the smoke laden atmosphere can cause a flashover of open wire transmission lines, antennas and other high voltage equipment. Motorised fire extinguishing apparatus is provided for dealing with paddock fires at several large broadcasting stations. The equipment is mounted on a standard truck chassis and includes water tanks, pump hoses, ladders, hand extinguishers, knapsacks, hand beaters and implements such as shovels, rakes and axes. Regular inspections should be made to determine that extinguishers and other fire fighting plant and equipment are in their designated places, are readily available and ready for use. All equipment and plant should be examined at least once a year to ensure that they are in first class operating condition. *Figure 32.2* shows a unit provided at one station being put through a regular practice routine.

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Chapter 33

Equipment and Buildings

DESIGN CONSIDERATIONS

Modern radio equipment is, as a general rule, well engineered with excellent in-built protective circuits and chances of fire outbreak are not great. But fires do occur, and the cost of equipment replacement and loss of revenue-producing time can be considerable. In some cases it would be extremely difficult to measure the effect in terms of money. During one of the Apollo flights a fire occurred in a transmitter of a space tracking station. Fortunately, at the time of the fire, which put one of the two transmitters at the station out of action, the flight was not at a critical stage and the station managed to carry on its role with only one transmitter. Replacement parts flown in allowed the second transmitter to be brought back in service in time for the critical lunar landing operation.

A question which might well be asked of, say, a transmitter installation, is, 'What is the exposure to the transmitter?' Exposure to destruction of the unit can come from within the transmitter cabinet or cubicle itself, from within the room housing the transmitter, from the immediate area around the transmitter room, for example, the transformer vault, and from outside the transmitter building itself. This exposure has to be properly evaluated and controlled.

Nearly all transmitter and many other radio installations require forced air cooling for the proper operation of the equipment. Circulating fans and filters are provided for this purpose. Thermal detection devices are fitted in the larger installations and set to operate the control circuit to shut down the equipment and sound an alarm in the event of a high temperature arising from failure of the air supply, or other cause. However, these thermal devices often form part of the normal transmitter equipment and are inoperative when the transmitter is not energised and therefore should not be considered as a substitute for an automatic fire alarm system in the transmitter area.

No radio station has yet been constructed of components and equipment which are completely non-combustible. Practically all radio equipment wiring uses insulation materials which are combustible to some degree, given the right conditions. Other fire risk components which may be found in equipment include insulation boards, fan and pump motors, oil filled components, resistors, capacitors, meters and printed circuit boards. Although the components may have varying degrees of combustibility, fire can spread quickly once started particularly inside a unit or cubicle where the working temperature may be normally at a high level. Even the cubicle metal work is not immune, as seen in *Figure 33.1*. Part of the sheet steel and aluminium were consumed in this transmitter fire.

Much progress has been made in recent years in developing insulation materials with a low surface spread of flame. A typical example is glass reinforced plastic

Figure 33.1 Sheet metalwork damaged by fire

material widely used as cladding panels to prevent ice accumulation on television antenna panels. Lightning strokes and sparking from poor bonding practice of metal parts has resulted in fires seriously damaging these panels. Fire retardant fillers are effective but they have an adverse effect on the strength of the material. Also, the resin material is more difficult to handle. A new development which was used with the 330 m Emley Moor tower, Yorkshire, employed a new intumescent coating which was applied to the inner face of the panels. The coating had been developed specifically for use with glass fibre reinforced plastics.

Contrary to popular belief, very few fires appear to have been caused by actual overloading of conductors. In practice it is not easy to cause ignition by overloading a conductor. Tests have shown that in many cases a sustained current of more than five times the rated current capacity of the cable is necessary to create conditions where ignition will occur. Ignition caused by overloading of circuits is thus avoidable if the cable conductor is protected by a correctly rated device, such as fuse or circuit breaker.

Inspection of many fires by experts has shown that damage to the installation either by moisture, heat, wax from components, brittle or perished insulation, corrosion or mechanical causes was the real cause of the greatest majority of cable and wire fires.

In cases where there is a deterioration of the insulation material, it could be expected that a sizeable earth leakage current would be produced before conditions, even leading to the ignition state, were even approached. An examination of some power circuits of transmitters which caught fire showed that many of the fires attributed to this cause could have been prevented if earth leakage circuit breakers had been installed in the equipment.

The most important thing is to design equipment so that the possibility of fires will be reduced to a minimum. Next in importance is to be able to extinguish such fires that do occur while they are in their early stages. Fortunately there is now a wide range of sophisticated electrical and electronic equipment available in the fire detection field, including not only fixed temperature and rate-of-rise thermal devices, but also devices which are based on atomic radiation, infra-red, ultra-violet and light scattering principles.

BUILDINGS

Equipment buildings provided for radio engineering purposes range from a small blockhouse, hut or shelter type structure to a complex of buildings for a large transmitting centre. In the case of broadcasting sound or television studios it may even be a multi-storey building located in a city business centre.

Irrespective of the type of building, experience has shown that fire can start in so many ways and spread under such widely different circumstances that complete immunity from fire is almost impossible even with a well engineered installation. Although buildings constructed of non-combustible materials do not constitute a fire hazard, and may even successfully withstand internal fire to prevent spread to other buildings or areas, there is much that these buildings cannot be expected to do. They cannot, for example,

(a) Prevent a fire from commencing in the equipment installed within the building.
(b) Detect overheating of components, smoke or fire.
(c) Control the spread of fire within the equipment areas without the provision of adequate internal fire barriers.
(d) Prevent the entry of fire from other rooms, adjacent buildings or other external sources such as bush fires without adequate built-in facilities.
(e) Ensure the safe escape of staff who may be working in the building at the time of fire outbreak.
(f) Necessarily resist forces from exploding oil filled transformers, gas filled capacitors, welding gas bottles etc. during a fire.

Figure 33.2 shows the extensive damage which occurred to the transmitter building of one station following a fire. The building comprised cavity brick external walls, single brick partitions, concrete floor throughout, timber roof structure, corrugated asbestos cement roofing, and caneite and fibro ceilings. Reports indicated that the fire started in the ceiling area some hours after station shut-down and completely destroyed the transmitting equipment and power generating plant.

It would be extremely difficult to attempt to express fire hazard for all types of radio installations and buildings by a single index. There appears to be no alternative but to assess the fire hazards for each set of conditions encountered and then to minimize the risks. In many situations the designer may be severely

Figure 33.2 Damaged transmitting station building

limited in choice, but where he has alternatives, decisions should be made with regard to experience and best accepted practices.

The design of the building will be influenced considerably by the type of equipment to be installed, also the location and the local material availability situation. However, there are certain parameters of construction which should be used as constraints. These are

(a) For an unattended transmitting station situated in an area considered to be of low fire risk from environmental hazards the main equipment building should generally be of brick or metal construction with steel or metal roofing. Materials should be rated not less than 'fire retardant'.

(b) For an unattended transmitting station situated in an area considered to be of high fire risk from environmental hazards the main building should be constructed exclusively from non-combustible materials throughout and generally be of windowless design.

(c) Attended stations where fire protection facilities are provided should be constructed in accordance with local building regulations applicable to the area but using materials rated not less than 'fire retardant'.

(d) Where an emergency power generating plant is to be provided under the same roof as the main building, access to and from the generating room should be via fire doors with a minimum one hour fire resistance rating. The separating wall should be of material fire rated not less than that employed for the external walls of the building.

Where the generating set is located in a separate building, materials used in the construction should be not less than 'fire retardant' and the building should be separated from the main building by a distance of at least 3 m.

DUCTS AND CHASES

One of the major fire hazards at radio stations is that of electric power cabling either under the floor or above the ceiling. It was found, in a number of cases, that the temperature rise of cables within ducts or chases was greater than had been assumed, probably due to the fact that some of the modern electrical insulating materials also have rather better heat insulating properties than those used previously, so that a heat 'build-up' takes place in the cable duct or chase. As a result of known fire outbreaks in ducts, some engineers have installed smoke detectors throughout the building duct and chase distribution system.

Ducts are frequently run from room to room and floor to floor without any fire stopping facilities being provided. In these situations, a fire in the duct or in the room could spread by way of the duct to involve other rooms on the same floor and also on other floors. The installation of fire stopping facilities to retard the spread of fire and smoke has been found to be a wise investment. The relation between the fire stopping installation at opening and its effectiveness in retarding the spread of fire depends on the material used.

Very few transmitter or studio installations lend themselves to permanent sealing of duct and chase openings by using cement mortar to preserve the integrity of the floor or wall. One method widely practised is to use a flexible pillow type mass consisting of a fire retardant bag containing non-combustible mineral wool. The bag is pressure fitted into the opening to tightly pack the space around the cables and has been found effective in the retardation of fire, smoke and fumes. The bag is easily removed when work has to be done in the duct and upon completion of the work, the bag is reinserted as tightly as possible for a firm fit. Loose mineral wool is also sometimes used but this is subject to dislodgement from the opening in which it is inserted. Approved bags have the same fire rating as asbestos. Tests have shown that they will not allow fire to pass through an opening for 60 minutes at about 1000°C. This provides a chance to retard the fire during the critical early stages and minimise fire loss and the associated problems.

Another method which enables easy extension of duct cables as required, and at the same time prevents fire or smoke spreading, is to use asbestos dicalcium silicate plates which are easily worked for drilling and cutting. A fire resistive caulking material of incombustible inorganic fibre is used to fill gaps between cables to prevent smoke spreading. For a typical installation the asbestos dicalcium silicate plates are about 40 mm thick. This has a two hour fire rating.

Experience has shown that the cost of service restoration following a fire in a duct is influenced considerably by the manpower effort required in removing water, drying out and cleaning up. In some cases where only relatively minor damage was caused by the actual fire, the cost of restoration was nearly as great as the original capital cost of the equipment. At one combined studio-transmitter building installation, a fire occurred in the studio carpet, presumably from a dropped cigarette butt, and a cleaner on noticing the small fire, attacked it with the hose of a high pressure fire hydrant installed outside the building. The water flooded the studio, filled up underfloor ducts and chases and flowed down the ducts into the transmitter room which was at a lower level. The water entered the blower intake and was thrown throughout the transmitter, fracturing glass tubes and causing a fire to start in the bias contactor. Fortunately, the transmitter shut down and the fire died out, but the labour cost alone of restoration exceeded the original transmitter installation cost. Many cables, connectors and distribution boxes in the ducts and chases were affected by the water and could not be dried out *in situ*.

Engineers at many stations, aware of these factors, have graded equipment room floors to suitable waste outlets to minimise water flow into ducts and chases. This, of course, is highly desirable in the case of transmitter rooms where water or vapour cooled tubes are used because of the danger of pipe leaks. There is also the possibility of failure of the container of an oil filled component and the resultant spread of oil. For components with a capacity of less than 20 litres the component can be mounted in a receptacle of suitable size and shape to contain the oil. However for components with greater capacities controlled drainage to the building exterior is necessary.

Where underfloor ducts and chases are essential, it is common practice to install all wiring, junction boxes etc. on the side walls and leave the bottom clear. At one large station, cables are laid on an iron grid suspended above the chase floor which has a 1 in 30 grade to a waste outlet.

UNDERFLOOR CABLING

In transmitter and studio installations where large numbers of operating consoles or desks are involved, hundreds of interconnecting cable forms may be required. To meet specific needs and to give maximum flexibility, many of these equipment rooms are constructed on a raised floor. When considering the fire protection of the cabling installed in the space beneath the floor, generally 35 to 45 cm, consideration must be given to the grouping of the cables, the in-built factor of safety, care in handling during installation, ventilation to allow removal of I^2R losses, the combustibility of the cables, the combustibility of termination boxes and the means of access to the cables for fire fighting purposes.

Where practicable, the flooring should be constructed of metal decking type materials but where the use of combustible materials, such as wood, cannot be avoided the timber should be impregnated or coated with an approved fire retardant treatment.

Because underfloor spaces are high hazard areas, they should be properly protected. Protection measures should

(a) Raise an alarm immediately a fire occurs.
(b) Take immediate action automatically to extinguish the fire.
(c) Allow for the fire to be fought by normal means.
(d) Shut-down the equipment concerned.

The installation of ionisation type detectors is the most common method of detecting fires in these situations. In many installations where very large areas are involved, the area is broken up into zones, separated by non-combustible bulkheads and the fire alarm panel so wired that it will indicate the specific areas where the fire has occurred.

The decision as to whether or not to incorporate a fixed automatic carbon dioxide or other type system depends on the importance of the installation, the hazard risk of the equipment and the particular area where the equipment is installed.

STORAGE OF FLAMMABLE LIQUIDS

The quantities of flammable liquids held on a station should be kept to a minimum, preferably in accordance with the normal day-to-day requirements. However for a very big establishment in an isolated situation, it may be necessary to keep large supplies of transformer oils, lubricating oils etc. on hand to meet either emergency situations or normal maintenance requirements. Individual transformers associated with high power transmitters may have an oil capacity of up to 4500 litres and whilst it would not be normal to hold this quantity, about six 200 litre drums would be typical for an isolated three-six transmitter installation. This would represent only a fraction of the total oil contained in radio vault equipment, excluding electric power substation plant.

Where the quantity of flammable liquids is comparatively small, say less than 200 litres total, and is contained in drums or other portable closed containers, the liquids should be stored in a specially constructed steel storage cabinet. Each container in the cabinet should be limited to about 20 litres capacity. Where a large quantity is held, an isolated fire resistant store similar to *Figure 33.3* is essential. Particular care is necessary in the bonding and earthing of all metal parts of the building to prevent sparking from induced radio frequency voltages. Bonding and earthing arrangements, including an earth wiper on the metal door can be seen in the photograph. The empty drums outside the building are waiting shipment back to the supplier for refilling..

The storage of fuel for engine generating sets and station vehicles should be in accordance with well documented standard procedures. Where high radio frequency field strengths occur special attention will be required to bonding and earthing arrangements for tanks, piping, engine sets and switchboards.

Although the fire record of diesel engine sets at radio stations is reasonably

Figure 33.3 Flammable liquid store

Figure 33.4 Temporary distillate storage tank

good, even at those stations where continuous local generation of power is involved, there have been sufficient fire outbreaks to indicate that the fire potential should not be under-rated. Some fires have been caused by failure of the electrical equipment but the majority have been associated with diesel fuel and lubricating oil. *Figure 33.4* shows a temporary tank installation to provide for continuous generation of power when the commercial mains supply was interrupted for a long period at one station when a cyclone seriously damaged a 66 kV feeder line.

The use of the daily service tank for fuel oil minimises the risk of large quantities of oil being dumped into the engine room in the event of a major pipe fracture. However, experience has shown that in some cases there is sufficient oil in the daily service tank to cause complete destruction of plant and building. The

Figure 33.5 Damage in power generating room

photograph of *Figure 33.5* illustrates the extent of damage at one station when the daily service tank ignited and exploded.

It is not generally recognised that lubricating oil used with these engines can be ignited at temperatures well below the flash point. The reason for this is that even high quality type oil contains some light fractions which can be released. The release of these fractions allows them to be ignited at temperatures well below the ignition point of the oil, and the fire which results can flash back to the oil itself.

In the storage of gasoline associated with vehicle service needs, great care must be exercised, particularly at high power stations, to ensure that the system is thoroughly bonded and tied to a low impedance earth system. Vehicles being serviced should be earthed to a specially provided lug and, as a general rule, insulated filling hoses should be used to minimise the risk of sparking.

The problems associated with gasoline storage and refuelling operations in a high field strength environment have been the subject of much research work. Laboratory tests have shown that given the right conditions, ignition of fuel vapours can take place. For ignition by radio frequency discharge the source of power is usually provided by an antenna configuration which in the practical situation can be metallic objects such as wiring, pipes, tools, nozzles etc. The setting up of this antenna configuration whereby an opening gap is formed across which a discharge takes place need only take place for a fraction of a second in order to cause ignition of a flammable mixture.

The handling of gasoline with a properly engineered bowser system does not generally produce a flammable atmosphere except close to the fuel storage tank vents, the open fuel tank inlets during vehicle refuelling or near spilled gasoline. Nevertheless, effort should be directed towards the elimination of all conditions conducive to an explosion during fuel handling operations. These include close attention to bonding and earthing of the bowser installation, earthing of vehicles during refuelling operations, the provision of insulated hose nozzles and receptacles to provide non-metal-to-metal contact between bowser, and vehicle, and in some cases, the use of electrical insulation coatings on areas immediately adjacent to refuelling receptacles and vents. It is important that all earthing links and systems be of low impedance at the operating radio frequencies. It is not sufficient to provide simply for dissipation of static electricity.

Normal practice by some Administrations is to provide a commercially available Electronic Ground Indicator unit. The device has an earthing lead which must be connected to the body of the vehicle. The capacitance to ground of the vehicle balances an alternating current bridge circuit which then provides an interlock enabling the bowser pump to operate. The station vehicles are fitted with 5 cm long copper lugs to the metal work of the body to ensure positive connection of the grounding lead using a Mueller clip.

All conducting materials in the immediate vicinity which are mounted above ground level should be bonded and tied to a low impedance earth at intervals not exceeding 10 m in the case of high power high frequency broadcast stations. Where the bowser is located at a distance exceeding 500 m from the antenna of a medium frequency or high frequency station operating with a maximum effective radiated power up to 500 kW in the direction of the bowser the hazard to flammable material is substantially reduced. The design and configuration of the earthing requirements would be a matter of engineering judgment.

In the case of high power pulsed radiations, the potential power which could be extracted from each pulse is large compared with the minimum ignition energies for hazardous matter. The safe distance for bowser locations are therefore much greater than for the continuous wave broadcasting situation. For a typical radar establishment operating in the 1 to 2 GHz band and with a maximum transmitted power capability of 6 MW a safe distance would be about 2000 m along the beam path.

A fire which occurred at one station on an engine driven mobile crane using gasoline fuel highlights the dangerous situation which can exist with these machines on high frequency broadcasting stations. Some stations also employ fixed crane installations for handling heavy materials at the transmitter building and in the power house.

The crane which was damaged by fire when the fuel tank ignited was mounted on rubber tyres and employed a telescopic jib which at the time was extended out to the 10 m point. The steel lifting rope was attached to the centre of a 3 m length of steel mast leg and just as the leg was lifted about 2 m off the ground the operator heard a sound like an arc. The fuel tank immediately ignited. The machine had been engaged in shifting steelwork from a position about 50 m behind a curtain antenna powered by a 250 kW transmitter and a subsequent examination of the situation revealed that at the position of the lift where the spark occurred the structure together with its load was in a condition electrically resonant with the operating frequency of the transmitter by virtue of its halfwave length configuration.

DOMESTIC TYPE RADIO AND TELEVISION EQUIPMENT

Statistics of fires in domestic type appliances, taken over a ten year period, indicate that the combined total of radio and television set fires is third highest in a list of 13 electrical appliances. They contribute to about 12% of the fires. Only cooking and space heating appliances have higher figures.

From reports of several hundred known outbreaks of fire, about 60% were confined to the equipment, 15% spread beyond the equipment and damaged contents of the room wherein located, and 24% resulted in damage to both room contents and the building. In some cases even death resulted. In one particular case in June 1978, two baby sisters, aged 3½ months and 18 months, died when a colour television set exploded and set fire to a house in the country about 70 km from Tamworth, NSW. The fire engulfed the timber homestead within minutes. It burnt to the ground before the local bushfire brigade could muster.

In a break-up of the figures, the number of fires in mains operated television sets is nearly twice as great as that in radio sets. Power transformers appear to be the source of the majority of fires in radio sets whilst the horizontal output (flyback) transformer contributed to nearly 30% of fires in television sets. Another factor has been inadequate or breakdown of insulation of wires carrying high voltages which resulted in arcing. Other hazard areas include

(a) Uninsulated wiring and busbars between high voltage components.
(b) Paper based phenolic circuit boards.
(c) Inadequate separation between power transformers and components made of combustible materials.
(d) Faulty a.c.. switches.

(e) Faulty deflection yokes surrounding cathode ray tubes.
(f) Faulty automatic tuning devices.

In recent years the possibility of fire occurring in television and radio receivers has fallen sharply. Improvements in materials used for insulation of components have substantially reduced the risk of fire. Also the earlier equipment used tubes which generated a considerable amount of heat but with the introduction of solid state circuitry in later models the heat problem has fallen to a very low level.

PROTECTION REQUIREMENTS

Engineers have a responsibility to assess the fire risk and to design, specify, organise and act within reason to minimise it. The general requirements for fire protection, applicable to most large radio stations, may be summarised as follows:

(a) Provide non-combustible type construction for equipment buildings.
(b) Seal openings between equipment rooms, floors, ceilings and walls through which interconnecting wires, cables and ducts pass.
(c) Provide adequate fire barrier construction between transmitters and transformer vaults or any other areas containing large quantities of flammable liquids.
(d) Suitably lag steam pipes of tube vapour cooling systems where they pass through or near combustible materials.
(e) Store all combustible materials, including paper and the like associated with office services, in enclosed metal cabinets in rooms separated from the station equipment, or if this is not practicable, at a safe distance from equipment and from possible sources of ignition.
(f) Provide steel shelving in bin store rooms and keep the storage of combustible spare parts to a minimum.
(g) Provide power plant installation, including fuel supplies, in accordance with standard practices laid down for these installations.
(h) Provide a properly engineered fire protection system to suit the particular needs of the complete station. This to include an electrically supervised automatic fire detection system with alarms located where prompt response will be assured.
(i) Install automatic fire detecting wires or other appropriate devices in ceilings, under floors, in chases and other situations where massed cabling is isolated from the protected areas.
(j) Employ, where practicable, cables having fire retardant types of insulation or fire retardant outer jackets. Flame proofing of cables by using fire retardant paints and similar substances has not generally given satisfactory performance. However, a chemical resistant to flame which can be applied as a paint has recently become available as a spin off from space programme work. The substance is a co-polymer containing two fluorides that become more resistant to heat and deterioration as temperature rises. It has been reported that the substance can fireproof materials against temperatures up to 1200°C in a very high oxygen environment.

(k) Protect equipment from lightning damage with suitable discharge devices. This should include protection from high voltages, resulting from lightning on antennas, transmission lines, power mains, programme and telephone cable circuits.

(l) Protect equipment against surges in power mains due to switching etc.

(m) Fit pilot lamps to general purpose power outlets used for portable tools and soldering irons.

(n) Provide automatic controls to shut down air conditioning and ventilation systems and to close dampers, in the event of operation of fire detecting devices.

(o) Use non-combustible filters, preferably dry fibre glass types, for all air inlet systems, including transmitter cooling systems, building ventilation and air conditioning systems.

(p) Provide ample supply of portable extinguishers throughout the station, taking into consideration the particular class of materials in the various areas.

(q) Store tarpaulins or water proof covers at strategic locations to protect equipment from water damage.

(r) Ensure that all workmen employed on the station, including cleaners and office staff, are trained in the proper use of fire extinguishers and in other fire emergency procedures.

(s) Provide, for the station staff, adequate safe egress from buildings.

(t) Ensure that dead grass and other combustibles are moved from the antenna farm area and from around fences and buildings and also that fire breaks are properly maintained. *Figure 33.6* shows one station where tall dry grass had created a potential fire hazard situation.

Figure 33.6 Tall dry grass around antenna mast

(u) Employ insulation materials having low oxygen indicies. The oxygen ratio of air is 0.21 and the more the oxygen index exceeds this figure the more difficult is the combustion in air of the particular material. Typical figures for widely used materials are: polyethylene 0.17, polystyrene 0.18, polyvinyl chloride 0.45 and polytetrafluoroethylene 0.95.

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Chapter 34

Detection and Facilities

Fire protection facilities, such as automatic alarms, CO_2 and sprinkler systems, fire hydrants, and other such permanent facilities required for a radio station, should be installed as part of the initial engineering services of the building. Portable applicances, indicating signs and baseboards can then be placed in position immediately access is given to the building, and before installation and operation activities commence.

The location of fire hydrants and portable appliances is important and every care should be taken to ensure that they are placed in prominent positions and are readily accessible. Portable extinguishers should be conveniently located, but not so close to the equipment that they are intended to protect as to make it difficult to gain access to them in the event of fire. CO_2, sprinkler or other automatic extinguishing systems should be located in accordance with recommendations laid down by fire underwriters for the particular system.

The fire hazard from modern radio equipment is not usually great, but for the high power transmitters where high voltages and currents are used, the working temperatures of equipment within cubicles may often be high, and breakdown of insulation can occur. The solution, of course, would be to use only those materials which are non-combustible, but for various reasons such as inferior performance, difficulty of fabrication or high cost of non-combustible materials, this is not yet regarded as a practical possibility. Oil filled equipment is used to some extent in almost all large transmitters and fire precautionary measures are sometimes based more on preventing excessive damage to equipment than on protecting the building against the spread of fire from within.

With regard to components used in the equipment, many components will malfunction, if subjected to prolonged temperatures above about 55°C. Some types of transistors will be permanently damaged at temperatures above about 80°C, and temperatures above 150°C may also result in widespread damage and in some cases with complete replacement of whole units being required.

In the case of transmitters with steel cubicles, a fire which might originate within a cubicle would generally be restricted to that cubicle but early indication of approaching breakdown by means of a suitable detector may result in reduced damage by allowing early action to be taken and so facilitate quick restoration of service.

For most types of rack type equipment, including radio link equipment, the fire hazard is restricted to the possible ignition of small quantities of transformer insulation, capacitor dielectric, resistors or small quantities of fabric insulated cable. Oil filled components are seldom used and sections of the equipment are segregated by the use of metal covers. The apparatus as a general rule is well protected electrically, and fires are infrequent within the equipment. Heat damage rarely extends from one section of enclosed equipment to the next. The risk to the building of fire commencing in this type of equipment is not very great.

Fires have also occurred in some unusual places such as on steel masts and towers. It was recently reported that fire broke out in the electrical equipment hauling the lift of a 300 m television tower. Firemen had to climb the steps to attack flames and thick smoke which billowed from the equipment at the stop landing. In another unusual case, fire broke out in the high voltage sectionalising coil of a medium frequency radiator when a bird's nest ignited. Fires have also been reported in fibreglass and Perspex ice shields over television antennas as a result of lightning strokes, faulty electrical wiring to a.c. lighting circuits and faulty bonding of metallic parts.

FIRE DETECTION

There is a wide range of devices available for the detection of fire, and the type of unit to be installed in a particular location should be determined only after careful consideration of the nature of the fire which would most likely occur in the immediate area.

Smoke detection is capable of providing the earliest possible indication of an incipient outbreak of fire and its application has been widely recommended for the protection of radio type equipment. Modern devices are sensitive in nature and it is important that station staff be reminded of this fact, particularly when working with soldering irons etc, close to the unit. *Figure 34.1* shows a typical smoke detector installed within the cubicle of a 10 kW broadcast transmitter. Care should be taken to ensure that the detector is installed clear of obstructions to air flow, and in an area of maximum effectiveness.

Figure 34.1 Smoke detector inside transmitter cubicle

A new type smoke detector called Vesda (very early smoke detection apparatus) shows promise for duct application. It is based on the principle of measuring the light scatter from minute dust or smoke particles. Two inlets are provided for the measuring point of the apparatus, one to monitor the air flow through the duct and the other to monitor the air outside the building. The air samples are compared and departures from pre-set levels of air cleanliness cause an alarm to be set off.

Heat actuated devices which are generally fixed temperature and rate-of-rise detectors are desirable for fire detection in engine plant rooms, since the products of combustion in engines or high velocity air current may cause operation of smoke detectors.

The detection of smoke in equipment air cooling or exhaust systems is often a problem. The purpose of having smoke detection in the duct system is primarily to shut-down the equipment, particularly the blower motors. In some installations fire and smoke dampers are operated. The presence of smoke in the duct can be detected in two ways; detectors may be fitted within the duct proper or a sample of air flow can be bypassed to a detector chamber located on the outside of the duct. Because of stratification of smoke within the duct, sampling the entire cross section is the only consistently effective method of detection.

It is important that fire detectors be properly located. If they are haphazardly located, serious consequences may result. At one establishment, smoke detectors installed in an equipment area failed to detect a fire in the air conditioning system in its early stages due to bad positioning of the detector probes and heads. The blower fan failed allowing a bank of electric heater elements to heat filter pads to ignition point. The equipment room was fitted with an automatic smoke detector system, two detectors being fitted in the ceiling and one probe in the inlet duct of the air conditioning plant. Due to the blower fan not operating, air was not passing along the duct and no smoke passed into the equipment room, neither was smoke going downwards to the air conditioning inlet to affect the probe. The fire therefore continued to burn undetected, aided by the electric heaters. It was not until after smoke from the smouldering hardboard and partition lining around the unit had finally come into contact with a detector that the alarm sounded.

The early detection of an arc within an equipment cubicle is also important as many fires have been attributed to an arc or brush discharge setting fire to combustible materials. In particular, the large capacity of power supply systems used for high power transmitters introduces a hazard not associated with equipment operating at low power. In a typical 1 MW transmitter, the main rectifier system has a rating of 15 kV at 200A and the energy of the system is sufficient to sustain large and destructive arcs. The intense heat of an arc may quickly ignite combustibles in the immediate vicinity.

Arcs and brush discharges from irregularities on the surface of conductors carrying high voltage are not uncommon, and considerable care is necessary in the design, manufacture and installation processes to ensure that these are kept to a minimum by having all sharp edges rounded off so that the radii are not less than that required for safe operation of the voltage applied. Proper maintenance routines will also assist in minimising discharges by keeping conductors and insulating surfaces clean and dry.

In the power supply circuits, most discharges occur between conductor and earth or between conductors of opposite polarity. The flashover is usually preceded by corona. In the radio frequency circuits, particularly those operating above about 10 MHz, ionization of the air, which involves a time factor, does not occur as visible corona. The discharge occurs without warning and shoots into space, at the same time dancing along the conductor. The direction of air flow within the cubicle, the temperature and air pressure have considerable influence on the direction and behaviour of the plume. Upon the formation of an incipient arc current flows into the capacitance of the arc, and this causes a drop in its resistance until a condition of electric and thermal stability is reached.

An interesting aspect of the behaviour of conductors carrying high voltages at high frequencies is the effect of smoke. Tests have shown that an arc or discharge will develop at a very much lower voltage in the presence of smoke laden air, i.e. the potential rating of a system will decrease in a smoke laden environment. Depending on the concentration of the smoke, the distribution and its source, the voltage rating of a conductor can drop as low as one third its normal rating value. As many components and assemblies are designed on a factor of safety of 2 to 3, the chance of flashover, should smoke circulate in the cubicle, is very high. The early detection of smoke within the cubicle is therefore essential to enable power to be removed quickly.

Various devices are used for the detection of arcs inside equipment cubicles. The most commonly used are ultra-violet, infra-red and magnetic sensing devices. Tests have shown that commercially available ultra-violet detectors are suitable for the detection of power supply and radio frequency arcs but the infra-red units are generally unsatisfactory because of their insensitivity to radiation from radio frequency arcs. However, as ultra-violet detectors can be triggered by ambient radiation such as sunlight and artificial lighting, care in installation is necessary to ensure that they are properly protected in their installed position. Whereas the ultra-violet sensor detects an arc by the flash, the magnetic sensor detects an arc by the noise pulse. The magnetic arc sensor is essentially an antenna which couples a sample of the r.f. energy and any arc induced noise to a low pass filter which passes only the noise pulse to trigger a circuit.

PLANNING FACILITIES

The extent of fire protection facilities provided for transmitters, as a typical equipment example, varies considerably from one organisation to another and, of course, varies with the power of the transmitter. Whether the station is fully staffed or under remote control is also an influencing factor. The most important thing is to design the transmitter equipment so that the possibility of fires will be reduced to a minimum and to ensure where possible that any fire is self extinguishing, by the choice of appropriate materials or that the rate of spread of the fire is so slow that there is a good chance of extinguishment in the early stage. Next in importance is to be able to get to the seat of the fire with fire extinguishing material before much damage is done to the equipment.

Current practice of operating radio stations of many types and powers on an unattended basis has brought with it problems associated with fire. The risk of fire may be considered to be greater than for a staffed station, if only for the reason that a small fire could go undetected and possibly build up into a major blaze with catastrophic effects. In February 1965, a television and microwave station at Saarbrucken in the Saar State was destroyed by fire when new equipment was undergoing acceptance testing and the station was unattended. The installation comprised a permanent building housing two 10 kW television transmitters which broadcast the Second and Third programmes and a microwave radio relay terminal which carried the television programme from the studios, a temporary building housing two u.h.f. transmitters and an electric power sub-station. All these buildings and the facilities were destroyed but the mast supporting the antenna systems was undamaged. A Commission of Enquiry set up to probe the cause came to the conclusion that the fire started in one of the working transmitters. The extent of damage to the building and equipment can be gauged from *Figure 34.2.*

Figure 34.2 Building and equipment damage
(Courtesy Leo Forster)

Factors which should be taken into consideration in planning the installation and operation of unattended stations include the following:

(a) Transmitters which are to be operated on an unattended basis must be provided with adequate and reliable control and protective circuitry engineered specifically for unattended operation. A transmitter of high reliability when operated by skilled staff may not necessarily be a reliable transmitter if left unattended and operated under automatic conditions.
(b) The whole installation of a station which is to be operated unattended requires special engineering planning and design work. Special precautions not usually necessary at an unattended station must be taken, to ensure adequate protection of the station, taking into consideration all aspects of the environment.
(c) Time switches with up to one hour delay should be provided to switch off all lights and non-operational power outlets following visit of staff to the station.

(d) Unattended stations must be inspected regularly and properly maintained by skilled technical staff, under the supervision of an experienced radio engineer.

Where the remote equipment is installed in cubicle type housing, practice by many designers is to install an extinguishing system in each cubicle. These systems will operate automatically to flood the cubicle when the internal temperature exceeds a pre-determined value or smoke is detected. As each cubicle is separately fitted, equipment in other cubicles would not be affected in the event of the system operating, and so service could be maintained by alternative means.

As an additional control measure, many remote stations have smoke detectors fitted into the air exhaust ducts. When smoke is detected, the power to the equipment is automatically removed and an alarm extended to the control station.

Where automatic CO_2 flooding systems are fitted, arrangements should be made to introduce a manual safety switch to disconnect the control of the automatic discharge of the CO_2 system from the fire alarm circuit. The switch should be fitted with visual and audible off-normal indications. A number of accidents have occurred to staff in these automatic type installations, and the operation of the manual safety device during maintenance should be part of the normal safety precaution routines. The health hazard from the gas is due to its suffocating properties rather than to toxicity and in practice a concentration of about 9% is the limit to which most people can tolerate without eventually losing consciousness.

Another popular extinguishing agent used for radio installations is bromochlorodifluoromethane (b.c.f.). This agent has many advantages over CO_2, the principal ones being

(a) The relationship between the two extinguishing agents concerning health hazard and inhibiting factor is as follows

	Dangerous Concentration % Vol to Air	*Extinguishing Concentration % Vol to Air*
b.c.f.	24	5.2-10
CO_2	9	28

It should be noted that CO_2 has a very high asphyxiant risk at extinguishing concentration.

(b) The possibility of thermal shock effect on equipment by application of b.c.f. is remote in comparison with CO_2. (b.c.f. boils at −4 °C whereas CO_2 sublimes at −78 °C).

(c) Because of the lower charge pressure and higher extinguishing qualities of b.c.f., the b.c.f. cylinder is smaller and much lighter than the CO_2 cylinder, for comparable extinguishing effectiveness; for example a 2.7 kg b.c.f. cylinder weighs 4 kg gross, whilst a 6.3 kg CO_2 cylinder weighs 27.5 kg gross.

(d) B.c.f. is particularly clean and has been tested on working circuits without detrimental effect. B.c.f. leaves no residue and is non-corrosive. There is less risk of condensation occurring with b.c.f. than there is from CO_2.

Figure 34.3 Automatic b.c.f. system fitted to a broadcast transmitter

(e) The head of the b.c.f. cylinder has an indicator button which shows on discharge, whereas CO_2 cylinder must be weighed to establish the contents.

By medium of the control unit, the earliest possible protection of equipment is afforded on actuation of a detector, by flooding the cubicle from a b.c.f. gas cylinder with a cartridge operated discharge system. For an equipment cabinet of 1 m^3 capacity, one 2.7 kg cylinder affords adequate protection. Volume ratio between gas and protected area is about 2:1.

Figure 34.3 shows a typical installation provided at one station to cater for two low power broadcast transmitters.

A new gaseous fire extinguishing agent currently under study by some organisations is bromotrifluoromethane (b.t.m.). It is claimed to be superior in all respects to other fire extinguishing mediums for flooding electronic type equipment, although it is more expensive. It does not have the toxic disadvantages of CO_2 and b.c.f. In a recent demonstration in an equipment room with an induced fire within a large pack of pvc cables a number of volunteers remained in the room for up to 3 minutes after it had been flooded with b.t.m. to 5% volume to show that although it is an efficient fire extinguishment at 5% concentration, it is still capable of supporting life.

Figure 34.4 Mobile CO_2 units for transmitter and vault areas

B.c.f. may be preferred to b.t.m. in a total flooding installation where staff are not expected to be present during normal operation because of its lower cost. Such areas are inside transmitter cubicles and transformer vaults. However, in areas which may sometimes be staffed by visiting personnel during operational periods such as transmitter hall, steps should be taken that either type, if used, is fitted with lock-off devices or a predischarge alarm to prevent discharge into the occupied area.

At staffed high power transmitting stations, suitable extinguishers should be located at strategic points throughout the equipment room areas. These units should be located in halls, equipment rooms and shelter areas. For a CO_2 installation the majority of the units can be 3 kg capacity but 22 kg units, as shown in *Figure 34.4*, should be located in alcoves close to each transmitter room, and also at appropriate points external to each transformer vault.

Where a station caters for a large technical staffing complement, there would be a considerable building requirement for administrative support staff and facilities. At some stations, the offices are located in the transmitter building, while at others, a separate building is provided. Fire protection for these office type buildings does not require the same facilities as the equipment buildings. Foam units, water gas units or hose reels may be provided.

Recognition must be given to the value of fixed automatic sprinkler protection systems as a means of reducing fire damage at large multi-transmitter installations and in studio buildings. Experience has proved that if a fire gains such proportions so as to operate sprinklers, the sprinkler if properly installed and maintained, provide for effective control and extinguishment with very little hazard to personnel and with no measurable increase in damage to the radio or electrical equipment as compared with damage traceable to heat, flame and smoke.

An automatic sprinkler system performs three important functions:

(a) It detects an outbreak of fire in the area it is designed to serve.
(b) It automatically releases water under pressure at the seat of the fire.
(c) It initiates the operation of an audible and visual warning system to occupants of the building and transmits a signal to a fire station or control point.

Water is the life blood of a sprinkler system with supply being provided from the mains supply or overhead gravity tanks. As most gravity tanks are not sufficiently high to provide high pressure, an automatic self starting electric, diesel or petrol booster pump is usually installed.

The most common sprinkler heads used at transmitting station installations are the soldered cantilever link and the bulb types. The soldered cantilever link uses an alloy of several metals built into a solder acting as a bonding material for a fusing element.

The link is held in position at constant tension by two cantilever arms fulcrumed centre wise. When the solder alloy melts as a result of heat from a fire, the cantilever arm parts in opposite directions allowing water to impinge on a deflector plate and covering a large area with spray. In the bulb head type a volatile liquid within a glass bulb expands and fractures the bulb allowing water to impinge on the deflector plate.

Experience by broadcast organisations with this type of installation shows it to be highly efficient with a rating better than 96%. Available records show that well over 70% of fires in radio installations which were extinguished by automatic water sprinklers were controlled by the operation of only one sprinkler head in multi head installations. This meant that water damage was restricted and that the system used only the amount of water necessary to control the fire.

DRY PIPE SPRINKLER SYSTEM

Some studio operating authorities are reluctant to install wet pipe sprinkler systems because of the risk of damage to equipment, carpets and furnishing in the event of accidental operation of the sprinkler system. The most widely used protection is the dry pipe sprinkler system. This system features a piping system containing air or carbon dioxide under pressure, instead of water. Only if a fire is detected by a separate ionization or thermal detector system is water allowed in the pipes. The sprinkler head must then fuse at 100 °C, before permitting water to discharge on the fire. The water is automatically stopped when the separate sensing device cools, even though the sprinkler head remains fused. This dual control greatly reduces the risk of accidental operation and consequent water damage, yet provides the added safety of the wet pipe system. Standards set down for automatic systems require that, in most instances, power to the radio equipment be shut off prior to the application of water. Also the floor must have positive drainage to minimise damage to the equipment and associated wiring, due to flooding.

One of the main objections against the dry pipe system is the time delay between the opening of a sprinkler and the discharge of the water. For a rapidly expanding fire, this could be disastrous. However, this problem can be partly overcome by the provision of devices which are quick opening and by ensuring the whole system, particularly the dry pipe valves, is properly maintained.

Some causes of failure of dry pipe systems have been pinpointed mostly to either corrosion or deposits upon seats and moving parts. Another cause has been due to the use of materials such as grease, paper or paint to make the seats air or water tight. The proper remedy is to re-surface the seats or replace the rubber facing.

SWITCHBOARDS

A question which frequently arises is whether or not automatic sprinklers should be removed from non-fire-resisting areas in which high voltage equipment such as switchboards are located, because of the problem of applying water to 'live' electrical equipment. On this point, the evidence from the reports of many fires of which fire protection associations have details indicates that in comparison with the risk of allowing a fire started by a high voltage unit to get out of control, the question of the discharge of water on the unit is of minor consequence. It is obvious that, if a fire originating in high voltage equipment is unchecked, it may within minutes require massive attack by the fire brigade with hose streams. Of the two evils, the evidence is perfectly clear that the question of water damage is minor compared with the risk of serious fire.

This argument is supported by an instance of a fire outbreak involving a 600 MW power station in West Germany. The station fire brigade was summoned after a watchman detected smoke in the station electronic computer room. Fire had spread from the computer room to the high voltage cable distribution room through apertures for cable ducts which had not been fire stopped.

The fire fighters attacked the fire with CO_2 in line with local instructions which stipulated that water was not to be used on fires involving live electrical plant. Dense smoke from burning p.v.c. cables prevented the location of the seat of the fire and no progress was being made in extinguishing it.

When it became evident that the fire was likely to get out of hand unless swift action was taken to extinguish it, permission was granted to attack the seat of the fire with water. The fire was quickly extinguished with only slight effect on the electrical apparatus and cables. The company amended its regulations with regard to the use of water on electrical equipment in handling a fire situation.

REDUCING FIRE PROTECTION NEEDS

Factors which will reduce the amount of fire protection necessary and which should be considered in the equipment and building design phases are:

(a) Oil filled transformers containing more than 900 litres of oil should be fitted with Buch holz relay protection which should be interlocked with transmitter control circuits.

(b) Transformers should be operated with adequate safety margins and protection.

(c) Oil should be regularly checked for quality.

(d) Large transformers and other oil filled components should be installed in a vault with adequate fire barrier protection for adjacent rooms. Cable or other floor openings should be sealed or effectively boxed with metal to prevent the egress of oil from the opening.

(e) The vault floor should be so constructed that in the event of catastrophic failure of the largest transformer contained therein, the oil will be rapidly drained into a pebble drain or sump properly engineered for the purpose. The relative levels of floors of the vault and transmitter rooms should be such that in the event of a spillage, oil will not flow into the transmitter room or any other room of the building.

(f) The transmitter proper should, where practicable, be enclosed in sheet metal cubicles to ensure that fires which may start within the equipment do not endanger the surroundings external to the transmitter.

(g) The equipment should contain the maximum amount of non-combustible materials. Inorganic materials such as glass and porcelain are non-combustible, but organic materials which find wide application in radio equipment vary in combustibility. Most organic materials particularly those used as conductor insulation are combustible to some degree but whether or not they produce a self propagating fire depends on many external conditions such as air supply to the equipment, the rate at which heat is lost and other factors.

Polytetrafluoroethylene (p.t.f.e.) is excellent insulation for conductors. being non-combustible under normal conditions, but because of high cost, its use is mainly restricted to r.f. type cables and critical components. However, it must not be thought that p.t.f.e. is completely non-combustible. In the Apollo capsule accident in which the test crew lost their lives, p.t.f.e. insulation and components burnt vigorously. This was brought about by the atmosphere being almost pure oxygen.

Both p.v.c. and polythene are combustible as flexible conductor insulation materials. Rigid p.v.c. is relatively non-combustible, but in order to obtain flexibility for wiring, the introduction of the plasticizers which in themselves are flammable, seriously impairs the fireproof properties. Polythene is not easy to ignite but if construction of the wiring form is such that the molten materials is held in the combustible zone, polythene will burn very rapidly.

Fibreglass, which has found wide application in radio equipment, has been the cause of the extension of many fires. One of the most commonly used resins, polyester, is in itself not readily ignited in the mass but the very presence of the glass fibres of the re-inforcement material has a wick effect which tends to increase the flammability.

The range of plastics which has come to the radio industry since the Second World War is considerable. If all the variations, either modifications or different manufacturers' developments, are added to this, the list becomes very large indeed. Most are combustible as evident from *Figure 34.5* which shows the remains following a fire which extensively damaged a broadcast transmitter. The almost complete destruction of plastic materials is evident.

(h) Large battery installations at radio stations should be properly installed and adequately maintained. A fire occurred at one station destroying many cells of the station d.c. supply equipment due to bad installation.

(i) Good housekeeping is essential. This can be practiced by providing removable drip trays under outlet plugs or taps of oil filled components, by removing flammable materials and banning smoking by staff during maintenance operations. All ash trays should be emptied at regular intervals and, except where the station is staffed continuously, smoking should be banned at least half an hour before cessation of work.

At an unattended station, one member of the visiting staff should be charged with the responsibility of emptying ash trays and quenching the contents immediately the other staff have left the building.

Supplies of paper, including station log records and other combustible material which is in excess of the minimum required for efficient operation, should be removed from equipment areas.

Figure 34.5 Destruction of combustible materials in transmitter fire

(j) Ducts used for air conditioning, air circulation or transmitter cooling purposes must be of non-combustible material and should be fitted with smoke detectors, as should also cable ducts and chases.

(k) Filters used in connection with air duct systems must be of a type that will not burn freely or emit large volumes of smoke or other objectionable products of combustion when alight or attacked by flames. They should be well maintained and cleaned regularly.

(l) Any activity or occupancy within the equipment room and not directly associated with the installation, should be prohibited.

(m) Workshop type activities should be conducted in a separate room or area provided for the purpose, and not carried out in equipment rooms. There may of course be specific works applicable to the installed equipment and which may not be practicable to remove from the equipment room proper, but these should be kept to an absolute minimum.

ACCESSIBILITY

To provide for the contingency of the occurrence of a fire, it is necessary to make sure during the design and installation stages that all parts of the equipment are accessible to those fighting the fire. Cabinets and cubicles should have doors or removable panels so that hand extinguishers can be discharged into them quickly. Cable ducts, chases and air ducts should have removable sections or panels for the same purpose.

The most satisfactory types of hand appliances for use on radio equipment are the carbon dioxide and b.c.f. extinguishers. These types of units should be available in such quantities that whenever a fire occurs, one can be brought into operation by the staff without delay. Although it was common practice some years ago to recommend the use of carbon tetrachloride for radio and electrical fires because of the high dielectric strength of the liquid, the practice has been discontinued by many organisations because of the toxicity, both of the carbon tetrachloride itself and the gas generated when the liquid is applied to a fire.

ISOLATION OF POWER

Possible damage to radio and electrical equipment and danger to the operator must be considered in fighting fires in station equipment. The safest practice is of course first to isolate the power, and if the fire continues use the extinguishing means most suitable for the conditions.

Where power has to be isolated during fire, only the affected part of the electrical system should be isolated, otherwise there may be a danger of cutting off lights needed by the fire fighting crew or power to operate the fire pumps etc. However, if the fire has spread to the building, or contents, it may be necessary to apply water as quickly as possible by means of a spray or fog nozzle even though the power has not been isolated.

Sometimes large hose streams are required, but ordinarily a small stream is preferable since it prevents unnecessary water damage to adjacent equipment. If relatively clean water is used, the equipment can often be dried out with little or no damage beyond that caused by the current and fire, as many modern insulating materials are relatively impervious to water. If the power is not isolated, additional electrical damage may result and there may be danger of electric shock to the fire fighter.

It is not advisable to use soda-acid, foam or loaded stream type extinguishers on fires in radio and electrical equipment unless water is not available, since these liquids leave salts on transformer windings, on insulation, terminals and other parts likely to suffer subsequent failure. If it is necessary to use them on fires in radio and electrical equipment owing to the lack of approved extinguishing agents, the power should be isolated before any attempt is made to extinguish the fire. The liquids are conducting and they may cause additional electrical damage and involve danger of electric shock to the fire fighter.

OIL FILLED COMPONENTS

Oil filled transformers, circuit breakers, capacitors, reactors and other similar equipment containing oil involve the additional hazard of oil fires. The oil used has a relatively high flash point, but it may be heated and ignited by excessive current or an electric arc. After power has been isolated, such fire can be extinguished by the various methods of extinguishing oil fires. If the power cannot be immediately isolated, vaporizing liquid, carbon dioxide or dry chemical extinguishers can be employed without danger of electric shock but these hand extinguishers are not ordinarily effective for extinguishing more than very small fires of this type.

Improperly sealed wax filled capacitors have been the cause of much concern to equipment operators, particularly where they are mounted in a horizontal position. At least one fire has been attributed to one such defective unit when dripping wax fell on to a standoff insulator of the 10 000 V busbar feeding the plate of a modulator tube. Fortunately the short circuit current caused the transmitter overloads to operate and the fire burnt out after vaporizing the wax.

At the same station some 12 months following this incident, a fire broke out in the antenna matching hut due to improper earthing of oil filled capacitors. Six oil filled units of the balanced type made up part of the matching network and during tests to locate a fault in the system the earth strap bonding all the metal containers together was temporarily removed. When the 50 kW transmitter power was re-applied an arc occurred between two of the cases. The arc set fire to one of the oil soaked cork gaskets separating the capacitor lid from the tank, but was quickly extinguished by an alert technician.

TYPICAL FACILITIES

The fire detection and alarm facilities provided at a radio station will be determined by many factors including the size of the station, whether staffed or unattended, proximity to public fire fighting services, and the importance of the station from a public service or security point of view.

In the case of a typical unattended transmitting station, facilities include a combined thermal and early warning detection system covering all rooms of the station building. The equipment rooms are fitted with smoke detectors while the other rooms are fitted with heat activated detectors. Where an emergency power generating plant is provided, it also is fitted with a heat activated detector system. A central control panel located at a convenient point enables all detection devices to be brought to a common point. The panel has facilities for activating a visible and audible alarm, putting into operation an automatic extinguishing system if provided, and extending an alarm to a remote point such as the local fire station.

For a typical unattended station where the value of the equipment warrants, a smoke detection system associated directly with the equipment cubicles is provided. The detectors are wired to a control unit which has capability of causing the equipment and associated blower to be shut down in the transmitter from where the alarm originated, operating extinguishing systems to flood the cubicle and of extending an alarm to a remote point such as fire station or the control station staff. Power generating plant is provided with a thermal detection system and automatic fire extinguishing facilites may also be provided in this area.

Except for some very big stations, automatic extinguishing systems covering large areas are not normally installed. Where systems have been provided they protect high voltage vault areas containing large oil filled components.

Portable hand operated extinguishers of various types and internal hose reel to fire underwriters or fire brigade specifications are provided throughout the buildings and in locations determined by competent fire protection officers.

Water shortage facilities are also provided. A storage capacity of 45 000 litres is normal but some stations have 200-300 000 litres capacity. A diesel powered fire pump is also generally provided with the installation capable of feeding water at high pressure into a reticulated hydrant service.

Where a bushfire or paddock fire in long grass is a hazard, a fully equipped fire tender may be provided. As a minimum facility, fire beaters and knapsack spray units should be available.

For the unattended station, an automatic extinguishant flooding system is installed where the value of the equipment and its importance warrants such protection. Portable hand operated units are also provided for use when staff are on site. Although it is not usual to provide water storage solely for fire fighting purposes at very remote stations, visiting staff require water for drinking purposes and a single tank supply usually serves the needs of both requirements.

SPECIFICATION EXAMPLE

A specification drafted for the provision of facilities at a large staffed transmitting station in a remote location illustrates typical requirements for similar installations. The power house provided emergency power only and no automatic system was required.

(a) A properly engineered combined smoke and thermal automatic fire alarm system shall be provided throughout the station. The system shall cover

Figure 34.6 Typical fire alarm indicator panel

  - (i) Transmitter building.
  - (ii) Administration and amenities buildings.
  - (iii) Power house-workshop building.
  - (iv) Antenna matrix switch building.
  - (v) External plant depot building.
  - (vi) Garage building.

(b) The main fire alarm control panel shall be located in the control room of the transmitter building with a repeating indicator panel installed at the staff entrance vestibule to the administration building. A reliable 50 V battery system will be available in the transmitter building for operation of the alarm system. The panel shall accept calls from each of the points in (a) and shall operate fire gongs in each of these buildings. Facilities shall be provided for extension of alarms. *Figure 34.6* shows a typical panel for this purpose.

(c) Smoke detectors shall be provided in the following areas of the transmitter building
  - (i) Each transmitter enclosure.
  - (ii) Transmitter air exhaust ducts.
  - (iii) Transformer vault enclosures.
  - (iv) Control room.
  - (v) Programme input room.
  - (vi) Radio link room.
  - (vii) Laboratory and test room.
  - (viii) Workshop.

All remaining areas in the transmitter building shall be covered by thermal detectors.

(d) Manual fire alarm points shall be provided
  - (i) Adjacent to main control panel in the control room.
  - (ii) One at each end of transmitter hall.
  - (iii) One adjacent to repeater panel in administration building.
  - (iv) One on external wall of power house.
  - (v) One on external wall of antenna matrix switch building.
  - (vi) One on external wall of external plant depot building.
  - (vii) One on external wall of garage adjacent to re-fuelling pumps.

(e) A water storage tank system with a minimum capacity of 45 000 litres shall be provided exclusively for fire fighting purposes. A 10 cm hydrant system shall be provided to cater for interior and exterior protection of all buildings and the immediate area around the buildings. Each hydrant point shall be provided with a cluster of six 20 mm outlets in addition to the fire hose connection. Hydrants shall be so placed that all exterior portions of the buildings and the immediate cleared site area may be protected by using 1 × 40 m and 5 × 20 m lengths of 20 mm (4 ply) rubber hose fitted with a variable 5 mm nozzle which shall be provided as part of the facilities. A manual start diesel engine booster fire pump coupled to a 10 cm diameter hydrant system shall be provided at a point remote from the buildings. A pump operated by an electric motor remotely controlled from the transmitter building control room shall also be provided. The complete hydrant system shall be earthed in accordance with building earthing and bonding specifications.

(f) Portable hand fire appliances shall be provided as follows:

(i) Transmitter building: all rooms accommodating working equipment and also the store room shall each be supplied with one only 3 kg CO_2 unit at each door. Two 22 kg mobile CO_2 units shall be provided in the transmitter hall outside the enclosure of each high power transmitter. Additionally, two 22 kg mobile CO_2 units shall be provided external to each transformer vault enclosure.

(ii) Antenna matrix switch building: one 3 kg CO_2 unit shall be provided inside the building and another unit on the outside wall near the exit.

(iii) Amenities building: one, 9 litre foam unit and one, 9 litre water gas container shall be provided in the corridor.

(iv) Power house: two 9 litre foam units shall be provided adjacent to each diesel generating set. One 22 kg mobile CO_2 unit shall be provided inside the power house near the main roll-up entry door. Additionally, one 22 kg mobile CO_2 unit shall be placed inside a covered enclosure at a point external to the main entry door. Two 3 kg CO_2 units shall be provided at the main power board and one CO_2 unit shall be provided at the outside wall of the store room.

(v) Unloading areas: one 9 litre water gas container shall be provided near the gantry of each unloading area.

(vi) Workshops: one 3 kg CO_2 unit and one 9 litre foam unit shall be provided in each workshop area with the foam units mounted adjacent to the exit point.

(vii) Filter cleaning: one 3 kg CO_2 unit shall be provided near the door.

(viii) External plant depot building: two 9 litre foam units shall be provided at entrance to depot and two at the exit.

(ix) Garage building: two 9 litre foam units shall be provided at the pumps and one unit provided in each vehicle park area.

Figure 34.7 Water tank storage and fire pump house

(x) Illustrated coloured charts shall be prominently displayed near each piece of fire extinguishment equipment. These charts shall show its correct use.

(g) A motorised fire unit mounted on a standard truck chassis shall be provided as part of the station fire extinguishing facilites.

The unit shall be designed and fitted out to deal with grass fires in the field and outbreaks in the small outbuildings. It shall be fitted with an integral water tank of at least 900 litre capacity an associated pump together with 50 m of hose with high heat resistant properties. The unit shall also be fitted with four 3 kg CO_2 units and two 9 litre foam units, four knapsacks, six handbeaters and a tool box compartment containing two axes, four shovels and two rakes.

The vehicle shall be fitted with a device at the rear to enable an auxiliary mobile tanker to be towed. There shall be fitted on the front of the vehicle a winch with 50 m of steel rope of breaking strain at least two tonnes.

Figure 34.8 Hydrant point

The vehicle shall also be fitted with a first aid outfit and a mobile radio system.

Figure 34.7 shows water storage tanks at the station comprising two 130 000 litre tanks and the fire pump house. The additional storage capacity covers gardening and lawn requirements.

Figure 34.8 shows one of the hydrant points located on the property close to the main building.

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Chapter 35

Electric Shock Hazards

Putting out fires near live radio equipment is likely to be dangerous and may result in severe shock. The shock may be caused by the extinguishing agent acting as a conductor and passing a current through the fire fighter. It may also be caused by direct contact with live equipment or flashover to a conducting hose nozzle or similar metallic device. Most of the experimental work done on this subject has been with water as the extinguishing agent but some information is also available on other agents, particularly those used in portable units such as carbon dioxide, foam, vaporising liquids or dry chemical substances. The experimental work has also been concerned with mains frequency power. However, in order to prevent confusion by non-technical personnel, it is usual to consider all voltages, irrespective of frequency, as being equally hazardous.

ELECTRICAL CONDUCTIVITY OF WATER

Water supplied from rivers, lakes, reservoirs, bores or wells contains impurities that make it conductive. The conductivity varies considerably from one source to another but irrespective of the source, consideration must be given to the shock hazard presented to the fire fighter, particularly where high voltages, such as those encountered with high power broadcast, television and radar equipment, are in use.

Although most water in its natural state will conduct electricity, it can often be used safely when proper precautions are observed. For example, water has been used for many years for cleaning the insulators of high voltage power substations. It has also been widely used in fog deluge systems for protection of power station transformers and although there have been several reported cases of accidental discharge of these systems, they have not affected the operation of the equipment.

The severity of shock to the fire fighter is influenced by many variables, including:

(a) The voltage of the conductor on which the water is contacting.
(b) The amount of current flowing through the fire fighter.
(c) The conductivity of the water being applied.
(d) The characteristics of the water stream, i.e. the break-up resulting from the pressure of the supply, the design of the nozzle, wind conditions and interference to the water stream by apparatus in the path of the conductor.
(e) The distance separating the fire fighter and the conductor.
(f) The cross sectional area of the water stream.
(g) The resistance to earth through the body of the fire fighter.

(h) The resistance to earth through the hose.
(i) The length of time that the fire fighter is exposed to current flow through his body.

SAFE DISTANCE FROM ENERGISED EQUIPMENT

The problem of determining a safe distance from an energised conductor has been studied by many researchers but there is no clear cut rule available because of the large number of factors involved.

It has been generally agreed that there is not a great hazard when directing water streams on to a conductor with a potential of less than 600 V to ground from distances likely to be encountered under normal fire extinguishing situations. Most work has therefore been concentrated in the high voltage field.

The formula used for calculation of the approximate current through a solid stream of water is:

$$I = \frac{aF}{\rho l}$$

where a = cross sectional area of the nozzle orifice, E = voltage of the energised conductor above earth, l = distance separating nozzle and the conductor ρ = the specific resistance of the water being used.

The formula indicates that current flowing through the water stream is proportional to the voltage of the exposed conductor on which the water is falling. In practice it will be less than the calculated value because the stream is not completely solid for the whole distance between nozzle and conductor. In fact a hose stream can be considered as being divided into three major sections:

(a) The jet section.
This is immediately adjacent to the nozzle and in which the formula can be applied with a reasonably high degree of accuracy.
(b) The expansion section.
In this part of the stream, the water is beginning to break up and the resistance per unit length begins to rise.
(c) The broken section.
This section which occurs towards the end of the stream is composed mainly of discrete drops of water and the resistance per unit length rises rapidly. When it reaches the stage of being a spray mist, it may in fact be a reasonably good insulator.

The length of these sections in a particular stream depends on many factors such as water pressure, nozzle design, nozzle diameter, wind velocity, wind direction and the speed of movement of the nozzle by the fire fighter.

Because of variations in the stream characteristics which can arise in practice from the above factors, correlation of the experiments of many researchers is not easy. As a general rule, however, it can be assumed that the minimum distance which the fire fighter should observe between the nozzle and an energised exposed conductor should be increased when the nozzle diameter is increased or when the voltage of the conductor is increased.

The safe distances recommended by one radio engineering organisation, with several large transmitting stations, is shown in *Table 35.1.* The distances for the

Table 35.1 Limit of safe approach to live electrical equipment

Voltage of Conductor (V)	*Safe distance (m)*
1 000	1
2 000	1.5
5 000	2
7 500	3
10 000	4
15 000	5
25 000	8
66 000	10

various voltages were determined after taking into account the sizes of the nozzles fitted to the hoses, the water pressure with the fire booster pump in action and the conductivity of the water supply which was obtained from a property bore. Large signs have been installed over critical areas indicating the voltage and safe distance, for the benefit of fire fighters.

USE OF SPRAYS

In addition to solid water systems some stations are provided with water spray systems. The spray provides a cooling effect through the high rate of evaporation of water into steam. The electrical current conducted by a properly regulated spray is very small and consequently it is possible to approach much closer to an energised conductor than when using a solid stream. Nevertheless sufficient clearance should be maintained to prevent direct voltage flashover to the fire fighting apparatus. The safe distance would be determined by many considerations including layout of the equipment, but 120 cm has been suggested as a safe distance from exposed conductors of 10 kV potential at mains frequency.

When dealing with equipment with high radio frequency potentials, many engineers are concerned with the particular hazards to which a fire fighter is exposed in the situation where the equipment is alive. It is well known that the flashover voltage point of a standard ceramic insulator, as used extensively in radio equipment, is reduced to nearly 70% by a change in humidity from zero to 100%. The application of the spray may result in an immediate drop in the design factor of safety and the situation could lead to a violent flashover. The arc could also spread to the fire fighter's hose nozzle. In one case, the loud explosive noise so startled a fire fighter that he lost control of his plant and it fell across a large energised oil filled capacitor.

Many items of equipment operate at relatively high temperatures due to skin and dielectric losses and the cool water spray on striking these hot items will frequently cause violent impingement effects with staccato-like sounds. These may also startle the fire fighter. Spraying cold water on the hot glass of a transmitting tube can be particularly hazardous.

The flashover problem becomes acute when the spray falls on dirty insulating material. In the case of the ceramic insulator, as an example, a clean dry standoff insulator of 25 cm straight skirt will have a flashover value of about 100 kV but when dirty and wet it will fall to 10-20 kV; the value depending on the nature of the foreign material and the frequency of the applied voltage.

A further aspect which has been brought to attention is the modified electrostatic discharges which occur from unshielded equipment with high field strengths, such as inductors in high power circuits. Under normal circumstances, a capacitive current will flow via the body of a bystander to earth if his feet are in electrical contact with the earth. If however his body is insulated, such as when wearing rubber soled shoes, and he touches an earthed member with his hand, then the body charge will be discharged via his hand. When a fire fighter with a wide angle spray approaches a large energised inductor the field distribution can be considerably modified and may result in a higher body charge compared with the no-spray situation. The discharge current which is of short duration may cause an unintentional reaction of the muscles should the fire fighter contact an earthed object. This could result in him making contact with live equipment.

Care should be exercised in using fog and water equipment on fierce fires in transmitter cubicles where aluminium sheeting is being consumed in the fire. Aluminium and other metals which are easily oxidised burn at exceedingly high temperatures as is evidenced by their brilliant radiation and, if water or fog is applied in an attempt to extinguish the blaze, an explosion would result because of the decomposition of the water.

Experiments with spray devices have shown that drizzle size droplets produce short duration plumes and steamers which combine to form gossamer-like cones when applied to high voltage radio frequency conductors. When the droplets are of a size normally encountered in rain, an impingement plume is produced, particularly with stranded conductors. These are frequently observed on transmission lines and antenna conductors at high power stations during periods of rain.

Fixed spray systems have been provided at some stations in transmitter halls, vault areas, and sound and television studios. They have been responsible for minimising damage during several recorded fire outbreaks, and when properly engineered and installed, are highly efficient and very reliable. When installed over high voltage equipment, it is necessary to ensure adequate clearance between high voltage points and the nozzle, and also that the system is properly earthed.

A recent approach to the high power transmitter problem has been the joint use of water fog and carbon dioxide. The combination takes advantage of the great cooling action of water fog and its effectiveness against solid material fires together with the well proven effectiveness of carbon dioxide against flammable liquids such as transformer oils. The combination results in a protection system which requires less material than what would be needed if each were employed alone.

PORTABLE FIRE EXTINGUISHERS

Some portable fire extinguishers contain substances which are good conductors of electricity and present a serious hazard when used on fires in energised equipment. Tests on the conductivity of portable fire extinguishers containing water, such as soda acid type and the loaded stream type, indicate that lethal currents can occur when a standard unit with a 3 mm diameter hose is used at a short distance from a high voltage energised source. The current can only be reduced to a safe value when the extinguisher is removed to a point where the solid stream breaks up into discrete drops on the conductor.

It is generally agreed that these units must be used no closer than 120 cm on an exposed conductor of 1 kV potential. This compares with a distance of about 30 cm for a unit with the same size hose and filled only with water taken from the public supply. Because of these problems it is practice at some stations to avoid installing any of these conductive types in the vicinity of radio and electrical equipment in order that persons unfamiliar with the various types may not run the risk of electric shock.

A foam stream which may be produced by chemical or mechanical means has a lower conductivity than a solid stream of generating solution. The conductivity depends on the concentration of free ions but because it varies over a wide range it is usual to apply the same restrictions as those applicable to water.

Extinguishers of the carbon dioxide type produce a discharge containing carbon dioxide vapour and solid particles of dry ice (carbon dioxide). The substance is a good electrical insulator and for practical purposes may be considered to be non-conducting.

Liquids of the vaporising types such as bromochlorodifluoromethane and bromotrifluoromethane can be safely used on energised equipment. They do not ionise and therefore are non-conducting.

The dry chemical type which is based on a combination of powders is also regarded as being non-conducting and safe for use on fires in energised equipment. They do however create a clean up problem after use. The most widely used types are sodium bicarbonate base powder, potassium bicarbonate base powder, potassium carbonate base powder, potassium chloride base powder and ammonium phosphate base powder. Two other dry powder agents are granular graphite and fine granulated sodium chloride. Both these are effective in dealing with burning metals but are limited by gravitational forces in smothering only horizontal areas. Dry chemicals present practically no problem with regard to toxicity.

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Chapter 36

The Transformer Problem

Oil insulated transformers are commonly used in the larger radio transmitters and due to the flammability of the oil they present a considerable fire hazard. Fires in oil insulated transformers and reactors can be extremely intense and therefore it is important that their location be carefully planned. Some transformers have been known to burn for several hours before being brought under control.

After power has been disconnected, such fires can be extinguished by any of the several methods of extinguishing oil fires. If the power cannot be disconnected, carbon dioxide, vapourising liquids or dry chemical media may be safely employed. Small hand extinguishers would be effective only on minor fires. Extensive transformer fires in a vault can be dealt with most effectively by flooding the room with foam or carbon dioxide. The main characteristics of oil filled equipment installed in the vault of a large transmitting station may be classified as follows:

(a) The wide frequency response of some transformers.
(b) The use of large reactors.
(c) E.h.t. and modulation transformers required to handle syllabic loading conditions.
(d) Transformers required to tolerate transmitter short circuit and recycling conditions.
(e) The large number of transformers required for a single high power transmitter.

The number of components provided with a transmitter varies considerably from one design to another. For example, one 250 kW transmitter used eight large transformers whereas recent designs use only two units. One installation suitable for speech clipped high level modulation, installed in 1970, uses one each of the following for each transmitter:

E.h.t transformer	4275 litres
Modulation transformer	1350 litres
Modulation reactor	1350 litres
Screen supply transformer	675 litres
Distribution transformer	675 litres

The amount of oil contained in units in a typical vault is therefore considerable, and from a fire hazard point is a real problem. In fact in this installation the stored oil has the same heat of combustion as about fifty 200 litre drums of gasoline.

NON-FLAMMABLE COOLANTS

With the large amount of oil contained in the vaults, the question of a non-flammable coolant for oil filled transformers has been investigated many times by operators and designers, and only under some rather special conditions has it proved advantageous to use the non-burning fluid in place of mineral oil.

The generic name askarel is often applied to these 'fireproof' liquids. They are defined as "dielectric fluids which are both non-flammable and incapable of evolving explosive gas mixture when decomposed". In all cases they are composed of chlorinated compounds and when subjected to an electric arc release hydrogen chloride and finely divided carbon.

The major transmitter manufacturers have not so far recommended the use of askarel coolant for transmitter equipment. One reason is the higher dielectric constant as compared with mineral oil. This raises doubts as to whether modulation transformers and modulation reactors would perform satisfactorily without extensive re-design and testing. The dielectric constant of typical mineral oil is 2.2 compared with 4.5 for askarel, a difference which is significant at the higher audio frequencies. A survey among suppliers showed a general reluctance to attempt re-design using askarel particularly with units required for high power plate modulated transmitters employing speech clipped or trapezoidal modulation.

Another factor is that askarel cannot be used in station oil circuit breakers or oil switches. Local overheating or arcing may cause the formation of hydrogen chloride. However, a well designed unit would ensure that this is absorbed by a gas scavenger included in the fluid for this purpose. The main factors associated with the use of askarel for radio equipment may be summarised as follows.

Advantages

(a) In the event of a transformer or reactor becoming involved in a fire starting in the vicinity, there is practically no risk of burning oil spreading the conflagration to other parts of the vault.

(b) Transformers using mineral oil must be installed in a fireproof vault equipped with pebble drain and fire fighting equipment. Askarel units do not require this restriction, and can be installed within the transmitter enclosure or other convenient location.

(c) The fluid is not subject to sludging, oxidation and other chemical degradation under normal operating conditions, and hence regular fluid testing and filtering is not necessary. Records exist which show askarel mains power units in service for over 20 years without attention.

(d) The dielectric strength of askarel is equal to that of mineral oil and is satisfactory over a wide range of values.

(e) Askarel is permanently stable in all respects below 175°C. Decomposition when it commences, results in the production of hydrogen chloride and carbon in the form of soot. The hydrogen chloride forms over 97% of all gaseous products.Laboratory tests and practical experience with substation transformers have shown that chlorine, carbon monoxide and poisonous hydrocarbons such as phosgene are not formed. Hydrogen chloride is fire resistant and non-explosive. Being soluble in water it can be disposed of easily.

Disadvantages

(a) Askarel is much more expensive, being some 2.5 times the price of mineral oil.
(b) Askarel is denser than mineral oil, being about 1.5 times as dense. This is an important economical point for transformer vaults where rails are not to be provided and the floors have to be designed to carry large units.
(c) Askarel cannot be used to refill a transformer designed for mineral oil. The fluid is a solvent for certain materials used in conventional construction, but materials are available which are completely compatible.
(d) In the case of modulation transformers and reactors, redesign would probably be necessary to take into account the greater dielectric constant.
(e) Transformer cases must be specially designed and gasketed for askarel.
(f) Askarel is denser than water and any condensation in the transformer case will float on the top of the coolant, thereby increasing the susceptibility of the unit to internal flashover between terminals and between terminals and case. Several failures have occured in practice from this problem with electrical distribution transformers mounted on roof tops.
(g) The corrosive nature of liberated gases resulting from arcs necessitates careful selection of materials and protection of exposed copper conductors, terminals and the transformer case.
(h) Gases which are generated during a transformer fault may exert sufficient pressure to cause rupture of the tank.

Dry or air cooled type transformers do not of course use flammable coolants and are used extensively throughout many radio installations. Even the mains and modulation transformers of most modern transmitters up to 10 kW carrier output are of the dry types.

The four general dry types encountered in radio equipment are: Self cooled unventilated, Self cooled ventilated, Forced air cooled, Sealed tank gas filled.

The sealed tank gas filled types found wide application in some wartime aircraft radar systems and used nitrogen gas. Another gas now used for this purpose is perfluoropropane which is non-flammable, non-explosive and has high dielectric strength.

Dry type transformers and reactors have about the same fire hazard as motors of equivalent voltage, size and insulation. Most fires were caused by insulation failure and in many cases were confined to the unit in which the fire originated. this contrasts with fires in several oil filled types where considerable damage occurred to external attachments and equipment in the immediate vicinity.

Where used as mains transformers the dry type is however, more susceptible to damage by lightning because the basic impulse strength of this type is only about 50% of an equivalent oil filled unit.

OIL DETERIORATION

With all the experience and knowledge available with the deterioration of transformer oil, it is suprising how little attention is given by many station engineers to the checking and maintenance of the oil of transmitter vault equipment. At some stations, regular and accurate checks are made on the quality of the oil, whereas at others practically no attention is given to this aspect.

At two 50 kW stations using identical equipment, and installed at about the same time, the modulation transformers failed within 6 weeks of each other after 12 years of service. Neither station engineer had conducted any oil checks over this period, and on removal of the transformers from their cases, the extent of the sludge build-up and the corrosion to windings, insulation, copper terminals and even the case, was such that both units had to be scrapped. A temperature measurement of the oil of one of the units taken about 5 minutes after failure indicated a reading of 15°C above the maximum operating temperature recommended by the manufacturer. Although the transformers contained only 650 litres of oil, they were mounted within the transmitter enclosures inside the building which at one of the stations contained three 10 kW transmitters and a fire could have resulted in serious consequences.

After failure of an e.h.t. transformer at one 100 kW station, the oil was drained and a layer of sludge approx. 15 mm deep was found on the bottom of the tank. Sludge was also deposited on the coils of the transformer. The coils were dark brown/black in colour and inspection of the cellulose insulation showed that it had become extremely brittle as a result of thermal degradation. Severe corrosion had occured in the vertical tubes leading to the breathers and to a lesser extent at the corners of the tank lid. In the breather tubes a dark brown deposit was present. Moreover, a considerable amount of this deposit had from time to time become dislodged and fallen on the top of the cores located immediately below. An examination of the corrosion product was made and identified as a hydrated ferric oxide, a component of conventional rust. Analysis of samples of the sludge showed iron contents up to about 4.5% by weight. Copper was found to be present to the extent of 0.9% by weight.

The oil provided for transformers and reactors serves a dual purpose, namely insulation and cooling. Whilst marked degeneration of the oil does not appreciably

Figure 36.1 Typical oil filled vault equipment fitted with conservator tank and dehumidifier

affect the conduction of heat, as long as sludge is not deposited on the core-coil assembly, its properties as a high class insulating medium are affected during operation by external factors, such as the intrusion of moisture and dirt and by ageing of the oil as a result of chemical reaction with atmospheric oxygen. The extent of such ageing depends largely on the method adopted to prevent the access of air to the oil.

Ageing of the oil in service is due to chemical change in the constituents of the oil caused by oxidation of the hydrocarbons. Through various reaction stages this leads to the formation of organic acids, in the course of which the dielectric loss factor rises. When ageing reaches a more advanced stage, solid products are deposited in the form of sludge.

The oxidation rate is largely dependent on the temperature of the oil and the extent of the oil surface in contact with atmospheric oxygen. The formation of acids leads to corrosion, principally in the iron components in the form of rust, and to gradual destruction of other materials such as insulation. Furthermore, the increased loss factor of the oil implies deterioration in the dieletric properties of the oil impregnated solid insulation of the transformer. Such effects are of course highly undesirable and every effort should be made to protect the transformer against the early onset of 'ageing' of the oil.

BREATHING ARRANGEMENTS

The method of preventing the access of air to transformers has varied over the years. It is now practice with some transmitter manufacturers to provide open or free breathing type cases of 50 kW transmitters, and to provide conservator tank with dehumidifier for the e.h.t. transformer, modulation transformer and modulation reactor for powers of 200 kW and above. *Figure 36.1* illustrates some of the components of an installation with conservator tanks and dehumidifiers. The illustration shows modulation inductor or reactor, the modulation transformer and the distribution transformer. *Figure 36.2* shows the modulation transformer on the left, and modulation reactor on the right, of a 250 kW medium frequency station installation of the late 1960s. The use of a new layout of core and windings compared with earlier installations of this power has resulted in good symmetry without electrostatic screens between the windings, and has contributed to a considerable reduction in the size and weight of the units. Equipment in more recent designs is very much smaller in dimensions.

In the open or free breathing type of construction, the oil surface which is only a few centimetres below the cover is permanently in contact with the surrounding air. This further ages the oil by oxidation and the condensation of moisture due to fluctuation of the temperature. In contrast, the oil is a conservator tank is at much lower exposure and is correspondingly less inclined to deteriorate by oxidation. The dehumidifier which in most cases is silica gel crystals also prevents moist air from entering, and from condensing.

Some experiments were carried out several years ago at a station in a severe tropical environment with a flexible rubber membrane between the oil and the air in the conservator tank in order to prevent an exchange of moisture between the oil and the solid insulation. The test showed that the seal offered no improvement

Figure 36.2 Modulation transformer and reactor of 250 kW m.f. transmitter (Courtesy Brown, Boveri and Co)

over other transformers fitted with the standard conservator and dehumidifier, provided that the dehumidifier was properly maintained.

ACID LEVELS

Acid values of 0.2 to 0.3 mg of KOH per gramme of oil should not give trouble, and unless reached in a very short time will not indicate rapid deterioration of the oil. Acid values as high as 1.0 mg of KOH per gramme of oil, however, show that the life of the oil may be limited and it is normal practice at many stations to change the oil prior to this value being reached.

It is unwise to allow high acid values to develop, as the transformer core and windings then become contaminated to such a degree that even the most careful cleaning and flushing with new oil will not remove all traces of acidity. A new filling of oil would then tend to deteriorate at an increasing rate with correspondingly shortened life.

INHIBITORS

There is some advantage to be gained by adding an inhibitor to the oil. Inhibiting an oil involves adding a substance that mitigates deterioration, i.e. an anti-oxidant. A check with many station operators revealed that about 60% of transformers associated with transmitters of 50 kW and above are know to be filled with inhibiting oil. The complete absence of harmful effects attributable to the inhibitor has been confirmed by extensive tests and experience by electric power operators, and has shown considerable promise in radio installations.

Tests have shown that the dielectric constant of inhibited and uninhibited oils are almost identical over the range 20°C to 100°C and measurements on modulation transformers and reactors have indicated that a change in the oil from uninhibited to inhibited has negligible effect on the frequency response performance.

SHORT CIRCUITS AND RECYCLING

Some of the peculiarities of high power transmitters, particularly those used on higher frequency broadcasting where frequent switch-on and frequency change takes place, include the large number of flashovers, short circuits, re-cycling and other phenomena which takes place. This places a considerable strain on the transformers, and the number of failures of large units is cause for alarm. In two large installations alone, the records show nine transformers as failing on one station, and two failures and two more requiring re-pegging at the other. Fast acting vacuum switches have done a lot to minimise transformer failure but the problem is still of some concern to high power operators.

The main effect of the short circuit or recycling is to cause coil conductors of the transformer to be violently displaced as a result of internal unbalanced electromagnetic conditions. With concentrically wound primary and secondary coils the horizontal axes may not coincide and therefore a vertical force acting upon the coils is introduced in addition to the usual radial one. This vertical force has often been responsible for the distortion of coil ends particularly with the older designs of transformers in which the impedance is low. With sandwich wound primary and secondary coils as in the rectangular shell type of transformer, the axes of the individual coil sides seldom coincide, on account of the differences required in electrical clearances from coils to core and of the differences in winding spaces. In some of the above troubles, the lack of symmetry introduced distorting forces acting radially upon the coil sides which became pushed in towards the core or forced out away from the core,depending on the relative positions of the axes of the coil sides and upon the relative short circuit currents flowing.

The list of transformer failures at radio stations is extensive and the chief causes, some of which resulted in fire, are summarised as follows:

(a) Short circuit between turns caused by the mechanical stresses set up by a flashover of power amplifier or modulator tubes and also transmitter recycling operations.
(b) Careless fixing and tightening of packing pieces forcing turns out of position and resulting in eventual short circuit.

(c) Loose core and tie bolts permitting excessive vibration, leading in time, to insulation failure.
(d) Inadequate oil quality maintenance and checks, resulting in overheating and eventual failure.

By far the greatest number of failures have been traced to short circuit between turns, and this can be caused in many different ways. Unfortunately with a fault of this type it is usually very difficult to determine the cause of the failure, as all evidence is generally eliminated by the very nature of the breakdown. Consequently, the cause of the breakdown is often a matter of conjecture, and however unsatisfactory this may be, from a point of definitely assigning the true cause, usually a very close idea of the real cause may be obtained by a careful study of the transformer itself and of the environmental and operating conditions. At one high power radar station, a large oil filled transformer developed a short circuit, exploded and spread burning oil over a wide area. Damage in the region of several million pounds was caused as a result of the fire.

TRANSFORMER PROTECTION

Overloads if allowed to persist result in accelerated deterioration of transformer insulation and resultant loss of useful life, or even failure. Short circuits result from internal insulation failures within the transformer between turns or between windings and, if not cleared quickly, introduce a danger of fire, explosion or damage to the transformer.

Nearly all of the large oil filled units now provided at radio stations have temperature sensing devices that shut down the transmitter if the top oil temperature exceeds a preset value. The power distribution transformer of the transmitter may also be equipped with an internal circuit breaker to protect against over heating. The e.h.t. transformer and others with large oil capacities are often fitted with a device that detects a pressure change in the transformer oil due to violent internal arcing and will immediately operate the main breaker feeding the transmitter.

There is some difference in principle for short circuit protection of large transformers when comparing United States practice with that in some other countries. A mechanical pressure relief device is standard in the USA. Its function in relieving serious internal pressure within the transformer case is performed by a pressure relief vent. A steel diaphragm is lifted by the internal force and recloses, and reseals after venting the transformer. In Australia, for example, the device has no resealing property; it operates only as the result of a major fault which in any case would require internal examination, so the absence of this facility is not significant. The Australian device, called a Buchholz relay, is a simple and reliable device and has been used for many years. While performing essentially the same function as the USA pressure relay, it provides the trip and indication facilities lacking in the relief vent. In addition, it provides a facility not available in the alternative device, namely the detection of incipient faults within the transformer. Electrical breakdown of oil or cellulose insulation is accompanied by the release of gas which is trapped in the Buchholz relay and, when sufficient gas has been trapped, a float switch operates an alarm to warn the transmitter operator.

From information available regarding fires in high voltage transformers, the evidence seems to point to the following conclusions:

(a) The most complete electrical protection will not necessarily function quickly enough to prevent oil in the transformer being ignited in the event of a serious internal fault.
(b) Automatic fire extinguishing systems which are correctly engineered and installed can limit damage to a transformer in the event of a fire, because extinction should take place in a very short time.
(c) In the absence of a built-in automatic extinguishing system the type of fire which can occur in a large transformer may take a long time to extinguish, with the result that damage may be considerable and other units or buildings would probably be severely exposed.

OIL CIRCUIT BREAKERS

Oil circuit breakers are also a fire hazard because of their oil content. Unfortunately the static nature of circuit breakers, like transformers, makes them liable to neglect in the matter of periodic maintenance. It is essential to carry out regular and periodic examination and testing of oil, the interval depending on the amount of load switching which is performed. Where a breaker is known to have cleared a short circuit, it should be inspected at the very first opportunity irrespective of the normal maintenance inspection period. The oil should be tested by taking a sample from as near the tank bottom as possible, and if carbonised or will not withstand the recommended voltage test, the breaker should be removed from service until the oil has been replaced.

Switchgear for transmitters is often installed above cable chases thus necessitating the passage of cables through the floor. All such points should be sealed off to prevent the flow of burning oil into the chase as well as to eliminate any draught of air through the breaker.

PROTECTION OF WALL OPENINGS

Unless an opening in a wall is fitted with a fire barrier device, the opening is a potential fire hazard. However, it would be extremely difficult to fit effective devices to all openings, such as normal building access doors and windows and the hazard associated with these is generally accepted as a considered risk. In the case of openings between many equipment and plant rooms, for example transmitter and transformer vault areas, this would not be acceptable.

Where openings of access doors and lead-through cut-outs are required to be fire protected, it is desirable to limit the aggregate area of the openings. This is necessary because it is not an easy matter to give the same level of protection to an opening as that afforded by the construction in which the opening exists. *Figure 36.3* shows a lead-through arrangement for vault equipment associated with one transmitter that falls short of requirements. The busbars have been taken through a sheet of Perspex mounted in a wooden frame. A more suitable arrangement would have been to fit a thick steel plate in an iron frame and take the busbars through suitably dimensioned lead-through porcelain insulators. Materials which are combustible or have a relatively low melting point are unsuitable in this situation.

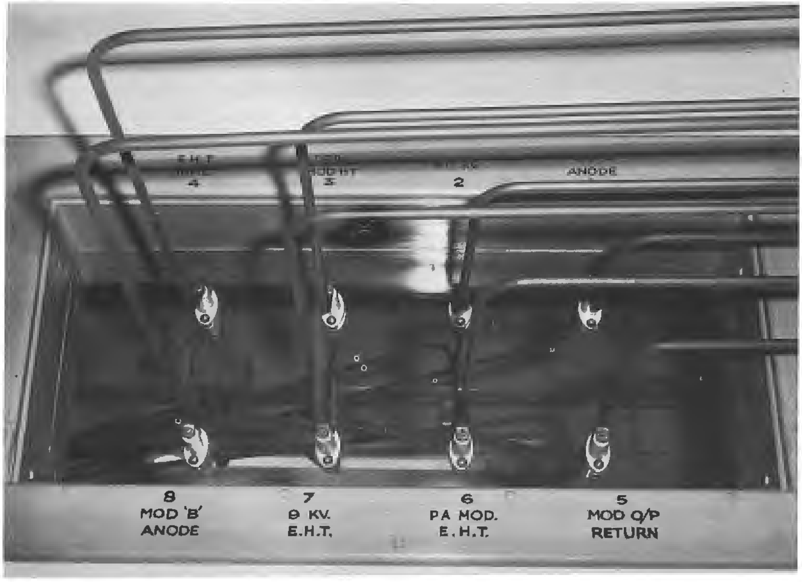

Figure 36.3 Unprotected lead-through arrangement for hazardous area

Where insulated busbars or cables are employed a metallic transit unit has found wide application. It is a rectangular metal frame set into the wall through which the busbars or cables pass. Insert elastomer blocks of half block sections grooved to fit individual cables are fitted over each cable. A positive seal is made by compressing the entire assembly.

The material of the insert block expands when heated and forms a firm, incombustible seal. As the insulation of the cable is consumed in the fire the seal fills in the gap so preventing the fire from passing through the wall. The material has been tested to withstand a temperature of 1100°C for three hours and it is also effective as an oil barrier so that oil from a ruptured transformer will be blocked from entering ducts and chases in the floor.

Openings in fire barriers to allow the passage of air exhaust and air conditioning ducts should be protected by automatic fire dampers located inside the ductwork, and in the section that passes through the barrier. Ductwork materials of low melting point, for example, fibre glass materials, should not be used. Most Codes stipulate that installations be so made that the possible spread of fire or products of combustion through fire-rated fire resitant or fire stopped walls, partitions, ceilings and floors, ventilation and air handling ducts will not be substantially increased.

The principle to be adopted for openings through fire barriers, is that all openings, including cable holes, should be fire-stopped by blocking them with suitable non-combustible materials.

FURTHER READING

Electrical Transmission and Distribution Reference Book, Westinghouse Electric, East Pittsburgh, 1950

Chapter 37

Lightning Hazards

LIGHTNING PHENOMENON

The protection of the station against fire and damage caused by lightning is probably one of the most difficult tasks which confronts the radio engineer. Practically every radio station uses a steel mast or tower and the attraction for lightning possessed by these structures and antennas is very common, and in fact one of the major sources of trouble at many stations using tall structures is from lightning which causes not only service interruptions but also severe damage to equipment and plant. The damage is the result of fire from arcing and heat and from mechanical forces produced by the passage of a large current through impedance in the path of the discharge current.

The cost of repair can be very high and includes cost of replacement of the damaged equipment, labour charges and incidental expenditure such as motor transport to the site. The loss of revenue due to break in programme transmission or traffic could be considerable. The cost incurred in repair of the damage at the time may not always be the final cost as a result of the lightning stroke. In addition to the immediate damage severe electrical and electromechanical stresses on equipment and components may result in subsequent failure and their origin in the lightning stroke may not be recognised or appreciated.

An analysis of one network comprising some 90 major broadcast, television and radiocommunication stations spread over a region with an isoceraunic level (the number of days that thunder was heard) varying from 10 to 20 indicated that there were 252 instances of damage resulting from lightning. For every fault in radio equipment there were about 1.5 faults in the power supply facilities spread over fuses, protectors, cables, transformers, switchboards, switchgear, meters and voltage regulators.

The figure covered a five year period and also showed that damage incurred at major stations occurred more frequently than at minor stations such as translators even though much more elaborate protection and earthing facilities were provided at the major stations. A contributing factor to the lower incidence at small station was that the stations were mainly installed at relatively unexposed sites and structures were much smaller.

In a three year study of a network in Japan, comprising 419 microwave radio relay stations, lightning caused damage at 299 of the stations. It was found that the lightning damage occurrence rate increased almost proportionally with the isoceraunic level, and that it was necessary to introduce into station design standards a classified risk assessment for lightning.

Masts and towers whether erected on flat terrain or on high mountain peaks are usually well above the local natural features and this circumstance makes them prone to lightning strokes. This is particularly so in areas of high isoceraunic level, and when coupled with conditions of high soil resistivity, as is often the case on many radiocommunication and television station mountain sites, the protection of equipment and safety of staff becomes a major problem.

Lightning phenomenon is made manifest by a discharge between cloud and earth or cloud and cloud. As a result of certain processes which take place during periods of thunderstorm activity, an accumulation of electric charge occurs in the cloud. The generally accepted theory is that the charge arises from the presence of a large number of ions in the atmosphere. These charges have their counterparts in equal and opposite charges in the earth.

As the charges grow, the potential between cloud and cloud, and between cloud and earth increases. As a result of measurements with balloons, it has been estimated that the gradient in the region between cloud and earth is sometimes nearly 1 MV per 300 m. On this basis, a 3500 m cloud would have a potential at the base of over 10MV. The average power per stroke is about 100 million MW.

In the formation of a stroke to a mast or tower, the potential gradient is most intense in the vicinity of the charged volume of the cloud. When the gradient exceeds the dielectric strength of the air across which it appears, the intervening air breaks down and an initial discharge will take place from the cloud to earth via the structure. This initial discharge, or pilot leader as it is sometimes called, carries a charge with it, and as a result of this, the potential gradient directly ahead of it is high, and further breakdown of the air space ahead of it follows. The leader darts forward in an irregular path and charges the stroke channel. The amount of current in the leader is not very high and has been estimated to be less than 100 A. Also its velocity of propagation is not very high, being less than 50 cm/μs compared with 300 m/μs for the propagation of electricity along a conductor.

As the tip of the leader approaches near the structure, the electric field increases in intensity and eventually a short upward leader rises from the earthed structure and meets the leader from the cloud. When they meet direct contact is established between cloud and the structure, and the high impulse current then flows. During the discharge, enormous currents can flow, and in a severe electrical storm many simultaneous discharges can occur.

Following the discharge, the potential in the charge centre will drop rapidly, but quite frequently other adjacent charge centres in the same cloud may discharge into it and traverse down the same path. This effectively produces successive peaks of current in the path and these can sometimes be seen with the unaided eye, as a flicker.

It is well known that tall masts and towers are struck more often than short ones. The reason for this is that when the path of the leader is close enough to the top of the structure, the electric field between leader and structure becomes sufficiently intense to cause the propagation of a leader from the structure, and when the two leaders meet the stroke current passes through the structure. If however, the leader approaches the earth at some distance from the structure, it is not cognizant of the structure and contacts the earth. In this way, a tall mast or tower, particularly if erected in an exposed position and well above surrounding objects, draws to itself leaders that without the structure would have discharged directly to earth in its vicinity.

DISCHARGE PATHS

When considering a lightning stroke to a mast, tower or antenna system, three discharge paths are possible.

In the first path which the stroke may follow, the capacitance between the leader and earth is discharged very quickly. The capacitance from the pilot leader to an earthed tower or insulated wire antenna system is discharged ultimately by travelling wave action and produces a voltage across strain or standoff insulators. This is generally referred to as an induced charge and is seldom a problem for high power transmitting systems where insulation levels are generally high. For low power or receiving systems where a low level of insulation may be used, induced charges can introduce flashover problems with antennas, transmission lines or internal equipment and cause fire unless adequate protection facilities are provided.

In the second path which the stroke may follow, the capacitance between the leader and an earthed structure is discharged. The tower and the associated earth system may be considered to be an inductance and resistance in series to the resultant travelling wave, and consequently a high potential may occur at the tower top. If the tower is supporting an insulated antenna system, the voltage difference may be sufficient to cause flashover with consequent damage to radio equipment.

In the third path, the capacitance between the leader and insulated antenna system is discharged. This injects the main discharge current into the antenna, and results in a surge impedance voltage being developed across the antenna insulators. If the discharge is of sufficient intensity, the insulation of the antenna above earth will be quickly exceeded, so causing flashover. Fibreglass insulators have been known to melt under heavy discharge conditions.

If the antenna system is an insulated mast or tower, such as used for m.f. broadcasting, with earth connection via shunt inductor or bleed choke, the voltage at the top of the structure may cause flashover of guy insulators initially, and finally damage to matching hut equipment. Flashover of the guy insulators on a mast can be particularly dangerous. In known cases, the transmitter r.f. voltage maintained a follow through with the initial lightning arc, and burnt through the wire guy rope causing it to fall to the ground.

It is unfortunate that the very tall structures required for radio purposes introduce an electrical hazard because of the effect of their inherent inductance, and the considerable time a lightning surge takes to travel from the top to the base and back to the top again. Because of this delay in propagation, the peak voltage at the top is not cancelled by the reflected wave. In other words, the reflected wave is not available at the top before the lightning current and its consequent surge voltage reaches its maximum value.

The very large potential impressed on the structural members by the lightning current creates a major problem for facilities such as coaxial cables, feeders, antennas, power cables and other services which do not carry the lightning current, if they remain at earth potential. It is not always an economic proposition to provide sufficient insulation to prevent breakdown, and where conductors must be isolated, such as power feeds to lamp circuits, some engineers have fitted surge diverters between conductors and the structure at the top. Additional protection may be required at the feedpoint at the base of the structure, and also at intermediate levels for a very tall structure, because potentials on the insulated conductors will rise as a result of the stroke current down the conductor having to cope with the inherent inductance and resistance of the conductor.

Most coaxial and feeder cable inner conductors can be effectively bonded to the structure at the top by balanced-to-unbalanced transformers or other similar arrangements, and this helps to minimise potential differences at the top. However, the speed of transmission of a surge inside a cable of high capacitance can be very slow compared with the speed down the outer sheath which would probably be bonded to the structure, and this is an important factor to be considered in designing protection measures and insulation levels for these cables.

THE EARTHING PROBLEM

The earthing of radio installations plays an important part as regards the behaviour of equipment and plant, and also the safety of staff when lightning disturbances occur. There are, however, few fields of radio engineering in which empirical methods are more largely employed.

Earthing systems vary widely in their effectiveness. Two identical systems installed at two different sites have been known to vary in the ratio of 50 to 1 in their effectiveness because of the different types of soil. In other cases, a large expenditure has been incurred in providing a complex earthing system when the same protection could have been obtained more economically by utilisation of excavations required for the tower foundation.

To afford maximum protection, a low resistance earth system is required. A question often asked is, "What should be the value of this resistance?" It is not easy to give an adequate answer to this question because, even if it were possible, the conditions of site might render it uneconomical to obtain, even if it could be achieved in practice. A recommendation of a maximum value of 10 ohm has been made in some codes but the geological, rainfall and site conditions at any one location prevent precise statements being made as to standardisation of a low limit of resistance. Naturally, the more important the installation or the greater the probability of lightning stroke, the greater would be the effort and installation work to obtain a low value. Some engineers have set a maximum value of two ohm for towers carrying high capacity microwave broadband systems because of the low level of insulation used in modern transistorised equipment.

The problems associated with earthing are often of a very complex nature mainly because:

(a) Contrary to popular belief, the earth is a very poor conductor of electricity.
(b) The earth is not homogeneous and has characteristics of which often little knowledge is available to designers.
(c) Safety introduces questions of the probability of contact by staff or fire in components which are not easy to formulate in equations.
(d) Conductors associated with earthing systems are generally buried out of sight, have complicated shape and can only be examined and their properties determined with difficulty.

(e) The installation of an earthing system in an unfavourable situation can involve the outlay of considerable expenditure, and in some cases can be a significant proportion of the total station capital cost.

(f) It is seldom that the resistivity of the earth near the surface, and more so at a depth, is known before the installation of an earthing system, and it is often only the installation of this system which gives the first indications as to the properties of the earth at the particular location.

(g) The resistivity of the top layers of the earth sometimes shows wide seasonal variations due to the effect of rain, drought, frost and humidity. In some situations, this effect may be noticeable to depths up to two metres, particularly in areas subjected to regular annual wet and dry seasons. Variations in resistance of 1 to 5 are not uncommon when electrodes are buried less than one metre deep in coarse grained soil.

High resistivity situations result in considerable voltage drop for lightning discharge currents flowing through the earth. In this regard, the earth cannot therefore be considered to be always at zero potential. A very high potential gradient can develop during a discharge and can affect a wide area of the earth's surface. As well as causing mechanical and heat damage to radio equipment and plant, a man walking across an area of high potential gradient may have sufficient current diverted through his body via his spaced legs as to cause death. The field strength on the surface of the earth increases towards the base of the tower to a maximum value at distance d to

$$E_s = \frac{\rho I}{2 \pi d^2}$$

where ρ = soil resistivity, I = discharge current from the tower and d = distance from tower.

For a soil resistivity value of 100 Ω/m, a discharge current of 1000 A and distance 1 m

$$E_s = \frac{100 \times 1000}{2\pi \times 1^2}$$

$$= 16\,000 \text{ V/m}$$

With this field strength, a deadly current would pass through the body of a man with a step one metre long if a value of 1000 ohm is assumed for resistance from one foot to the other.

Some engineers consider that a lightning stroke can be such a hazard to staff working near a mast during a lightning storm that wooden walkways in the vicinity of the structure are provided with an earth mat in order to reduce the resistance in the area to a minimum.

EARTH SYSTEM BEHAVIOUR

A buried earth system has inductance and capacitance and it is interesting to assess what effect this has on a lightning discharge current of rapid variation.

When the current impinges on a buried rod, it enters the earth which in addition to its resistivity also has a dielectric constant. Thus, in parallel with the conductive current to earth, a capacitance current exists when the current changes with time. The current in the rod also forms a magnetic field which is maximum at the top of the rod and minimum at the bottom.

The capacitive time constant of any circuit is the product of capacitance and resistance. This it depends on resistivity and the dielectric constant, and for an average soil with a dielectric constant of 8 to 10, it will be about 8×10^{-9} s. For rock, a value of about 8×10^{-7} s is typical.

The inductive time constant is the quotient of self inductance and resistance. As a result, it is proportional to the square of the length of the rod. For a rod three metres long in moist soil, the time constant is about 1.1×10^{-7} s. For the same electrode in rock, the value is about 1.1×10^{-9} s.

Since all these values are less than the time generally assumed for the shortest lightning impulse, current and voltage in the rod will follow such impressed impulse of the order of 10^{-6} s without any significant time delay, and will behave as in the steady state situation.

As far as the natural oscillation of the rod is concerned, the period depends only on the dielectric constant and length (from the square root of the LC product) and for the above example is equal to about 2×10^{-7} s. This is also beyond the duration of usually assumed lightning strokes, and indicates the frequency up to which the rod behaves as a resistance.

In the case of buried wires and straps as used in radial, counterpoise and other earth systems, the self inductance of the long conductor plays a larger part with respect to the lightning currents, since the inductance increases as the square of the length. The capacitive effect of the ground does not change, compared with the rod, since only soil resistivity and dielectric constant of the earth are controlling factors.

Due to the long conductor length in many installations, the discharge current may suffer an ohmic drop, due to the internal resistance of the conductor, before it spreads out into the earth. The effectiveness of buried long conductors is limited by the degree of attenuation which is determined by the ratio of the conductor impedance to earth resistance. The joint effect of self inductance and earth resistance leads to a lower and ever decreasing wave velocity. Also, the surge impedance value decreases hyperbolically with increasing time. For a long wire, this may be 100 ohm or more for the practical start of the impulse current, and in theory decreases to zero, but in practice the impedance cannot drop lower than the d.c. earth resistance of the buried conductor.

CURRENT CARRYING CAPACITY

A factor which should not be overlooked in the design of an earth system is its current carrying capacity. Current passing into the earth from the system electrodes will generate heat due to resistive losses and this will have an effect on the moisture content of the soil surrounding the electrode. Where the earth system is used as an equipment earth, as well as for lightning purposes, small currents may pass to earth continuously, but they will as a general rule cause little heating and consequently negligible change in the moisture content of the soil. When high currents of comparatively long duration flow to earth due to equipment faults, sufficient heat may be generated to vaporise moisture, and so cause an increase in resistivity of the soil near the electrode. In theory, lightning discharge currents which may be high currents of short duration do not cause dissipation of much heat by the normal process of thermal conductivity, but in practice instances are known where heavy lightning strokes have caused the generation of steam and explosion of moist material around the electrode when the voltage gradient exceeded the critical value.

The resistance of the earth system is not affected by the high voltage gradient during a lightning discharge unless this gradient exceeds a critical value which varies with the nature of the soil. If the gradient exceeds this critical value arcing from electrode to earth will take place. This increases the effective surface area of the electrode until the gradients beyond are reduced to values which the surrounding soil can withstand. A properly designed earth system will ensure that gradients are kept well below the critical value and the resistance and resistivity can then be assumed to be unaffected by voltage.

PROTECTION ECONOMICS

Equipment can be positively protected against damage from a lightning stroke by completely enclosing it inside a metal container. However, this would be impractical in many cases, particularly for most large antenna systems.

In determining the degree of protection to be provided, it is necessary to compromise between the cost of providing protection and the consequences of being struck. The main factors to be considered are:

(a) The frequency and severity of lightning discharges. This information may not always be easy to obtain but figures on isoceraunic levels are readily available. From this, the probability of being struck can be calculated.
(b) Importance of the equipment.
(c) The nature of the system. Elaborate earth mats are required for some types of antenna systems to meet propagation requirements. A typical medium frequency radiator may require an earth mat consisting of copper wire radials at three degree intervals and extending 200 m or more from the base of the mast. When a good earth such as this is required for propagation purposes, the earth would generally be far in excess of what would be required for adequate lightning protection.
(d) Consequential loss resulting from damage. Many high capacitiy microwave radio communication terminals carry a very large volume of telephony, television, data and programme traffic, and damage to equipment particularly if fire results because of poor lightning protection, can mean heavy financial loss as well as interruption to essential services.
(e) Hazards to staff.

To meet the worst conditions, the discharge capacity of a protective device would have to be extremely large and the cost would be very high, but much less so to meet the more likely conditions. The value of the apparatus to be protected and the availability of a fire extinguishing system must also influence the money spent on protective gear. Therefore, lightning protective devices are available in various capacities to meet economic demands. If a horn gap is wrecked by a heavy lightning stroke to a mast radiator, undue concern will not be felt. The destruction of the horn gap will probably have saved expensive matching and metering equipment and prevented a fire. However, lightning is not interested in economics. If the cost of a more elaborate lightning protection was not justified and the simple horn gap was unable to deal with the big chance stroke, then the inevitable clash between the laws of economics and chance must be accepted.

PROBABILITY OF BEING STRUCK

Statistics on damage to radio installations due to lightning have a scientific and economic aim. They are intended to study the regional distribution of lightning strokes and to investigate whether this distribution is purely fortuitous or whether it is influenced by local topographical and geophysical factors. It is well known that the frequency of lightning strokes is mainly determined by meteorological influences because a lightning stroke as distinct from static voltage build-up is only possible when a storm cloud passes over the point in question and discharges. The meteorological components therefore should be separated from the others.

As a result of measurements and observations, it is possible to make estimates

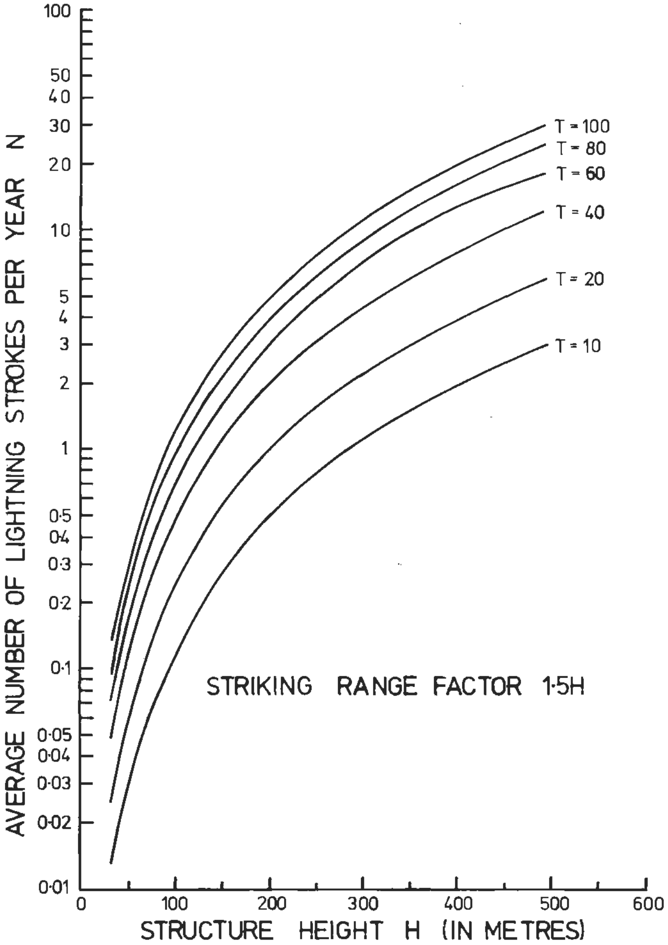

Figure 37.1 Calculated number of times structure likely to be struck by lightning

of the probabilities of radio structures being struck. In practice, the figures may vary from year to year, they may be affected considerably by local conditions and are based on isoceraunic levels which vary throughout the land.

From an economic point, it is desirable to concentrate the means available for lightning protection as far as possible at the installations where the statistically determined danger from lightning is greatest. This is not to say that lightning protection is only justified in this zone; rather it should be applied everywhere. The amount of protection applied should be determined through a consideration of the probable savings in plant damage expense and the value placed upon continuity of the radio or broadcasting service. For example, a radiocommunication route carrying high capacity international traffic would justify a greater expenditure for protection than one carrying small capacity systems for local traffic.

The annual number of times that a structure is likely to be struck by lightning can be estimated from the formula

$$N = 0.178\, T\pi\, (SH/\text{km})^2$$

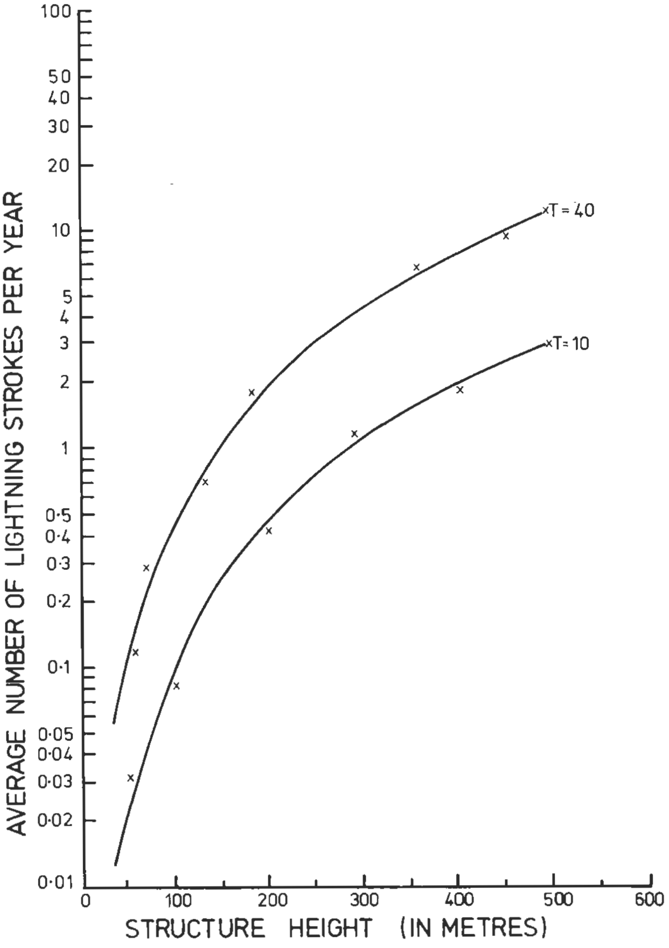

Figure 37.2 Measured number of lightning strokes

where T is isoceraunic level, S is a striking range factor and H is height of the structure.

The value of S has by no means been accurately determined mainly because of variations due to local conditions. A value of 1.5 has been assumed in this work.

Figure 37.1 shows the calculated number of strokes per year for radio masts up to 500 m in height and *Figure 37.2* shows a plot of field measurements or observations of the number of strokes to medium frequency radiators and television support structure erected in areas away from high mountains.

ISOCERAUNIC MAPS

Isoceraunic maps are published by meteorological organisations of most countries. These maps average, over a considerable number of years, the observed number of days on which thunder was noted. In fact, they are known in many countries as thunder day maps. The highest activity is in tropical areas and the lowest is in polar regions.

Although they do not give direct information on the intensity, duration, or number of strokes that occur, they constitute useful data. They are useful in estimating the probabilities of masts and towers being struck, because experience has shown that these probabilities vary with the isoceraunic level. The number of storm days per month varies throughout the year, as a general rule, but a comparison of the data obtained by several studies on the seasonal variation of the number of lightning disturbances produced to radio systems in a given region with the number of thunder days, indicates fairly close agreement.

There is no completely satisfactory way of observing and recording thunderstorm occurrence. The thunder day concept has the merit of simplicity but has many deficiencies. Some of these include the lack of information on the duration and severity of storms, on the number and type of lightning discharges and on the distribution of thunderstorms throughout the 24 hour day. Also there is no distinction made between discharges from cloud-to-cloud and from cloud-to-ground. Discharges from cloud-to-cloud are of little interest to the radio engineer as far as protection is concerned, even though they are a significant noise factor in equipment operation.

To provide a better index of lightning severity, instruments have been developed to record lightning strokes by means of the electro-static field change which takes place during a lightning discharge. The instrument records automatically the occurrence of flashes to ground over a known area. Results of readings from some adjacent stations have indicated large differences in the annual registrations and in the number of registrations per thunder day. The counters respond to a proportion of cloud-to-cloud flashes and hence a correction factor must be applied for conversion to numbers of ground flashes or of total flashes. Also, an effective range of response must be determined before an estimate of the number of flashes to ground per unit area can be made.

CONE OF PROTECTION

Because of the attraction of the mast for leaders that pass close to it, there is a region surrounding the mast where strokes are highly improbable.

Either a leader contacts the ground at some distance from the structure or approaches sufficiently close to the mast to contact it. This region is for convenience termed the cone of protection and its boundaries have always been in dispute. Various sizes to the cone have been given by workers in this field, ranging from 1 to 5.5 times the height of the structure. However, results of recent studies show that a steel structure cannot be relied upon to give complete protection within any particular zone. This is because low intensity discharges follow an erratic course to earth and are known to sometimes approach close to a structure from an angle without generating a connecting streamer. The leader may then progress onward to earth and strike a building or the earth very close to the structure.

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Chapter 38

Lightning Protection

STRUCTURE PROTECTION

Protection of a structure against lightning damage can be given by the provision of a good conducting path to the general mass of the earth. There are however some secondary effects which must be considered. The essential connections between the station building and equipment and the structure in the form of antennas, transmission lines, coaxial cables, waveguides, power and communication cables and the like, permit the entry of heavy currents into the station buildings. There is a consequent risk of fire damage to buildings and equipment, and of injury to station personnel who may be in attendance at the time of the stroke.

In the case of a structure used as an antenna, such as a medium frequency broadcast mast, an extensive earthing system is necessary in order to meet the electrical requirements of the structure as a radiator. This same earthing system doubles as an efficient earth for lightning protection purposes. However, in the case of a structure used simply as a support for, say, television, frequency modulation, radiocommunication or high frequency antennas, no earthing system is usually required for the proper functioning of the antennas. A protective earthing system is necessary to cater for the lightning problem.

In order to prevent flashover to the insulated antenna during a lightning stroke, the earth impedance should be low. Suppose, for example, that the tower footing impedance is 10 ohm and that the lightning discharge current to the tower is 10 000 A crest, then the tower potential will attain 100 kV with respect to earth. If the impulse flashover voltage of the antenna insulators is less than this value, they will most likely flash over. An analysis of many antenna insulator flashovers during lighning has shown that they could nearly all be explained by the product of the impedance of the tower earth (ohm) and the lightning current (A) being greater than the flashover value (V) of the insulators. In order to prevent or minimise such flashovers, a low footing impedence is usually sought.

The rate of change of the stroke current is also an important factor when considering insulator flashover problems. It explains those cases of flashover where the product of the tower earth resistance and the lightning current are substantially less than the impulse flashover value of the insulator string.

It can be shown mathematically that if account is taken of the surge impedence of a tall tower, high voltages can be built up at the top of the tower when a lightning discharge occurs, even when the resistance of the earth system at the tower base is zero.

The magnitude of this voltage increases with increasing stroke current steepness and tower height. The tower behaves initially as a transmission line with distributed capacitance and inductance during the time that the wave front travels to the base and returns, then as a circuit with lumped resistance and inductance, and finally as a resistance equal to the d.c. value. The laws appropriate to the velocity and reflection of waves in long conductors determine the initial voltage at the top of the tower.

Static charges have also been of concern at some stations particularly those located in dry inland regions or subjected to hot dry winds during parts of the year. The static build-up is thought to result from the deposit of ionised particles carried by the wind or by induction charging of the radiator by a charged cloud passing overhead. At least three inland medium frequency stations with radiators exceeding 200 m in height have reported regular guy insulator flashdown during summer periods. All three are located in grain growing areas where dust, minute straw particles and carbon particles from burn-off operations are regular ingredients in the atmosphere during summer months. Staff living on site and nearby residents reported noise similar to rifle fire occuring for intervals of up to 5 or 6 seconds as arcs occurred on flashover of the top set of guy insulators in turn from top to ground level. Even in daylight, arcs could sometimes be seen.

A major problem which frequently occurred was that the flashover across the guy insulator initiated by the static discharge was maintained by the transmitter radio frequency voltage resulting in a modulated arc. At one station the staff could hear the station programme. The insulator cracked and had to be replaced. Impedance monitors have been found to be effective in detecting this type of condition in order to momentarily switch off the transmitter.

EARTHING SYSTEMS

The extent of the protection offered by the structure depends on the degree to which the earth system diverts discharge currents away from the building and equipment. There does not appear to be agreement among the various authorities and administrations for a minimum value of earth impedance for diversion of these discharge currents. On some radiocommunication routes carrying international traffic, there are specifications calling for a maximum of 2 ohm whilst others, rather than specifying impedance value, require a buried network dimensioned in relation to the size of the installation.

The desirable characteristics which an earthing system must possess may be listed as follows:

(a) The system must carry such currents as are likely to arise from equipment faults and lightning strokes with the minimum potential rise above earth or other conducting objects in the immediate vicinity.
(b) The system must carry such currents for the maximum time likely to occur, without overheating or damage.
(c) The system must have sufficiently low surge impedance to prevent flashover from earthed metalwork to insulated conductors or flammable material during lightning discharges.
(d) The impedance of the system must be reasonably constant throughout seasonal cycles.
(e) The materials used in the system must have high resistance to soil and atmospheric corrosion.
(f) The cost of the installation must be as low as possible.

It is not often appreciated that the conductivity of the material constituting the earth's surface is very low compared with the high conductivity of many metals. Two main constituents of the earth, silicon oxide and aluminium oxide, actually are highly prized radio type insulator materials, and the conductivity of the earth is due in large measure to salts and moisture embedded between these insulators. However, even a very poor conductor will carry a large current if the cross section is made large enough and fortunately in this respect the earth by its great volume presents no limitations.

A considerable amount of information is available on earthing, but soil resistivity, geological conditions, rainfall, and site conditions prevent any precise statements being made as to the standardisation of a low limit of site resistance. The resistance obtainable at any one site depends very largely upon the impurity of the moisture saturating it. Unfortunately, in areas where lightning is high, the rainfall is usually heavy, and conducting salts in the soil are leached out of it. This is the position generally on mountain tops and in tropical areas where vegetation does not always provide a source of acid from which salts can be derived.

In addition to the economic aspects each site will have its own particular features to be taken into account when designing a protective earth system. Some situations may dictate that only one system is appropriate while others may allow any one of a number of systems to be installed. In selecting a particular design of earth system and conductor sizes, its current discharge limitations must be recognised. If these limitations are exceeded, the material around the conductors in the ground may be exploded by steam generation or may be dried out, particularly during a prolonged equipment fault, to the extent that the resistance becomes very high.

RADIAL SYSTEM

This method utilises a system of regularly spaced stakes driven as deeply into the earth as is practical under the prevailing site conditions, set out in radial lines and interconnected by conductors of suitable cross section buried in the earth. The number and length of such radials are dictated by the earth resistivity as found by measurement at the site.

At a typical 250 m guyed television mast installation on an elevated site, several earth rods are driven at the mast base, at each guy block anchorage, and at appropriate points around the station building, then radially bonded together by bare strap buried about 30 cm below the surface. All normally earth metalwork including mast, guys, structural steelwork, building roofing etc. is bonded to the earth system by short runs of wide strap to ensure low impedance discharge paths. Resistances as low as 0.4 ohm have been obtained with this method.

In designing any system it must be appreciated that the effective impedance of the earth system is its surge impedance. To achieve low values of surge impedance, experience has shown that it is better to provide a greater number of short radials rather than a few long radials. Many hilltop radio installations are provided with radial earth straps about 5 cm wide at about 60 degree spacing and up to 30 m in length with each end terminated with two or three earth rods tightly fitted into drilled holes or driven up to 2 m into soil. At some sites where lightning problems are not great, only four radials have been provided with satisfactory results. In these cases, however, it is usual to install the stakes at much closer intervals along the radials compared with systems using larger numbers of radials. Overall there is not a great deal of difference in cost.

Measurements show that the effectiveness of buried radial conductors decreases when their number is increased beyond a certain point. There is seldom little additional benefit in increasing the number of arms beyond six. However, from a lightning point of view, a radial system with many conductors has the advantage over a simple system of only a few conductors in that its facilitates in the discharge of the very steep fronted currents.

There have been many stations built on mountain tops where there is a complete absence of soil and where the rock is so hard that it can only be removed by intense blasting. The provision of a low resistance earth system under these circumstances is very difficult. One method which has been used in many such localities is to lay out a system of radials at about 5 degree spacing to a distance of 50 m, where space permits. The radial wires are laid on the surface, held down by rocks or pins power driven into rock crevices. At some sites concentric bonding has also been employed so that the whole earthing system takes on a spider web appearance. The relatively high capacitance of the screen provides a reasonably low impedance path to dump the steep fronted lightning discharge.

The effective earthing of guys on masts is important, except of course where the structure must be insulated for radio transmission purposes. It is not sufficient to rely on the concrete anchor block to provide good earthing. Measurements have in fact shown that the resistance of some concrete footings increased with time as the block cured, to something like twice the initial value over a period of five years. Without a good earth connection there is the possibility of damage through arcing at the anchor point. Because of the high stress in the ropes, conductivity across joints can be assumed to be high. The earthing system for one 500 m guyed mast comprises a radial network of three straps 15 cm wide and 20 m long at the base of each guy anchorage. The outer end of each radial is connected to an 2 m rod and the common centre point is tied to the guy rope by a 19/2 mm cable.

CAGE SYSTEM

This system makes use of the large excavations which are necessary to provide foundations for the structure. Various methods have been used, including vertical metal sheets against the walls, galvanised wire mesh covering bottom and walls, and vertical rod systems. All have been used with some measure of success but the vertical rod system is currently the most favoured method.

In this method a cage is formed by driving galvanised iron stakes around the perimeter of each excavation. A minimum of four is used but 16 would comprise a typical installation. For soil conditions, the stakes are driven one metre but where the floor is rock, as is often the case for mountain top sites, the rods are grouted into drilled holes with gypsum and bentonite.

The tops of the rods are drawn together to form a cone and bonded with a glavanised steel strap. A strap is taken to the leg of the tower where it is bolted at a point above ground level and another taken to the adjoining excavation so that all networks are finally bonded together. All bolted connections are covered with a corrosion-resistant paste and a suitably treated tape.

Measurements have shown that resistances of 0.5-1.0 ohm have been obtained at some difficult sites with this method.

One of the problems associated with this system is that the lightning discharge will travel through the concrete block to earth and there is always the possibility of damage to the tower foundation should the rods heat to a high temperature. To avoid this, some engineers prefer to fix the rods close to the walls and leave the rods parallel to the walls rather than forming a cone. A wide earth strap from the tower leg is then taken over the surface of the block and down the side to the rod bonding strap.

Where the cage system is used for a mast used to support a television antenna etc. the single thrust block excavation may not allow a sufficiently low enough resistance to be obtained. A radial system has often been used to supplement the cage in this situation.

COUNTERPOISE SYSTEM

A buried counterpoise is provided around the base of the tower or mast and consists of a number of stakes usually about 2 to 3 m in length driven into the soil or into drilled holes. The number of stakes is determined by calculation and depends on prior investigation by resistivity measurements. The connection from each leg of the tower is made over the surface and down the side of the foundation block to the top of a counterpoise rod which is buried about 30 cm below the surface of the surrounding earth. The conductor connecting the stakes is generally 5 cm by 3 mm size mainly for mechanical reasons, ease of attachment to the stakes and to allow low resistance joints to be made. Also a wide strip has a greater capacity for discharging current than a circular conductor of equivalent metal cross section because of the larger surface area in contact with the earth.

It is interesting to note that increasing the diameter of a round stake in this and other similar types earth systems results in a small electrical advantage compared with increasing the depth. Measurements and economic studies show that it is pointless to attempt to reduce the resistance by increasing the diameter of the stakes. It is more effective to increase the length or the number of stakes. Many engineers favour star section stakes because the configuration not only gives high resistance to bending during driving, but they also give a large surface area contact with the earth.

BURIED PLATE SYSTEM

Although buried plates have been used as earth systems at many radio stations, their effectiveness and economic advantages have often been questioned. In some cases the plate is buried vertically while in others it is buried horizontally. However, both types involve considerable excavation work and heavy tamping is necessary to ensure that soil is in good contact with the plate. In many installations the plates have been bedded in bentonite which is an earthy hydrous aluminium silicate similar to Fuller's earth. Typical plates installed at several stations comprise sheets about two metres square. The thickness of the plate has very little affect on the system resistance and 1 mm sheet has been used where corrosion is not a problem. From a resistance aspect, a plate electrode is not much more effective than a simple ring of the same diameter but it has of course greater capacity for discharging steep fronted waves. Compared with a stake, a plate one metre square and buried to a depth of one metre has a resistance about equal to a single stake buried four times this depth.

To minimise installation costs where plates are proposed, advantage is often taken of foundation excavations, and the plate placed on the bottom or against a wall before the foundations are poured. In some cases the connection wire or strap is taken up through the concrete block to the leg of the tower and in others it is taken up the wall and over the top of the block, so that the discharge current does not have to pass through the block on its way to earth.

GRID SYSTEM

The grid system has been used in many situations where the nature of the earth has made the driving of stakes impractical. The system is based on the fact that the flow of current into ground from an electrode system has the same path as the emission of electric flux from a similar configuration of conductors having isolated charges. For a deeply buried system the resistance is proportional to the earth resistivity and inversely proportional to the capacitance of the electrode system and its image.

The area enclosed by the grid should be made as large as possible, as the impedance decreases with increase in area enclosed. Where a low impedance is required, criss-cross conductors may be added.

The diameter of the conductors should be such as to adequately handle the maximum discharge currents expected but, in many cases, mechanical considerations will determine the minimum sizes.

The grid conductors should be buried to the maximum depth practicable when considered in conjunction with economic aspects and the nature of the earth. Where conditions are such that the depth of the conductors is of the same order of magnitude as the diameter of the conductor the resistance will generally be very high. This is because the distribution of current in the upper semispace is virtually cut off.

The resistance of the grid is determined primarily by the largest dimensions of the grid conductors and only to a small extent by the smaller dimensions, such as cross section or thickness.

STAR SYSTEM

For many years the star system of earthing was used by some engineers for broadcast studio, radiocommunication and combined studio-transmitter installations, mainly because of the need to minimise mutual interference between different services. The system frequently adopted was to use separate earths for a.c. power, equipment and screens, and for lightning protection where structures were involved.

The separate earthing systems arose out of the belief that provided these systems could be effectively isolated, one from the other, then no mutual interference would result. It was thought particularly desirable to keep the a.c. safety and neutral earths separate in order to avoid a.c. power frequency interference into programme and low level circuits in the station complex.

The star system relies on the electrical separation by open circuit between the various earth systems to prevent mutual interference. Although in theory it provides an ideal earth system, it is extremely difficult to maintain in practice. The system is expensive to install on a large station, casual and unintentional contacts nullify the principle, and instructions regarding earthing methods when carrying out equipment extensions are usually complex and often difficult to implement. Also, because of the potential differences which frequently exist between equipment using separate earths, a hazardous situation which may be a danger to life or cause a fire can be created.

At one radiocommunication station erected on a dry sandy site where the star system was provided with separate earths for the a.c. mains, equipment and the tower, the potential difference between the a.c. and equipment earths was so high that a spark could be drawn from rack equipment when using a soldering iron earthed through the a.c. system. Interruptions to service as a result of lightning disturbances were also higher at this station compared with others along the route.

Mainly as a result of the hazards created, this type of earth system is now restricted in its use.

EARTH CONDUCTOR MATERIALS

The most common metals used for lightning protection earth systems are copper and galvanised iron. Copper is used almost exclusively where the earth system also forms part of the radiating system, such as a m.f. radiator, and galvanised iron is widely used for television, microwave and other masts and towers where the galvanised iron structure is used for support purposes only.

Copper, in addition to having high conductivity properties, is relatively free from underground corrosion problems, except in some special situations. The main reason why it suffers minimum corrosion is that it is cathodic with respect to other metals likely to be buried in the vicinity of the earth system. Hence, the designer may have confidence that the integrity of the buried earth system will be maintained over many years, provided that the conductors are of adequate cross section to perform their function and are not subjected to mechanical damage.

A major disadvantage of copper, however, is that it forms galvanic cells with buried structural steelwork, lead covered cables, etc., with which it is connected. It is therefore likely to hasten the corrosion of those metals. Some designers have tinned the buried copper to reduce the potential of the galvanic cell. The result is a reduction of the potential with respect to zinc and steel to about half, and eliminates the potential with respect to lead covered cables. Other practices adopted include liberal application of corrosion-resistant paste and treated tape, use of non-metallic cable jackets and conduits, and also cathodic protection.

The use of galvanised straps, cables and stakes for earth materials eliminates the adverse effect of the earth system materials on other buried conductors. With such a design, however, there are often situations where the protection of the earth system itself requires attention. Where this is required some form of cathodic protection, often in combination with the galvanised steel or the use of resistant steel, may be necessary.

Many areas in which masts and towers are installed are aggressive to both copper and galvanised iron. This applies particularly to soils with a high saline content. For many years, advantage has been taken of the low resistivity of soils of low lying sites which are subject to periodic salt water flooding for the installation of m.f. radiating system. However, the corrosion problem is a serious matter and some engineers have shifted their installations because of the high maintenance costs of structures and earth mats. From an examination of the earth mat materials it has been concluded that the corrosion of buried copper in these areas is due to the aggressive nature of the soil, possibly assisted by galvanic corrosion. At a number of similar sites it has been noticed that where copper radials emerge from the soil, they have corroded to about half their original diameter after only eight weeks of service. The outside of the wires were covered with a layer of green basic copper chloride with a powdery layer of cuprous oxide underneath. However, samples of the wire dug up from the normal depth of about 20 cm showed much less corrosion even after six months service. The wires were coated with a thin layer of cuprous oxide only. The chemist who carried out the analysis reported that "the corrosion product is typical of electrolysis and whilst the source of the galvanic corrosion occurring is not clear, it could be due to the differences of aeration or salt content of the soil or escape of current from the transmitter leading to anodic conditions at the surface".

A galvanised earth system has a comparatively short life in soil with a high saline content. Stainless steel, of type recommended for use in sea water, has been successfully used in many such situations. The connections to the tower legs are made via galvanised iron straps with suitably treated joints at the strap-earth rod junction. The joints are made above ground and treated with corrosion-resistant paste and synthetic tape to prevent corrosion of the joint. In areas where the corrosion problem is severe it may be desirable, after installation of the earthing system, to carry out measurements to determine whether any form of cathodic protection is necessary for the steel tower.

EQUIPMENT ON STRUCTURES

The types of antennas used for television and radio communication purposes are inherently self-protecting, but care should be taken during installation to ensure that they are solidly connected to the main structural ironwork of the mast or tower to eliminate arcing. Where coaxial cables or waveguides have an insulated jacket of polyethylene or similar material, there is no problem as far as corrosion is concerned. Galvanised iron straps and galvanised steel nuts and bolts are suitable hanger materials. It is necessary, however, to break the insulation covering at frequent intervals in order to secure a metal to metal contact so as to ensure that there is minimum potential differences between the structure and the waveguide or feeder in the event of a lightning stroke. *Figure 38.1* shows a typical insulated flexible waveguide installation at a microwave radio relay station. A protected bonding clamp can be seen at the fifth clamping point from the top.

Where the antenna system or other equipment is mounted on or near the top of the structure, a properly engineered air terminal should be installed to provide an adequate cone of protection for the equipment. This is a particular requirement for the aircraft warning lighting system, as regulations require placement of lighting at the top of most structures. Waveguides, feeders and other support facilities should be bonded to the structure at the top and bottom, as a minimum. In the case of tall structures many bonds may be required to keep difference of potential between the structure and the feeder to a minimum.

Where ice is a problem it is current practice to protect television antennas, and in some cases even radiocommunication antennas, by fibre glass shrouds. There have been cases where the shroud has been penetrated by lightning strokes resulting in the shroud catching fire. A metal grid is necessary to prevent this happening. The location of the metal work comprising the grid must, of course, be carefully chosen so as not to affect the antenna radiation pattern. Experience by one organisation has shown that for television antennas, four equally spaced peripheral vertical wires joined by horizontal bands about every two metres gives effective protection from lightning strokes to the structure and has minimum effect on the radiation pattern.

Figure 38.1 Clamping and bonding of insulated waveguide

In the case of tall structures used as radiators, it is not possible, except for shunt fed installations, to connect the base directly to a low impedance earth for protection purposes because of the high operating r.f. voltages. In the absence of protection, base and sectionalising insulators may flash over as a result of a lightning stroke. Such a flashover is not necessarily harmful, but if as is likely, it is followed by a r.f. current arc supplied by the transmitter then the insulator may be damaged unless special precautions have been adopted to prevent the arc from travelling over the surface of the insulator. Base insulators made of fibre glass are extremely difficult to extinguish should the arc cause them to ignite.

A particular problem of equipment protection exists with the sectionalised radiator where the two sections of the structure are connected electrically by a network. Sometimes this network will be an inductor to electrically lengthen the radiator, in other cases it will be a capacitor to shorten the radiator. For dual frequency radiators, a parallel combination of inductor and capacitor may be used. These units are prone to damage. Several instances of fractured support insulators and distorted coils have occurred. In some cases the lightning current forces have caused physical displacement of the coil turns, resulting in a change in inductance and so upsetting the mast matching conditons. The usual method of protection is by horn gaps.

Equipment used to supply power to a radiator for lighting purposes has to cater with two problems. One is the difficulty of taking a.c. feeder wires on to a structure with high r.f. potential, and the other is to ensure that the equipment can withstand the effects of a lightning discharge and will not ignite. For many years the feed at the base has consisted of suitably rated r.f. chokes with bypass capacitors. Although these units are frequently damaged by lightning they are still popular with short masts and low power transmitters. For tall masts and high power transmitters an isolation transformer with a large air gap is commonly used. This gives good r.f. isolation and also has good lightning protection properties when used with the standard horn gap. *Figure 38.2* shows a typical isolation transformer. In this particular installation the unit was mounted inside the matching hut and used in conjunction with a pair of high voltage r.f. chokes. A similar isolation transformer, but without the r.f. chokes, was used at the mast sectionalising point.

Figure 38.2 Isolation transformer

GUY INSULATORS

The protection of insulators in guy or catenary ropes is not an easy task. There have been many instances where insulators have been completely destroyed or cracked by the direct effect of lightning discharge or by a sustained r.f. follow-on arc from transmitter power. Many guy ropes have also been burnt through or severely damaged as a result of insulator flashover because infra-red detectors had not been fitted.

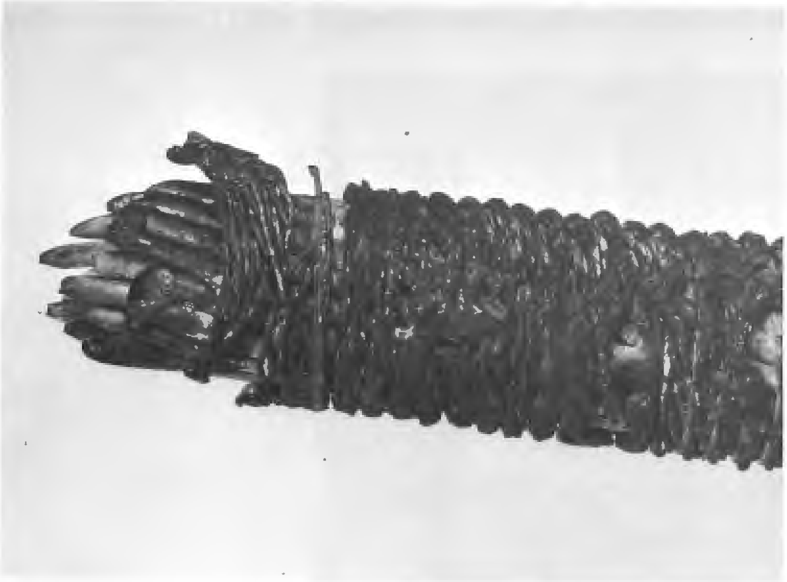

Figure 38.3 Burnt-through guy rope

Although hollow insulators have been used for many years as guy insulators, they are being superseded by solid types because of many failures which have occurred in areas of high lightning incidence. *Figure 38.3* shows a complete burn-through of the guy rope of one large radiator and *Figure 38.4* shows the associated hollow type insulator damaged as a result of the arc. The arc took place from the right hand insulator metal end cap to the rope.

Figure 38.5 shows a solid type insulator which does not suffer from this drawback. The rope is well removed from any flashover point. Any arc which may occur would be across substantial steel fittings, and being exposed, would be quickly extinguished. In the hollow type, the rope is virtually shielded from air movement and the gas build-up inside the insulator from vaporised materials tends to prolong the arc and increase its intensity.

In the case of egg type insulators, the arc occurs over the face of the insulator and causes chipping, cracking and sometimes complete shattering. The replacement of guy insulators and other types used for wire rope break-up purposes is a difficult and expensive operation and extra design effort to ensure adequate protection is well worth while. Replacement is also a hazardous operation and mast collapse is not unknown as a result of this work.

Normal practice for the determination of the location of guy insulators in the

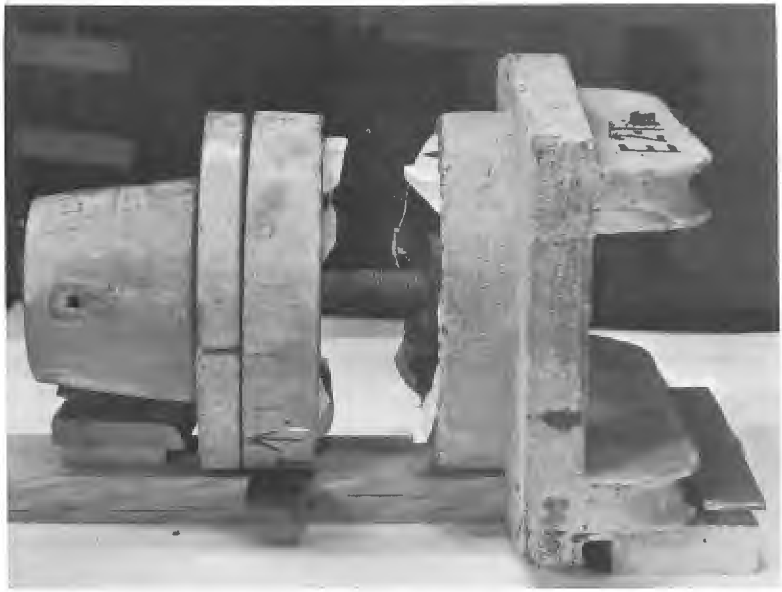

Figure 38.4 Damaged hollow type guy insulator

Figure 38.5 Solid type guy insulator

rope is often to simply divide the guy rope into an equal number of sections. This of course results in some insulators being more highly stressed voltage wise than others. Where high voltages are concerned the best procedure is to design the spacing so that the potential across each insulator is approximately the same.

The insulator near the anchor block is however an exception. Correct spacing will also give an even voltage distribution when the potential of the mast rises as a result of a lightning stroke.

BUILDING PROTECTION

Experience with many mountain top radio installations in areas of high lightning incidence has shown that the most effective method of protecting equipment and staff inside a building is to install a type of Faraday cage around non-metallic buildings. If the building is constructed of reinforced concrete, the metal beams and reinforcement can be utilised to provide the cage. If the building is of masonry or wood construction, a screen of wires of straps erected on the outside of the building will provide the same effect.

When a lightning discharge occurs, the currents flowing in the metalwork forming the cage, create a magnetic field inside the building but it is of relatively small amplitude and no dangerous potentials exist in the ideal case. However, because a compromise construction is generally used there will be some potential difference between metal parts, the extent being determined by the efficiency of the cage. In any case, an external counterpoise or other type earth system is provided as part of normal equipment earthing and bonding requirements, and this minimises any potential difference rise in equipment. Buildings constructed on the Faraday cage principle have proved their merit in many severe lightning areas whereas other types of construction with the roof, guttering and other metal parts connected to earth in the usual manner, have resulted in covers of junction boxes and the like being blown off, equipment damage, cable failures, and in some cases fire outbreak, during a lightning discharge.

The type of earth system provided for the building protection is governed by the type of building construction. In the case of reinforced concrete construction, many designers consider the metal reinforcement members of the foundations and floors when the concrete is in contact with the earth, provides a good earth point for the building. The steel bars are welded together at a number of points to ensure electrical continuity and galvanised straps brought out to appropriate locations in equipment rooms. As an alternative arrangement the reinforcing bars are not welded together, but several are extended within the building and bonded together by a strap laid around the edge of the foundation. This type of earth is inexpensive as very little additional material or work is involved beyond that required for the building construction. Resistances of less than one ohm have been obtained by this technique at some stations.

This principle has also been used to provide a low resistance earth system in an area where earthing conditions are unfavourable. Tests have shown that a concrete encasement contributes to the reduction of earth resistance. At one station on a rocky site with a footing type concrete building foundation, 12 mm diameter bare stranded copper cables were embedded in the centre of the concrete footings approximately 5 cm above the base of the footing. The outer footings were 60 cm below ground level, 37 cm wide at the base and in the form of a rectangle with sides 10 m by 17 m. Two copper cables, each 20 m in length, were embedded in the concrete and run in opposite directions. One end of each cable was brought out of the concrete and connected to the transmitter earth busbar. Eight weeks after installation the resistance was measured at 2.6 ohm.

Three years later the resistance had not changed. There are however many engineers who do not favour this method because of the possible damage to building foundations in the event of a large discharge current. Many cases are on record where lightning discharges passing through tower concrete foundation blocks have resulted in explosion and damage to the foundation. There is also evidence that in some installations of this type, the earth resistance showed a gradual rise with time as the moisture of the concrete dried out.

Another form of building earth, consists of a counterpose constructed around the external perimeter of the building. A buried conductor about 5 cm by 3 mm surrounds the building about 1 to 2 m out from the foundations and is bolted to stakes, about 2 to 3 m deep, driven into the ground or tightly into drilled holes if rock is encountered. The numbers of stakes required to achieve a certain value of resistance is governed by the resisitivity of the earth at the site. However, stakes separated by spacing less than their length will contribute very little to overall reduction in resistance. Where the counterpoise earth system does not provide a resistance equal to the designed value it is often supplemented with a radial system.

Earth systems provided for the tower and building should be solidly bonded together. In order to test independently the two earths at the annual inspection routines, the bonding between the two systems is generally carried out via removable links above ground level at the tower base.

Where metal runways are provided to support waveguides and coaxial feeds between building and the tower, the runway should be securely clamped or bonded to the tower. Where entry is made into the building, the complete assembly including, runway, waveguides, feeders and the like, together with the metal entrance port should all be bonded together and connected by a low impedance strap to the building earth by the shortest path.

All other metal work including plumbing, building structural members and metallic equipment mounted on the external building wall and which may supplement the building earth or which might have a difference of potential, during a lightning stroke should be bonded to the building earth.

EQUIPMENT PROTECTION

Although the station building and equipment mounted therein may be protected from a direct stroke by virtue of the cone of protection offered by the mast or tower, heavy currents may enter via waveguides, coaxial feeders and pipes if inadequately bonded and earthed. Also, currents from lightning may enter via power and communication cables. Nearly every direct stroke will have some effect. Sometimes it may only be an arc between two metal objects or a blown fuse, but on other occasions cables may be punctured, circuit breakers may explode, instruments and terminal blocks may be damaged, and internal flash-over of radio and electrical equipment may result in large scale destruction and fire.

At one f.m. broadcast station during a period of intense storm activity an e.h.t. transformer, 12 mercury vapour rectifier tubes, two power amplifier tubes, and four meters were severely damaged in the transmitter over a period of three days. Records show that 50% of faults in 10 years were traced to lightning.

To minimise excessive potential gradients, a ring earth busbar is often installed around the inside of the equipment rooms to facilitate earthing and bonding of equipment and all metal work of the building. The busbar is connected to the main building earth system at frequent intervals, and for long busbars, at intervals of at least 6 m. Both ends of the busbar are connected to the earth to ensure low impedance by multiple earthing and bonding paths. In addition to equipment racks, frames and cubicles, incidental metal work such as window and door frames, plumbing, air conditioning duct work, filters and louvres are also earthed. Although this form of earthing is generally satisfactory for broadcast, television, and many forms of radiocommumication stations, two separate systems, a signal earth and a safety earth, may be required for those stations dealing with low signal levels such as satellite earth stations. The systems would nevertheless be joined at a common external point.

Power transformers require particular attention to ensure high reliability in areas of severe lightning incidence. Although all types of transformers should be adequately protected, the protection for dry types should be carefully designed. The basic impulse strength of dry type transformers is only about half that of the oil filled units, and is consequently more susceptible to damage by lightning surges on the mains feeder.

At one television station with a pair of 5 kW transmitters using dry type mains transformers, special lightning protectors having low breakdown characteristics were connected at the incoming mains lead-in and also at the terminals of the transformers at the time of the equipment installation. However, four transformers burnt out during lightning storms in the first two years of operation, and the transformers were replaced with oil filled units. No failures occurred over a three year period following installation of the oil filled transformers.

In general, the following precautions have been adopted at many stations to protect equipment and plant:

(a) Provision of a properly screened building and a low impedance building earth system.

(b) Proper bonding and earthing of all metalwork entering the building, including waveguides, feeders, power and communication cables, water pipes and the like, and the bonding and earthing of all equipment, plant and incidental metalwork within the building with low impedance straps.

(c) The provision of arresters and high insulation levels on equipment, such as transformers, which may be exposed to high induced voltages.

(d) Inbuilt protection facilities for low voltage equipment. Frequently semiconductor diodes are used for this purpose.

SAFETY OF OPERATING STAFF

Close attention to bonding, earthing and building shielding will minimise the danger to personnel when lightning discharges via the structures. However, there remains the danger to staff working on equipment, particularly equipment connected to external lines and cables, such as telephone and control lines.

When the tower is struck by lightning, all metal work including cable pairs connected to the earth system at the station will rise to a high potential with respect to remote earths. For example, the earth system potential at a station end of a telephone cable will be very much higher than the earth connection point of the cable at say, the bottom of the hill. Since the cable joins the top and bottom of the hill, it needs to be capable of carrying high currents to discharge the hilltop potential, unless steps are taken to bypass these currents.

Experience has shown that many cables become badly damaged and often burn away during high current discharge conditions. The provision of an isolation transformer will prevent the discharge taking place via the cable conductors. Typical equipment is designed to isolate the radio station end of the cable by a minimum isolation of 30 kV. The specification calls for a minimum working voltage of 30 kV for one minute but many samples picked at random will withstand pulses up to 100 kV.

At stations such as unattended ones, where the risk to personnel is small and the expense of isolation may not be justified, protectors are sometimes fitted to ensure that a visiting maintenance technician working in the station and in contact with station earth via equipment ironwork, will not be at a serious risk if he comes into contact at the same time with cable conductors which are connected to earth at a remote point. The protectors will discharge if the difference of potential becomes too great. All conductors are considered to be earthed by their capacitance if they are about a kilometre or more in length. It is desirable that protection be provided for all working pairs in the cable and spare pairs not fitted with protection should be bonded to the station earth busbar.

Figure 38.6 shows a panel provided at one broadcast station to minimise danger to staff working on equipment racks during periods when a lightning discharge takes place via the station radiator. Each circuit from the antenna matching hut and other points on the site is terminated on a micalex panel and bypassed to station earth via a gas filled protector. The circuit then passes through a surge choke and a second gas filled protector bypass. This second protector is connected to an independent earth plate by means of a well insulated earth lead. It

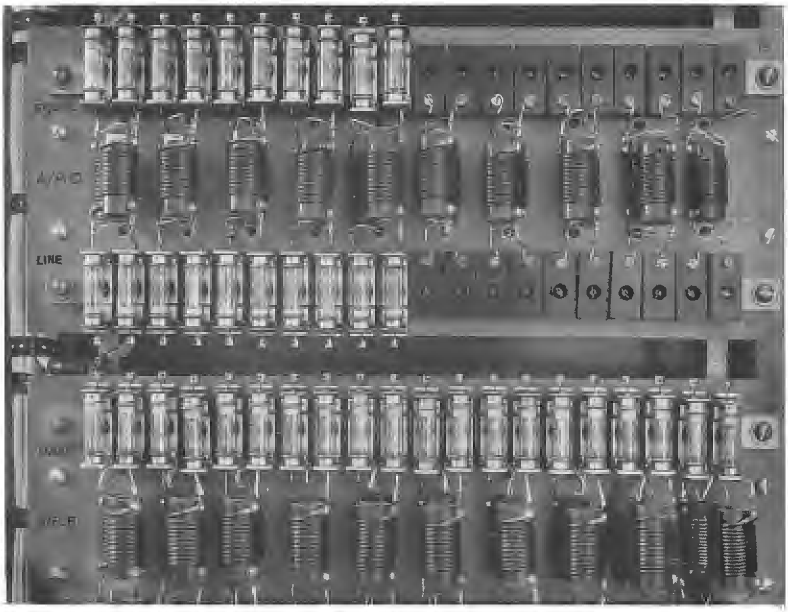

Figure 38.6 Lightning protection panel

is important to ensure that the panel is constructed of non flammable insulating material.

Open wire telephone pairs to radio stations are preferred by many engineers as there is a minimum likelihood of line damage. However, protectors should be provided on the line side of the cable lead-in to limit voltages within the building. The earth side of the protectors should be bonded to the building earth system via the shortest route. Where a property lead-in power cable is used it is practice by some organisations to install coarse protection at the pole head with protectors having a striking voltage of about 2 kV. This is backed up at the equipment end of the cable with low voltage gas protectors. Special four electrode types with electrodes arranged symmetrically around a common earth electrode in a glass bulb filled with a rarified gas are available for this purpose. When a surge occurs, the four branches are connected simultaneously to earth and provide quick discharge. Without the coarse protectors at the pole end, these fine protectors are frequently damaged under severe lightning conditions.

Another factor which will create a hazard to staff working on equipment occurs where coaxial cables and waveguides, particularly flexible types which are covered with insulating jackets are not properly bonded to the building earth at the entry point. Often these feeders fly off the tower at about 8 m or more above ground level and when the tower is struck by lightning and the potential rises to a high level, this voltage is transferred directly to the equipment rack where the cable or waveguide terminates. Several cases of fire have been reported when lightning discharged across insulated cable and components.

HORN GAPS

Horn gaps connected across sectionalising insulators or across base insulators to earth are extensively employed with m.f. radiators as a means of ensuring that voltages in excess of a prescribed maximum cannot remain on the structure. The horn gap is the simplest form of lightning protector, and is merely a shunt spark gap which breaks down at a voltage above the normal r.f. operating voltage of the radiator but below the breakdown voltage of the insulation of the radiator and the matching equipment. A typical configuration which has been used on many structures is shown in *Figure 38.7*. The angle made by the horn surfaces is such that any arc is extremely unstable and tends to travel rapidly up both horns until it reaches a gap too great for it to sustain itself.

Care should be taken to ensure that horn gaps are properly installed. Some radiators have the gaps installed from the structural steelwork member of the mast to earth rather than directly across the insultor end caps. When installed in the former manner, the horn gap spacing will change with movement of the structure, and during a storm with high winds the gap may open to several times its normal setting.

Figure 38.8 shows a typical installation at the base of a structure used as a dual frequency radiator for twin 50 kW transmitters. The multiple support insulators are prestressed oil filled types.

The particular setting of the horn gap is a compromise. If the gap is too small there will be too frequent operation on modulation peaks with a consequent interruption to transmission, and if too large there will be risk of damage to sectionalising or matching hut components or even to the transmitter.

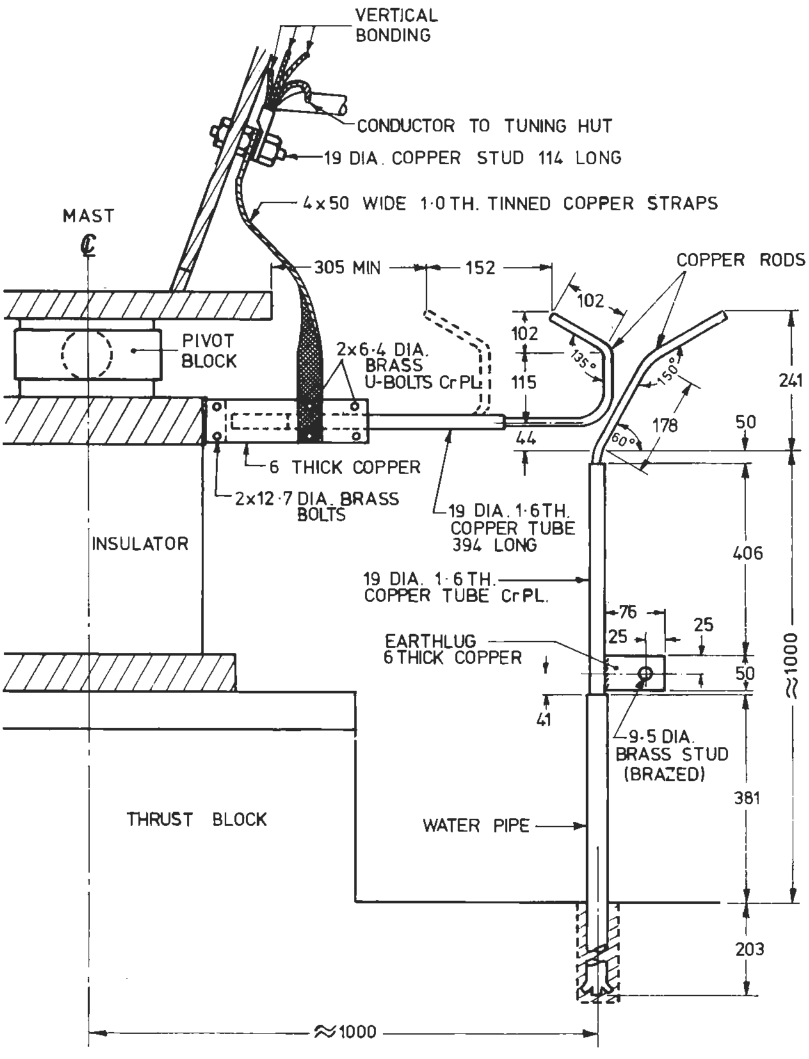

Figure 38.7 Horn gap for broadcast radiators

The main advantages of the horn gap are firstly cheapness, secondly consistency of operation with variation in applied voltage and thirdly their suitability at radio frequencies. Variations due to changing weather conditions do not greatly influence the settings employed except during rain conditions. They are however, subject to an appreciable time lag in some circumstances.

Investigations into fire and damage of matching hut equipment by lightning have shown in many instances that the spacing of the horn gap was too wide for effective protection. When this condition prevails a direct hit to the structure or a stroke in the immediate vicinity may cause voltages to be induced in the structure of sufficient magnitude to seriously damage equipment in the matching hut and transmission lines and the transmitter.

When an arc is struck across the horn gap, the power output of the trans-

Figure 38.8 Typical horn gap installation

mitter may sustain the arc until r.f. power is cut off or until the arc burns itself clear. Standing waves may also be set up along feeders due to the resonance of the tuned circuits having been destroyed by the arc. This may result in flashover of the line or at a component. The obvious remedy for this condition is to provide a means for the transmitter power output to be interrupted.

Sphere or ball gaps have been used as a substitute for horn gaps on many structures but experience has shown that they are not as effective as horn gaps. There is a much greater tendency to sustain the arc.

LIGHTNING PROTECTORS

Lightning protectors of the type commonly used for the protection of power lines and transformers have been used from time to time as a means of providing protection for masts and towers used as radiators. In most applications they have been provided additional to the horn gap.

These protectors generally consist of spark gaps between discs in series with resistance blocks or pellets. The resistance block which may contain silicon carbide has a constant voltage drop characteristic at mains frequency. However, the impedance characteristics are considerably different at radio frequencies, compared with mains frequency and they often heat excessively.

Of three installations of the pellet type in one area of high isoceraunic level, the records show that all three protectors were completely destroyed following direct strokes from lightning. There are nevertheless, units which have weathered many electrical storms in areas of high lightning incidence.

MINIMISING STEEP WAVE EFFECTS

When a lightning discharge passes from a mast into the antenna matching hut the extent of damage will be determined not only by the magnitude of the voltage

Figure 38.9 Series inductor

Figure 38.10 Shunt capacitor

but also by the characteristic of the wave front, for instance, damage to a mast matching inductor will depend on how the voltage divides between the turns.

When a steep wave front impinges on a coil, a large portion of the voltage of the wave is impressed on the first few turns. If the voltage is high, this endangers the insulation between the turns which is generally not as high as the insulation to ground. While most matching inductors have air dielectric spacing between turns, the turn spacing bars allow high voltages to track over the surface of the bars. If the bar is of flammable material it may ignite.

For a steep wave front which reaches the coil, the voltage at the beginning of the first turn is very high while that at the end of this same turn is zero at the instant of application. The coil in fact acts as a series of turn-to-turn and turn-to-earth capacitances when the wave is steep. When the wave front of the discharge is not steep, but has a gradual build-up, the voltage is more uniformly distributed among the turns and the chance of flashover is much less.

In order to minimise damage to the matching equipment from steep wave fronts, several approaches have been adopted. Some engineers prefer a series inductor of one or two turns between the horn gap and the matching hut lead-in, while others prefer a shunt capacitor arrangement. There are also installations in areas of very high lightning incidence where both inductor and capacitor are used. *Figure 38.9* shows an installation using a single turn inductor and *Figure 38.10* shows an installation using a shunt capacitor formed by two concentric tubular rings, the outer of which is earthed through the top of the glass window. For steep front waves, the inductance acts initially as a high series impedance and finally as a low impedance while the capacitance acts initially as a low shunt impedance and finally as a high impedance.

LIGHTNING CONDUCTORS

A lightning conductor is provided to conduct the lightning discharge to earth in a harmless way. Its purpose is not, as was once commonly believed, to dissipate the electrical charge in a thunder-cloud in order to prevent a structure from being struck.

Although much research effort has been associated with the use of radio-active materials for lightning conductors, there is as yet no published field proof that they provide any better protection than the conventional conductor. Laboratory tests have shown that the point-discharge currents for radio-active and ordinary conductors are not significantly different.

Although lightning discharge currents can be of great magnitude, they are of very short duration. Summarising the findings of various investigations in this field, it would appear that, on an average, 50% of lightning flashes consist of three strokes, and each stroke endures for not more than about 50 μs. There is a quiescent period between strokes averaging about 0.07 s. Measurements have shown that 90% of discharges exceed 2000 A, 75% exceed 10 000A, 25% exceed 40 000 A and 5% exceed 100 000 A. The maximum possible current in a lightning flash has been estimated to be 250 000 A. These factors are important in the design of lightning conductor and earthing systems.

As the current is of only short duration it is necessary to know the short term capacity of conductors. With short term duration currents, there is insufficient time for heat to be dissipated from a conductor by radiation or convection and it may be assumed that all the heat produced is absorbed by the conductor, the temperature rise of which is regulated only by the specific heat and the weight of the material.

It is difficult to determine accurately from theoretical considerations alone,

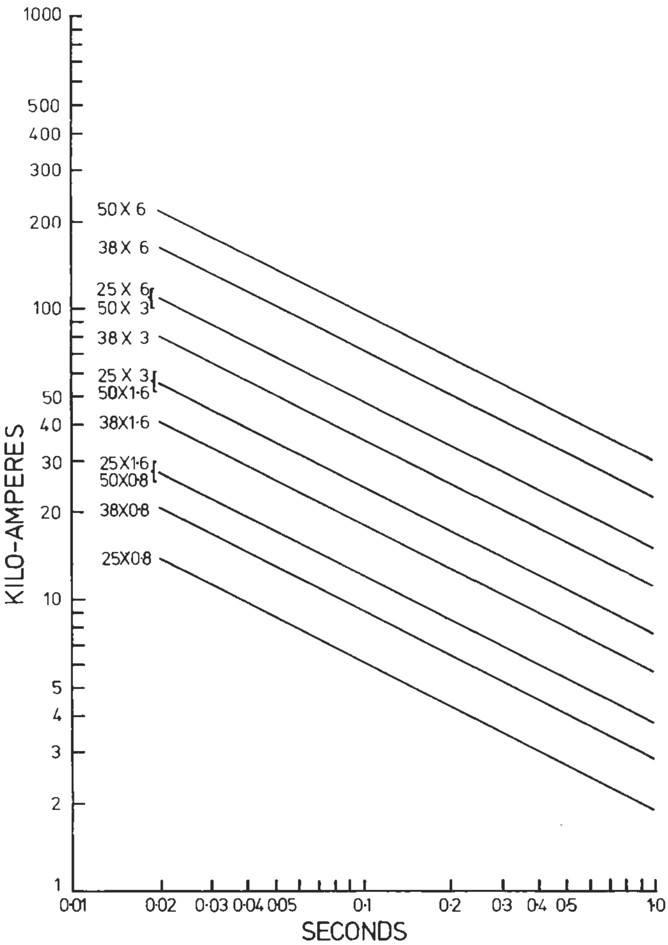

Figure 38.11 Short term rating of rectangular conductors for 50 °C temperature rise

the temperature rise of a conductor under high current short duration conditions, but for an assumed 50 °C temperature rise condition, *Figure 38.11* shows the ratings of typical rectangular copper sections commonly used in radio station earth system design. Although an exposed copper conductor would generally be capable of giving satisfactory performance well above a 50 °C rise there are times when conductors, particularly those of the cable type, are covered with p.v.c. or pass over materials which could be ignited or damaged should the conductor temperature rise to a high value.

Flat solid shapes are the preferred configuration for lightning conductors. The impedance of flat braid material is considerably higher than that of solid rectangular form and a few per cent higher than round cable. Experience has shown that braid used with horn gaps of mast radiators is severely damaged with heavy discharge currents. Widespread fusing of individual wires often results and the braid suffers considerable distortion. *Figure 38.12* shows displacement of wires

Figure 38.12 Displacement of braid wires following lightning stroke

at one end of a braid as a result of a lightning discharge. Round hollow conductors used as busbars in antenna matching huts have on several occasions been crushed when subjected to lightning currents. *Figure 38.13* shows one such damaged conductor which formed part of the matching equipment associated with a 200 m sectionalised radiator at a broadcasting station.

As a point of interest, with the increasing use of polyethylene covered flexible waveguides on radio communication towers, considerable care should be taken in the design of the lightning protection equipment to ensure that high lightning currents are not discharged from the tower via the copper waveguide. The cross sectional area of a typical 6 GHz waveguide would allow passage of a discharge current of only 25 000 A, for a 50 °C temperature rise. About 40% of stroke currents exceed this value. Polyethylene is flammable and is classified as slow burning.

Steel masts and towers do not present much of a problem in so far as handling and lightning discharge current is concerned. The high conductivity of the material allows even the highest currents to be handled with little effect on the structure. The problem is not so simply solved with the tall concrete structures now being erected in various parts of the world. The handling of currents

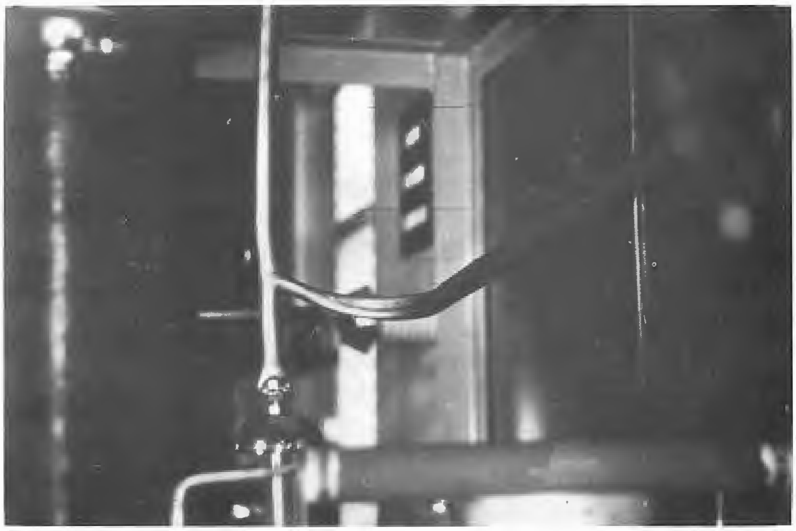

Figure 38.13 Crushed copper tubing of matching equipment

resulting from direct strokes requires special consideration during design, and facilities have to be built-in during the erection process.

The majority of these structures are constructed of reinforced concrete and the reinforcement material is frequently used as a lightning conductor. In some cases the reinforcement steel is used by itself and in other it is supplemented with copper conductors fixed to the outside of the concrete shell. The following are typical examples:

(a) The 200 m Post Office Tower, London, is an example where the reinforcement material only is used. The main and secondary air terminations are connected to the reinforcement steel bars, all of which are bonded together by welded joints. At the base of the tower the bars are connected to an earth electrode system driven into the blue-clay subsoil beneath the concrete foundation.

(b) Lightning protection for the 300 m Munich concrete tower is provided by five copper rods about 12 mm in diameter mounted vertically on the outside of the tower and bonded horizontally at about 4 m centres. These copper conductors are brought together at the base of the tower and brazed to a copper plated buried beneath the foundation. All the steel reinforcement material of the tower is bonded horizontally and vertically and this also is terminated on the copper earth plate. At the Stuttgart tower which has a similar lightning protection facility, there is visible evidence of several lightning strokes on the tower. With one recorded stroke it was reported that the station was out of service for three hours following damage to the power wiring circuits.

(c) For the J. G. Strijdom Tower in Johannesburg, erected in 1971, the earth electrode consists of a 25 mm x 3 mm copper conductor buried around the periphery of the site approximately 43 m x 27 m under the lower basement floor some 7 m below ground level. It is bonded to 19 strand earth leads and to the floor vertical reinforcement steel by high tensile bolts and crosby clips, respectively. No special precautions were taken to establish bonded connections in the reinforcement up the length of the tower, reliance being placed on the large number of random connections at tie points. A 38 mm × 3 mm copper conductor serves as an earth lead within the tower and is accommodated in one of the vertical ducts. It provides a convenient earth connection facility for building wiring, hand rails and steel stairways. It is bonded to the tower earth at the base and to the reinforcement steel at the top of the concrete structure, 230 m above ground level.

The base of the steel mast on top of the concrete structure is bonded to the steel reinforcement and the 38 mm × 3 mm copper earth lead. A 25 mm × 3 mm copper conductor is fitted to the steel tower and terminates on a 1 m stainless steel air terminal at the top of the mast.

(d) For the 330 m Emley Moor tapered concrete tower and its cantilever topmast supporting television transmitting antennas, lightning protection is provided by peripheral bands placed outside the tower at vertical intervals of 91, 182 and 274 m and additionally around the plastic antenna shroud. These bond the steel reinforcment, miscellaneous steelwork, doors, ladders aircraft warning lights and the antenna mast into the protective system terminating in four driven rod electrodes outside the tower.

A method of protection which has been finding increasing application in recent years is known as the LEA dissipative array system. According to the theory developed by its designers, strokes are prevented by slowly leaking off the storm generated energy over an extended period of time. The array systems are composed of one or many elements, each designed and employed to make use of the point discharge phenomena. Many hundreds of special points, combined with the associated ion streams, form minute electrical paths from the protected structure to the charged clouds. The resulting current flow prevents the build-up of sufficient electrical charge to permit the formation of a stroke channel to the facility. Secondary damage and fire losses are substantially reduced by inhibiting the influence of nearby stroke-induced transients and by preventing the fire hazard associated with the secondary sparking phenomena.

Since 1972 when the first LEA installation was accomplished, hundreds of these dissipative array systems have been installed throughout the world in areas with isoceraunic levels as low as 10 and as high as 260. Although design parameters are not readily available, reports on the effectiveness of many installations which replaced unsatisfactory conventional types indicate a high level of confidence in the system.

Another method, described as an integrated protection system, has also found application in high lightning areas. It uses an electrode assembly enhanced by electron sources with the electrode being coupled to a high voltage low impedance coaxial down conductor. The success of the system relies in the provision of a continuous supply of free electrons at the top of the lightning protection system.

These free electrons are intended to reduce the time lag from application of voltage to initiation of the streamer. The ionising sources are manufactured under licence with the source holders being gold plated to enable the terminal to be exposed to the atmosphere for long periods even under conditions of a poluted environment. Under ideal conditions the terminal has a designed protective radius of up to 250 m but this reduces with increasing height due to the erratic behaviour of low intensity discharges. The coaxial cable down lead provided with this system has an impedance very much lower than the normal bare conductor, with a result that the voltage between conductor and screen is less. The lightning discharge current is therefore contained within the cable and minimises side flashing to waveguides and feeder cables on the structure.

Right angle bends in lightning conductors should be avoided where possible. Conductors should always be firmly anchored but for right angle or sharp bends special anchoring arrangements may need to be provided. A high discharge current will produce an enormous force which will tend to straighten the bend. U type bends may also require special treatment because the inductance created by the half turn may be sufficient to cause a voltage flashover as well as physical movement. A current may have a 5000 A/μs rise rate.

POWER MAINS FEEDERS

Radio equipment is often damaged from lightning surges originating on the mains supplying power to the station. This problem has in recent years become of major concern due to miniaturisation of components and the use of transistors and printed circuitry. The use of this equipment has accelerated the need to provide adequate protection not only under lightning conditions but also for line switching surges.

Although protectors installed on the primary side of the station distribution transformer will provide for protection of the transformer if properly engineered, they do not always provide sufficient protection for equipment and plant connected to the secondary. At some stations, particularly radio communication stations where secondary voltage may be 240 V, it is practice to install a protector at the service lead-in point which will limit all surges to a peak of 2 kV. This will in most cases provide adequate protection for much of the power and lighting equipment but further protection to limit surges to peaks of 1 kV may be necessary for many equipment feeders.

At other stations, isolating transformers of unity ratio have been connected across the secondary of the station distribution transformer. These isolation transformers are designed for an insulation level of at least 25 kV at mains frequency with low capacitance between primary and secondary windings. The transformer is protected with protectors on both primary and secondary sides. The transformer cannot of course protect against voltages higher than the insulation level of the transformer itself, but voltages of sufficiently high level to cause breakdown at this point of the distribution system would be rare. At one station where an isolation transformer was installed, the faults caused by fusing of conductors and components resulting from induced voltage on power mains were reduced from 12 failures in one year to nil, over a four year period.

The station distribution transformer provided by the power supply authority should where possible have the neutral grounded. It is advisable to have this earth firmly bonded to the station earth system. Although some difficulties have been experienced with regard to interference into audio and video circuits, these problems can be solved by a well engineered installation. Power systems which do not have a path for surge currents between primary and secondary neutrals are likely to be damaged by lightning stroke at the station or on the line. When a stroke occurs, a high potential may occur across the primary and secondary windings of the transformer and be of sufficient magnitude to bring about insulation burn out. To minimise this type of failure, interconnection between primary and secondary neutrals or between primary protector earth and the secondary neutral is desirable.

Measurements and studies have indicated that with a lightning discharge of the order of 25 000 A through the lightning protector at the mains transformer, currents of about 10 000 A may flow to ground at the radio station under normal circumstances. The balance will go through the earth at the transformer and other earths on the primary neutral. With currents of this magnitude passing through station equipment and plant, it is essential to ensure that everything is connected to the common reference earth. To illustrate this point, an electric motor connected to a water pump burnt out when lightning struck the power mains feeding one television station. The station situated on the mountain top of a heavilty timbered area was provided with a large water storage tank for fire fighting purposes with an electrically driven booster pump. The motor was situated about 20 m from the station building and earthed by a single stake in the ground. The motor earth was not tied to the station earth. The heavy current which passed along the mains and through the station earth system momentarily raised the electric system to a high potential. However, the frame of the operating water pump motor not being tied to the station earth remained at zero potential and caused the motor insulation material to catch fire when an arc developed.

At many radio stations, power feeders are placed underground where they are installed on the site. Lightning protectors should be fitted at the junction of the cable and the exposed overhead conductors. A low impedance earth system, preferably below 5 ohm, should be provided at the terminal pole, and the earth point of the arrester connected thereto. Any metal protection associated with the cable system and not carrying current, such as lead sheath, wire armouring, iron conduit etc., should also be connected to this earth system. At the station end, this metal protection should be connected to the power switchboard framework which in turn should be solidly connected to the station earth system.

For a properly installed protective system, a lightning surge on an exposed power feeder will be reduced to the protector flashover voltage level before entering the underground cable. In accordance with transmission line theory, the surge will be reflected after travelling the length of the cable. The peak value of the reflected voltage will approach twice the value of the original voltage passing to the cable. The actual value will be influenced by the length of the cable through which it travels and also the steepness of the wavefront. Experience has shown that where the length of the cable installed exceeds about 20 m arresters should also be fitted at the station switchboard end of the cable. It is generally conceded that for power cables less than about 20 m in length the effect of the reflection is relatively small.

At one high power broadcast station in an area of high lightning incidence, a separate lead sheathed cable was provided for each of the three phase circuits in lieu of one single multi-conductor cable. The cables were about 50 m in length and sheaths tied together at the switchboard end, connected to the arrester earth points and the earthed station switchboard. In order to prevent dangerous circulating currents, the cable sheaths at the substation end were tied to the isolating spark gaps of the protectors and not directly to earth.

COAXIAL CABLES

The masts and towers assoicated with radio communication and television stations are frequently linked to remote equipment buildings by coaxial cables. These cables are endangered by high current when lightning discharges to the mast or tower and the use of buried standard lead covered cable is undesirable in these areas. Special sheathing and protection arrangements are necessary to minimise damage by the lightning currents.

The standard coaxial cable is covered with a plastic jacket and when lightning goes to earth from a tower the potential difference between earth and the cable sheath may be sufficient to puncture the plastic jacket. The insulating effect of the sheath can therefore be neglected and it may be assumed that the sheath of the cable is in immediate contact with the ground. The lightning current will travel along the sheath and if the ground resistivity is constant, the lightning current flowing along the sheath will find its way continuously to earth by discharge through the plastic jacket. The current flowing along the sheath decreases relatively slowly where the soil resistivity is high and it causes a drop in voltage along the sheath that appears as a sheath to core potential. The extent of the potential difference will be governed by the magnitude of the current and the conductivity of the sheath. If the value of the surge breakdown voltage between the core and the sheath is exceeded, insulation breakdown will occur. Even a lesser voltage can propagate along the conductors and appear as a potentially damaging voltage at the nearest repeater or terminal.

The problems associated with lightning can be overcome to some extent by various means. Guard wires can be laid above the cable to conduct away part of the current and thus reduce the current flowing in the cable sheath, longitudinal steel tape armouring can be laid over the plastic jacket, or longitudinal copper tapes can be overlaid on the plastic sheath.

The most recent practice which allows the standard plastic sheathed coaxial cable to be used is to lay the cable inside a galvanised iron pipe. Because the breakdown co-efficient of galvanised iron pipe to plastic jacketed lead sheathed cable is very high due to the low resistannce of the pipe and the high dielectric strength of the plastic jacket, the installation may be regarded as being immune to lightning damage. Even a bare sheath cable in contact with the conduit will benefit virtue of the lowered total resistance of sheath and pipe in parallel.

In an installed system the pipe is well bonded at all joints and through manholes, and also bonded to the tower earth system. Stakes are driven into the ground at frequent intervals and bonded to the pipe to lower the impedance of the pipe to earth contact so that it can carry more current and also to ensure that the pipe conforms to the earth potential gradient. Protection can be scaled to provide against the worst environmental conditions where economics are a vital factor. As a rough guide the required minimum length of pipe in metres is equal to the average earth resistivity in mΩ divided by three. Hence for soil of 1200 mΩ, a pipe 400 m would be required.

Even if the voltage between the cable sheath and conductors is insufficient to cause trouble, current can still travel down the conductors and damage associated equipment that has low dielectric strength. Protective devices connected between conductor and sheath, which should also represent chassis ground, can be used to limit the voltage at this point. The first line of protection would usually be sufficient to protect well designed standard vacuum tube type equipment from damage but for miniaturised equipment employing solid state components, a second stage of protection employing diodes may be necessary.

EMP PROTECTION

A man-made problem which causes the same type of damage as that resulting from lightning should also be taken into account during station design. This is the effect of a nuclear electromagnetic pulse (EMP). A nuclear weapon explosion produces intense transient electric and magnetic fields. Damage to equipment can occur at distances from the point of explosion far enough to be free from blast or other nuclear effects. Research indicates that in the case of a high altitude explosion, EMP damage to radio equipment can occur at distances greater than 1000 km.

The characteristics of the EMP are that it is a short duration pulse of high intensity with a frequency spectrum covering the range zero to at least 100 MHz. Peak electric field strength can be in excess of 15 000 V/m.

Damage from EMP effects can be reduced by practices already in use for lightning protection purposes such as shielding, filtering, voltage limiting, bypassing and low impedance earth systems. However the rapid rise time of the pulse, a few to tens of nanoseconds, requires close attention to design details to ensure that inductive effects do not mitigate against the full effectiveness of the measures taken.

Voltage pickup can occur by directly induced transients into circuits, via power main or transmission lines or from antenna systems. Although the energy introduced would probably be much below that of a direct lightning stroke to a mast or tower, the stress may be just as damaging. Lightning protective measures are not suitable for total protection against EMP. Ball gaps and horn gaps will not arc at sufficiently low voltages in the presence of fast rise EMP to protect antenna matching equipment. Fast acting gas gaps are necessary. In the case of microwave antennas the pick up voltage would be small but because of its length, considerable voltage would be developed along a long feeder particularly if insulated from an earthed structure. This could cause damage to transistors and other components if inadequately protected.

The EMP level can in most instances be reduced to a level where it will not cause damage to equipment and facilties by using appropriate voltage limiting devices, by shielding and by the provision of low impedance earths. A properly engineered shielded room is ideal but in many situations not practical. However much can be done during the building design stage to improve room and cable shielding at little additional cost.

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Chapter 39

Case Studies

The following case studies taken from Fire Department and radio station reports and records in various countries are typical of fires in radio installations and are intended to amplify points raised throughout the text concerning environmental factors including lightning, materials, protection facilities and causes of fire. They do not include fires resulting from vandalism or arson. It will be seen that combustible materials and construction and lack of automatic fire extinguishing facilities were responsible for heavy losses. The cost of providing good installation and protection may explain this deficiency but most engineers believe that the investment for adequate protection is in the long term the most economical course to follow.

TRANSMITTING STATIONS

EXAMPLE 39.1

A fire the cause of which was not determined occurred about 6.20 p.m. in a 2 kW medium frequency broadcast transmitter operating in an unattended mode and caused extensive damage to the working transmitter of a main/standby combination. The total loss was about £20 000 with little damage being caused to the adjacent standby unit and programme input equipment.

The interior of the transmitter hall was heavily smoke blackened but the steel framed, asbestos clad and plaster board lined building was otherwise virtually undamaged. The a.c. power board was badly smoke blackened and power could not be restored for two days as cable ducts had to be dried out and the power panel replaced by another with satisfactory insulation resistance following the use of water in extinguishing the fire.

Figure 39.1 shows the front of the damaged transmitter with rack mounted speech input equipment on the left and the standby transmitter on the right.

Factors which were considered to have stimulated the fire include:

(a) The high content of flammable materials.
These included Perspex covers fitted over high voltage terminals and plastic wiring insulation.
(b) Oil and wax filled capacitors which burst during the fire adding fuel.
(c) Inadequate maintenance, particularly of the air inlet filters.

At the time of the fire, the station was fitted with heat sensitive devices located in the ceiling. A contract had been let to install smoke detectors as well, but the work had not commenced.

Figure 39.1 Front of damaged transmitter

EXAMPLE 39.2

A fire at a medium frequency broadcasting station broke out about 3 a.m. and caused extensive damage. The station was located in an isolated area about 40 km from the nearest town, and staff lived on the site. In addition to three residences, the station comprised the transmitter and engine room building, an engine cooling plant building and a 38 000 litre bulk fuel storage.

The station normally generated its own power with two diesel engine generators and after shut-down, a small auxiliary diesel engine set provided power for mast lighting, crystal ovens and residential purposes. *Figure 39.2* shows the main engine generating sets after the fire. The unit in the background was down for overhaul at the time of the fire.

First warning of the fire was given by exploding corrugated asbestos cement sheeting which brought the staff quickly to the scene to find the roof burning fiercely over the workshop, binstore and passageway. All staff confirmed the fact that the fire initially was confined to the ceiling and roof area, and there was no indication of fire in any equipment or plant located on the floor of the building when they arrived on the scene. *Figure 39.3* shows a section of the damaged building.

Portable extinguishers were the only fire fighting facilities available at the station and these were quickly brought into action. However, by this time the fire

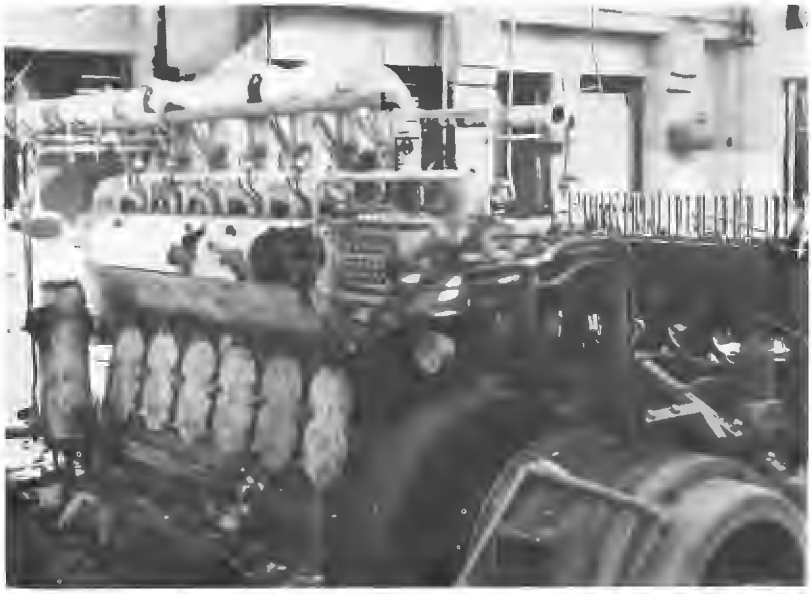


Figure 39.2 Main engine generating sets after fire

Figure 39.3 Fire damaged transmitter building

had gained such a hold that this equipment was quite ineffective. The exploding asbestos cement sheeting, intense heat and falling roof timbers prevented close approach. The entire roof structure was of pine timber construction which within a short time was a mass of flames throughout, and burning timber collapsed on the equipment in the building.

Following collapse of the roof, service fuel tanks in the engine room and oil filled transformers exploded, and boosted the fire beyond all control and hope of saving the equipment.

The water cooled transmitter, programme input and control equipment, test racks and emergency studio were completely destroyed. *Figure 39.4* indicates the extent of the damage to the equipment in the transmitter hall.

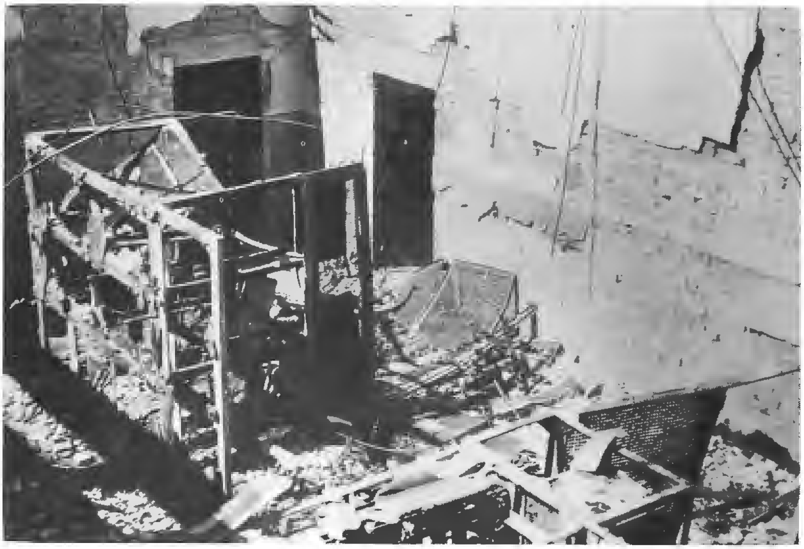


Figure 39.4 Transmitter destroyed by fire

There was no automatic fire detection or extinguishing systems installed in any of the buildings. Although there was adequate tank water supply available, there was no mobile pumping unit and hose available at the station.

EXAMPLE 39.3

The main transmitter at a 2 kW medium frequency station was extensively damaged and an adjacent standby transmitter badly damaged by heat and dense smoke given off by the burning transmitter which caught fire just prior to normal midnight shutdown time. The interior of the building was smoke blackened but otherwise little damaged. Radiocommunication systems also installed in the building were shut down as a result of the failure of the electrical power wiring. Total damage exceeded £20 000.

The station was operated on an unattended basis with alarms and control circuitry extended to a staffed centre about 17 km away. First indication of trouble at the station was evident the next morning when it was found that no programme was being radiated and the communication circuits were reported to be out of order.

When the station was visited, it was found that the broadcast transmitter which should have been transmitting on the previous evening was gutted, with no evidence of active fire or heat remaining. The control circuit had switched in the standby transmitter but it failed to start up, probably due to intense heat

Figure 39.5 Damaged transmitter

from the adjacent burning unit. *Figure 39.5* shows the extent of damage to the transmitter. The standby transmitter is located alongside the burnt out unit.

Neither the non-urgent alarm created by the failure of the 'on-air' transmitter or the urgent alarm resulting from complete failure of transmission had been received at the staffed centre due to failure of staff to switch the alarms through to an all-night attendant. This omission is not likely to have influenced the course of the fire as it appeared to have been of comparatively short duration and of great intensity.

Investigations suggested that the fire probably started in the minor high tension transformer, and oil in capacitors and various combustibles, including Perspex covers and plastic wiring, contributed to the severity of the blaze. There was also indication that the air blower re-operated after the initial failure. If this occurred the forced air draught would have substantially increased the intensity of the fire.

Points which suggested that the blower unit operated during the blaze include:

(a) The intensity of the blaze in the upper compartment suggested that it was force fed by the blower in the lower section. There was little damage to units in the lower section and only minor damage to plastic covered wiring within 10 cm of the aluminium tray separating the two areas. This tray must have been intensely hot and the condition of wiring, lack of damage to varnish and paint in this lower compartment suggested that the blower unit

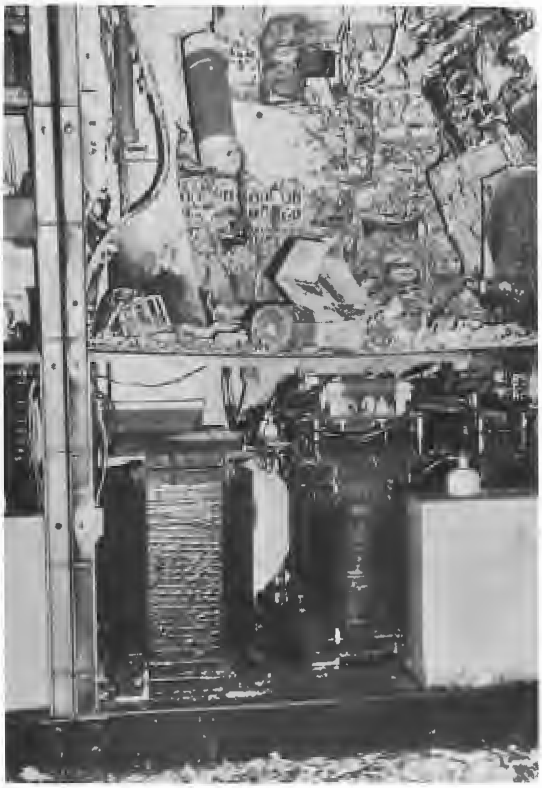


Figure 39.6 Extent of damage in the upper and lower compartments

was pulling in cooler air from outside, through the filter panel at the rear of the bottom compartment. This is evident from *Figure 39.6* which shows extensive damage above the shelf and negligible damage below.

(b) Smoke blackening down the frame of the cabinet. From the striated nature of the smoke blackening, it appeared that the air was being drawn into the lower unit at a much greater rate than would be possible by normal convection.

(c) Condition of the blower rotor. All blades in the rotor were in a uniformly clean and undamaged condition, suggesting that the rotor was turning during the worst of the fire. In contrast, the rotor in the standby unit had the external surface of the blades over one quadrant heavily smoke blackened, and the internal surface of the quadrant below these similarly sooted, indicating that the blower was not operating when major smoke generation was occurring in the transmitter.

(d) The only indications of heat damage to fibres in the filter unit were on its external surface. This external surface was also heavily sooted by combustion products, whereas the internal surface of the filter was comparatively clean and exhibited only smoke staining.

The transmitter was arranged for remote switching and, in the event of high tension overload and lock-out condition, to switch itself 'off'. To restart the transmitter, an earth controlled a chain of contactors, including the blower contactor. An earth probably occurred as a result of the destruction of plastic insulation on control circuit wiring which was in a wiring form at the centre of the blaze, and this earth brought the air blower back into operation until the main circuit breaker operated.

EXAMPLE 39.4

In the early hours of the morning a fire gutted a building used as a terminal station for h.f. and v.h.f. communication systems, and also as a workshops centre for installation and maintenance of radio facilities in the area.

The building was originally erected, some 24 years prior to the fire, as a combined studios–medium frequency broadcast transmitter complex, and was constructed of galvanised iron walls and roof. It was lined with caneite and hardboard type materials, and stood on a concrete floor base. Some extensions in brickwork were added to the building a few months prior to the fire and these were also extensively damaged.

Figure 39.7 Damaged transmitter building

Figure 39.7 shows part of the old iron building which housed the transmitters and the newly added wing. The gantry used for terminating the open wire transmission lines and the balance-to-unbalance transformers for the transmitter coaxial cable lead-ins can also be seen in the photograph.

The extent of damage to the transmitters and other equipment is evident from *Figures 39.8* and *39.9*. The room screening material provided when the building was installed for studio purposes can also be seen. Steel members used to support the roof collapsed across the equipment cubicles and racks during the height of the fire. The complete destruction of combustible materials used in the radio equipment is evident from an examination of the debris shown in *Figure 39.9*.

Figure 39.8 Front of transmitter cabinets and racks

Figure 39.9 Debris from damaged equipment

EXAMPLE 39.5

During the 1939–45 war a very low frequency transmitting station was severely damaged by fire and was out of commission for nearly six months.

The station generated a radio frequency power of 270 kW at 16 kHz and approximately 40 kW of this was radiated by the huge antenna system supported on twelve 250 m masts. Arcing, caused by a fault developing in the bonding of lead-flashing, set fire to the wooden roof of the station building and resulted in total destruction of the 5 m diameter antenna tuning coils and the plate tuning coils in the upper storey. The falling debris extensively damaged the amplifier units on the ground floor. The tuning coils had to be replaced, but the large oil filled plate circuit capacitors were undamaged. Considerable repairs to, and rewiring of, the amplifiers were necessary before transmissions could be resumed.

STUDIOS

EXAMPLE 39.6

The sound studios of a broadcast station were damaged when fire broke out in a multi-storey building. The studios were located on the 11th floor but the fire started on the 13th floor.

The fire, which occurred in the early afternoon, commenced in an unattended work area. The area was basically unlined, steel reinforced concrete construction and this together with the limited amount of flammable material stored, helped to contain the fire. However, limited access and heavy smoke made necessary the use of a large volume of water over an extended period of several hours.

Figure 39.10 Fire in studio building (Courtesy John Fairfax & Sons)

The firemen's task was made difficult when the two lifts in the building failed soon after the fire started. They had to carry heavy portable extinguishers up 13 flights of stairs to reach the fire.

Fire damage occurred in the studios because a ventilation system supplying inlet air was not equipped with smoke detectors and automatic shutdown facilities. Heat or flame coming down the inlet from two floors above ignited acoustic materials and set alight one of the walls. The fire was quickly brought under control but water damage was extensive. Equipment interwiring located in floor ducts and chases suffered damage and required replacement.

The building was equipped with an automatic fire detection and alarm system, and the fire brigade was quickly on the scene. Prompt action by their salvage crew in applying water-proof protective covers over the studio technical equipment minimised damage to the installation.

Figure 39.10 shows smoke and water vapour rising from the top of the building during the height of the fire. Seven hours after the fire broke out, firemen were still unable to approach the seat of the fire because of the heat. The 40 m tower mounted on the building was originally the antenna for the station but at the time of the fire was not being used for that purpose.

EXAMPLE 39.7

At 4.12 p.m. during transmission hours, fire of unknown origin, broke out in the sub-basement of a three storey building used as television studios. Television equipment and the building were extensively damaged. Total loss exceeded £200 000. A fireman died when he fell through a weakened timber hatch cover in the basement floor and drowned in 2 m of water which flooded the sub-basement.

More than 150 firemen fought the blaze for several hours and 700 000 litres of water and 9000 litres of foam concentrate were applied before the fire was brought under control. In the basement where the fireman drowned, more than 355 000 litres of water had accumulated.

In order to attack the seat of the fire, the fire fighters worked in total darkness, in dense smoke and in intense heat. They wore breathing apparatus, and as they were unable to see one another, kept in touch by tugging on the hoses.

The studios were in an old theatre built in the 19th century and when the building was altered for the studios, an extensive apron of timber construction was added to the stage, increasing the already high structural fire load of the building. The basement rooms of the building were used for television transmissions and control while the sub-basement was partitioned into compartments, some being used at the time of the outbreak for storage of records.

The fire started in the sub-basement and triggered the automatic fire alarm system which was also extended to the local fire station. A member of the staff attacked the fire and expended three extinguishers before he was forced to leave because of heat and smoke.

A massive application of high expansion foam was necessary as the foam was being constantly broken down by the intense heat. However, just when the fireman considered the situation had been controlled, a blast of hot gases escaped from the basement and welled up through the building. The firemen were forced to make a hasty exit from the building.

In order to save a new £300 000 colour television van parked in the yard behind the building, the van was shrouded in plastic sheets and blanketed with foam.

The building in which the studios were located had been badly damaged three times before by fire.

EXAMPLE 39.8

At 1 a.m. a fire resulting from a short circuit in the control room wiring caused widespread damage to studios, technical equipment and offices at the studios of a 100 kW high frequency broadcasting station. Although many irreplaceable tapes were damaged by smoke and heat, the majority were saved.

Notwithstanding the extensive damage by heat, smoke and water from the fire fighting operations, the staff were able to salvage sufficient materials to make the on-air transmission at 6.25 a.m. only twenty five minutes later than the usual on-air time.

EXAMPLE 39.9

A former television studio building being demolished caught fire, and a fireman who collapsed during the fire fighting operations later died.

The studio complex comprised newly constructed colour studios alongside an old building which was formerly a cinema. The old section which was being demolished caught fire. The cause of the fire was not determined, but a spark from oxy-acetylene cutting equipment was considered to be the most likely cause.

An automatic fire detection system which had been installed in the building was disconnected at the time of the fire, and when the outbreak was first observed materials were well alight. The fire spread very rapidly owing to the high content of combustible materials originally used in the construction of the studios.

Ventilation ducts throughout the building had been fabricated from fibreboard, and the collapse of these ducts allowed the fire to spread rapidly through otherwise fire resisting building walls. Many materials held in a store room were highly flammable and burned with fierce heat and intense white light.

In order to minimise damage to the newly erected adjacent studio building, the fire fighters made effective use of a water curtain. The total loss was about £300 000.

EXAMPLE 39.10

Premises which had been built about 100 years ago as a chapel and converted to use as television film studios caught fire causing damage of about £40 000.

Filming work ceased at the studios about 9 p.m. on Saturday, but the last of the staff did not leave the premises until about 10.20 p.m. when everything was believed to be normal. At about 11.30 p.m. the licensee of the public house which backed onto the studio smelled smoke but was unable to trace the source. Early on the Sunday morning at 12.30 a.m. one of the occupants of the public house heard 'popping' noises and saw smoke issuing from the roof of the studio, and raised the alarm.

The cause of the fire was not determined, but it is believed to have started in a small room leading off the front balcony of the studio. It appeared to have spread along the passage and also out through a large open port in a former sound room into the hall where it quickly involved the close boarded false ceiling and the main roof timbers. In addition to the main electrical wiring in metal conduit, a 1500 V three phase supply panel was provided for filming purposes and this had also been supplemented on the Saturday by a portable d.c. generator. Various temporary cables were in use leading to numerous arc lamps used during filming.

The walls were stripped of plaster, and about three quarters of the roof covering was destroyed. About four fifths of the contents, comprising photographic and lighting equipment, stage props, studio scenery and office equipment were damaged by the fire and the remainder was damaged by heat, smoke and water.

FIRES CAUSED BY LIGHTNING

EXAMPLE 39.11

A direct stroke on a 80 m tower located on an isolated hilltop, and used to support antenna systems of a microwave radio relay station, caused ferruginous and silicious materials laid over one of the earth leads to be vitrified for a distance of about 2 m from one leg of the structure. The galvanised earth strap fused in the process. Equipment which was damaged inside the building, included a travelling wave tube, high tension circuit breaker and a cable form which caught fire. When staff arrived two hours later, there was no flame but the cable form was still smouldering.

On another occasion at the same station, about twelve months prior to the above damage, a ground explosion occurred during a severe storm. A member of the station maintenance staff who was visiting the station at the time noticed water vapour rising from the ground for about 7 m from one of the tower legs. It was considered that the heat generated by the heavy discharge current vaporised water entrapped in the sand around the earth lead.

EXAMPLE 39.12

An oil filled capacitor containing 30 litres of oil exploded in a matching hut when lightning struck a 170 m mast used as an m.f. radiator. The 50 kW station was in operation at the time and an arc resulting from the circuit mismatch set fire to the oil. The hut was burnt to the ground.

EXAMPLE 39.13

A 200 m sectionalised radiator at a broadcast station received eight lightning strokes over a six year period and the following damage resulted:

(a) The blade of the main mast earthing switch which was a remotely controlled motor driven type was blown open when the mast was struck by a heavy lightning discharge. The 30 cm polystyrene rod connecting the switch to the motor caught fire and the switch was badly damaged at the contact face as a result of arcing. *Figure 39.11* shows the damaged blade and contacts. The connecting rod had been joined at the top of the insulated handle.

(b) A surge counter provided to measure the number of strokes and current of each discharge burnt out.

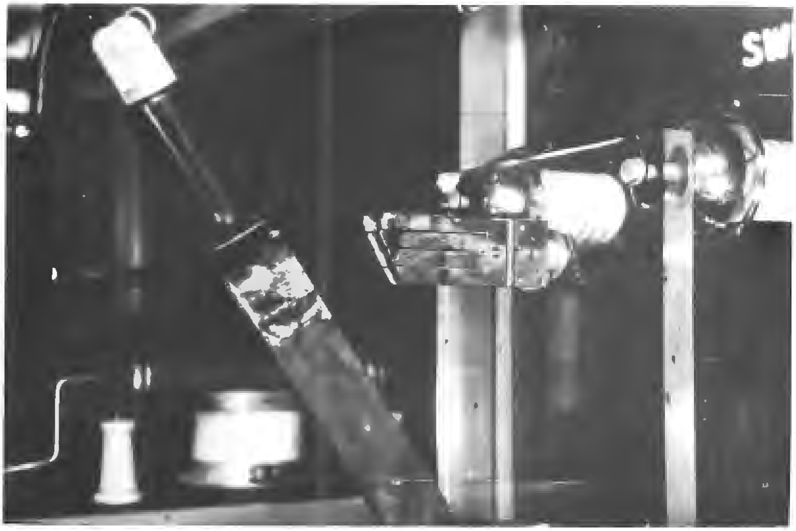


Figure 39.11 Damaged earthing switch

Figure 39.12 Broken skirt on lead-through insulator

(c) A tubular copper busbar connected to the earthing switch sagged as a result of being crushed by a high discharge current. An arc from the busbar burnt a hole in the wall.

(d) The skirt of a porcelain lead-through insulator shattered. The insulator was used to provide a seal between the 2.5 cm diameter copper feed tube to the mast and a 30 cm square plate glass window. *Figure 39.12* shows the broken skirt. The plate glass was not damaged.

(e) The copper braid lead connecting the mast to the horn gap was badly frayed. Fusing of some strands occurred and solder was melted from a lug connection.

(f) The r.f. line current meter in the transmitter burnt out. It was connected to line via a current transformer arrangement.
(g) A clamp was blown off the sectionalising coil about 170 m above ground level. On another occasion three support insulators of this coil were shattered and the coil turns displaced from their previous spacing.
(h) The main transmitter high tension fuse operated on several occasions and insulation was burnt off one of the leads.
(i) The telephone cable connecting the matching hut and the transmitter building was burnt out.

EXAMPLE 39.14

An antenna mounted on top of a 50 m tower and used for f.m. broadcasting was struck by lightning an hour before closedown and the coaxial feeder and transmitter were badly damaged. The feeder was a 3.8 cm foam dielectric flexible type with a plastic jacket. The outer copper sheath melted for about 20 cm from the antenna connection point and the copper was heavily discoloured for about 1 m.

The plastic jacket exploded for about 3 m of the cable length and caught fire. It was pitted over a further 6 m length. The cable had been bonded to the tower only at the antenna point and as a result, a high voltage was transferred to the transmitter. Voltage flashover occurred, and the high tension filter choke shorted to earth and damaged the filter capacitors. Two components in the final stage also required replacement and the insulation was burnt off the high tension lead.

EXAMPLE 39.15

The very high electromagnetic forces created by the large current from a direct stroke to a 230 m broadcast radiator brought about the collapse of the outer conductor of a pressurised 3.8 cm diameter rigid transmission line.

The line was connected directly to the base of the mast without any matching equipment but with an r.f. choke to earth for static bleed purposes. The cotton covered coil caught fire and blackened the wall of the coupling hut.

The lightning discharge current travelled along the line for about 8 m before reaching earth via a copper strap at the third supporting wooden post. The line outer conductor collapsed for almost the full 8 m length except at the points where porcelain spacer insulators supported the inner conductor. The wooden support post was charred where it touched the earth strap.

EXAMPLE 39.16

The four bottom plates of a high pressure gas filled capacitor rated at 38 kV and forming part of the matching network of a 280 m medium frequency 10 kW radiator melted and fell from the support shaft when lightning struck the mast during a late afternoon storm.

The gasket seal was punctured and the nitrogen gas had escaped when the unit was inspected by the station staff.

Two r.f. chokes wound with silk and cotton insulation on 1.5 cm diameter porcelain formers provided for mast lighting purposes were burnt out and the insulation material caught fire as a result of the stroke. A wooden shelf on which the chokes were mounted was destroyed by the fire.

EXAMPLE 39.17

About half an hour after commencement of transmission one morning, a severe electrical storm occurred in the vicinity of a 50 kW broadcast station with a 200 m radiator at a tropical location. The area surrounding the station was very flat and the radiator normally attracted a high percentage of the lightning strokes.

Standard practice under storm conditions was to earth the main antenna because of previous experience with damage to the building and equipment, and to transmit at 10 kW power on a shorter emergency antenna located in the cone of protection zone of the main radiator.

When it became apparent to the operator that a severe storm had developed, he attempted to start up the 10 kW standby transmitter. The a.c. contactor for the cooling fan exploded, and the insulation on one lead caught fire but was quickly extinguished.

About this time the main antenna was being struck repeatedly, and a heavy lightning discharge which passed through the matching hut equipment and along the open wire transmission line burnt out the line current ammeter in the 50 kW transmitter and melted insulation on the meter leads. Later examination showed that the meter was open circuit but an arc had formed inside the case allowing power to be fed to line. Corona discharges were taking place almost continuously throughout the transmitter cubicles, and one high intensity arc set fire to an oil filled capacitor. The transmitter shut down automatically and staff applied carbon dioxide to extinguish the fire.

EXAMPLE 39.18

Part of the concrete footing of one leg of a 50 m selfsupporting structure at a radio station was blown out when lightning struck the tower during a storm.

The top of each block was about 60 cm above the surrounding soil and no earth connections had been made directly from each leg to earth. A single copper lightning conductor about 3.7 cm by 3 mm had, however, been provided

Figure 39.13 Damaged tower footing

over the full height of one tower face, and connected to a stake earth system.

Apparently the lightning conductor was inadequate for the purpose, and the lightning discharged through one leg at ground level and broke away the block. *Figure 39.13* shows the hole left in the block, and cracks resulting from the discharge.

Installation staff who were near the structure at the time said that an explosion occurred at the base, and debris was hurled 20 m away.

Twelve months prior to this incident dry grass around the base of the tower was set alight following a direct stroke. However, rain which followed soon extinguished the burning grass.

EXAMPLE 39.19

When a lightning stroke made direct contact with a 100 m m.f. radiator it damaged the matching equipment so severely that complete replacement was necessary.

The discharge occurred about 6 p.m. when the station staff were about to reduce power in accordance with their licensed arrangements.

The porcelain insulator used as a lead-through from the matching hut shattered and fell to the ground, cotton covered wire r.f. chokes in the mast lighting circuit caught fire but extinguished after a short period. Two small oil filled capacitors and a mica unit exploded and the single matching inductor made from 12 mm diameter tubing collapsed. The three coil spacing bars made of fibreglass softened and one caught fire. One of three r.f. meters in the hut was undamaged even though the shorting bars had been applied across all three.

EXAMPLE 39.20

Lightning struck a rhombic antenna at a receiving station and caused extensive damage to the 200 ohm four wire transmission line. A terminating resistor was badly charred by fire and a balanced-to-unbalanced matching transformer damaged beyond repair.

At the pole near the antenna where the two wire feeder and four wire transmission line met, the four wires of the transmission line were welded together for 1.5 or 2 m and wrapped around the pole like a coil. All wire and insulators had disappeared from the first two spans of the line. Fractured porcelain insulators and short pieces of fused wire 15 to 100 cm in length scattered about the area and set alight to the grass. In some places, pieces of wire in which the four wires were welded together for a large part of their length were picked up. The following four spans had apparently been heated to a high temperature because they sagged considerably under their own weight and were discoloured. The fire burnt out 2 ha of grass before being brought under control.

EXAMPLE 39.21

Line insulators were damaged and the top of a wood transmission line pole was set on fire when lightning struck a curtain antenna at a 100 kW transmitting station, during transmission hours.

No damage was apparent on the antenna system but the tops of four insulators in the matching section near the line junction were cut clean away due to intense heat in the conductor and tie wire.

At the second pole from the antenna the lightning discharge passed over the insulator skirt, along the top of the wet crossarm and set fire to the pole at the point where the steel bolt joined crossarm to pole. Although the fire was extinguished by rain, the pole was later replaced because of the deep carbon tracks formed by the burning wood.

The transmitter suffered no damage and in fact continued transmission without staff being aware of the line damage. The damage was discovered the following morning during a routine inspection by lines staff.

Flashover from transmission line conductor to wooden cross arms had been observed on previous occasions at this station during storm periods. In several instances the flashover path did not extend from the conductor over the porcelain support insulator and then along the crossarm, but rather struck through the air to an area removed from the insulator thus bypassing some of the wood. Although charred holes resulted, the rain had apparently prevented spread of fire.

EXAMPLE 39.22

A large radiocommunications transmitting station with many rhombic antennas utilised unprotected wooden poles exclusively for antenna supports and transmission lines throughout the station. Electrical storms were prevalent in the area and over a six year period four antenna and three transmission line poles caught fire as a result of lightning strokes. Although in all cases but one damage was not extensive as the fire was extinguished by rain, it highlighted the need for protection for the poles.

The antenna poles which averaged 30 m in height were subsequently fitted with a 2 m lightning rod, a copper cable and an earth system. The cable at the base of each pole curved gently away from the pole 25 cm below ground level to terminate 3 m away on two 2 m copper stakes.

A 3 mm copper wire was fixed to each transmission line pole. The conductor was attached so as to project about 25 cm above the top of the pole, and at the base it curved away from the pole below ground level to terminate 3 m away on a 2 m copper stake.

No damage was reported over a four year period following completion of this work.

Section 5

Environmental Aspects in Radio Engineering

Introduction

The radio engineer's work is aimed at enabling natural laws and resources to be exploited with maximum economy consistent with many factors which include reliability, performance of materials, safety, aesthetics and controlled use of the electromagnetic spectrum.

It has been said that the engineer in carrying out his work has no special responsibility to determine the uses to which his developments are put because he is only an instrument in the hands of those who dominate the economic life in our society and whose principal objective is profit. However, this is quickly denied by modern radio engineers who assert that science and technology, principally through the work of engineers, have made the world a safer and more pleasant place in which to live and that they have developed equipment to much greater degrees of reliability, levels of performance and efficiency by comparison with former times.

The problems of designing and maintaining radio plant and equipment in environments which cause decreased reliability, degrade the performance and cause damage by corrosion, atmospheric contaminants, wind, rain, pests etc. are continuing problems but with good design and maintenance their effects can be reduced considerably and in some cases eliminated entirely.

However, when dealing with aesthetic issues, such as with masts and towers where work is under increasing public scrutiny, emotions often cloud the real issues. Environmental studies are now mandatory for many large projects and frequently it becomes a multi-disciplinary exercise in which sociological, economic, technical and other objectives are brought into a balance which is acceptable to the community at large.

Extreme views regarding the management of the environment are forcefully put forward either publicly or in more covert fashion and on those issues where the public and the radio engineer may be in conflict, such as on structural designs, the engineer needs to be sensitive to aesthetic considerations.

Chapter 40

Reliability

RELIABILITY FACTORS

Radio equipment is working in all parts of the world, in outer space and in all types of environments. In practice no single condition such as humidity, vibration, shock, low or high temperature, high altitude etc., is usually present by itself but is in combination with one or more others.

Almost every imaginable material is used in some form, due mainly to the complexity of the equipment, wide frequency range, component part requirements, modes of assembly and the rather specialised functional and service requirements which must be achieved with a minimum of maintenance and maximum reliability over a wide range of environmental conditions. One of the most important problems with many materials is that of service life. Particularly with many of the more recently introduced materials, it is important to know how long they will continue to function satisfactorily, as part of the system for which they are designed.

The rapid development of components, primarily micro-circuits, in radio engineering is expected to continue for a long time and it is essential to use components that not only have the desired function but which are also stable during the estimated life of the equipment. The most frequently used components can be grouped into three categories as regards their function. These are passive components such as resistors, inductors, capacitors etc, discrete semiconductor components such as diodes, transistors and thyristors and various types of micro-circuits such as linear micro-circuits, digital micro-circuits and programmable memory devices etc. Micro-circuits are primary elements in modern radio systems and they require very little space in relation to the large number of logic functions they are able to perform. In order to provide satisfactory system performance and operation in modern communciations, component quality must meet higher reliability and long term stability requirements than so-called entertainment components.

The planned life of radio equipment depends upon many factors including the initial capital investment, the standard and frequency of maintenance provided, the desired reliability and obsolescence. For some types of equipment and service, for example a broadcast transmitter, a life of 20 years or more may be expected with a high degree of reliability. A much longer life may be expected for a mast radiator under a favourable environment. Then again, for some parts of the equipment, tubes and the like, a life of several thousand hours may be satisfactory.

The reliability of equipment is influenced considerably by the standard of design and workmanship, the quality control exercised during manufacture and assembly, the quality of materials and the finishes used in the equipment. This is often shown up by the way in which a wide range of equipment, supplied by one manufacturer accustomed to maintaining a high standard, will invariably withstand the conditions of service much better than equipment manufactured by another whose standard is not as high. It is evident that for equipment to operate satisfactorily under unfavourable environmental situations, particularly those associated with high humidity and high temperature, the greatest care must be taken at all stages from design, to the choice of the raw materials and components, to the manufacture and packaging, and to the proper installation and maintenance.

The great range of physical factors and economic considerations make it essential during design and manufacture to give much weight to experience records. No amount of laboratory testing can truly simulate the many combinations of temperature, humidity, voltage, frequency, mechanical stresses and atmospheric conditions which may be met in actual service, and the extent to which extreme situations and conditions can be discounted in order to produce an economic installation without, at the same time, incurring unreasonable maintenance changes. This can only be determined by practical field experience over a long period of time.

With the widespread increase in power output of transmitters in recent years, and the problems being caused to plant resulting from electrical discharges, more attention is being paid to the operating environment. It is not easy to predict, for example, the extent of radio frequency corona discharges from antennas and transmission lines which are required to operate at high power over a wide range of field environments. The power dissipated in these discharges can be of the order of several kilowatts and as a consequence the discharges can damage the system by melting conductors and cracking insulators.

A considerable amount of radio equipment is installed in air conditioned buildings out of direct contact with the weather, and particular environmental problems are not posed. However, much equipment is installed in situations which are apt to be very detrimental. Designers and manufacturers have therefore to provide for these situations. One specification for a high power broadcast transmitter with internal and external components set the following limits:

(a) *Ambient Temperature at sea level:*
  + 1 to 50 °C for indoor units
  –30 to 50 °C for outdoor units
(b) *Ambient Humidity:*
  0-100% relative humidity up to 40 °C
  0-75% relative humidity up to 50 °C

For external plant such as antennas, transmission lines and transmission line switches the following parameters were set in one specification for a system in the tropics:

(a) Temperature: 10 to 40 °C. The upper limit is the maximum expected shade temperature but Tenderers should note that, depending on surface conditions, the temperature of a component exposed to the sun may rise to 85 °C or higher in still air.
(b) Humidity: Any relative humidity up to 95% within the temperature range 10 to 35 °C and up to 75% at temperatures above 35 °C.
(c) Wind velocity: Up to 36 m/s at ground level which may be in gusts or in

continuous motion. The system is to be capable of survival at wind speeds up to 63 m/s.

(d) Rainfall: Heavy monsoonal rain, high humidity salt spray and salt laden air.

(e) Dust and smoke: Deposits of dust expected from dust storms, deposit of ash from scrub and grass fires that may continue for several days, followed by either light winds or rain showers.

Good design incorporating the proper use of raw materials with appropriate finish is essential to meet these conditions. The greater the complexity of the equipment, and the longer the service life required, the greater the design, manufacturing and installation effort required for success. However, the selection of the best type of materials in many cases is not easy. The selection of insulators for antenna systems, for example, becomes difficult when the operational environment is taken into consideration. The insulators may be subjected to high mechanical stresses, vibration, high winds, high voltage, high frequency, rain, salt spray, industrial fumes, fog, dust, solar radiation, carbon products from bush and grass fires, bird droppings, swarms of insects etc., all of which can degrade the effective insulating properties of a device and result in large and random variations in the theoretically evaluated, static electrical or mechanical stress. Any of these factors may lead to temporary or permanent malfunction of the insulator or to sudden and complete failure.

DETERIORATION AND FAILURE

The primary factors in the deterioration and failure of materials are physical and chemical agents, heat, sunlight, moisture, certain salts and alkalis, wind and abrasive dust. The secondary factors are the biological agents, fungi, bacteria and insects. The metals and inorganic materials are as a general rule resistant to the effects of light, oxygen, ozone etc., but water is one of the most serious deteriorating influences on these materials. However, for organic materials such as plastics, the situation is almost the reverse. Water has little effect on the mechanical properties of many plastics, although water can change the electrical properties of some types. Ozone and ultra-violet light can be especially severe on many plastics. Although active research is now overcoming many of these problems, there is still much more work required on light coloured or transparent products.

It is not always a single factor that causes deterioration followed by shortened life and malfunction. For a certain type of equipment or material, it may be a special factor of the climate which is most important. Field experience has shown that the deterioration of many radio materials and plant in hot humid areas is greater than in other environments. This is due to the combination of high temperature, high humidity, drenching dews and ultra-violet radiation. At a station close to the sea, salt laden winds, and soil conditions can intensify the problem, particularly for external plant. These conditions are in contrast to those found in hot inland rural areas where the air is dry and corrosion is not significant.

A great deal has been learned about the effects of humidity on components as a result of wartime experiences in the tropics. Open type power transformers absorbed water through voids in the varnish impregnation so lowering the insulation resistance, audio transformers encountered trouble due to electrolytic action of the fine copper wire causing open circuits, cotton braided wire formed a wick action enabling moisture to enter components, paper wrapped wax coated tubular capacitors suffered a fall in insulation resistance and wood-filled phenol mouldings were badly affected by a saturated atmosphere resulting in poor electrical properties.

In any examination of the failure or deterioration of materials, it must be borne in mind that some radio stations are erected in isolated areas, well removed from good engineering facilities and material supply sources, and because of this certain materials and equipment may be subjected to usage which results in accelerated deterioration not necessarily related to climate. These factors will be discussed later in so far as they affect the selection and use of materials since they have a bearing on the practical aspects of the problem.

DETERIORATION FACTORS

Practically all materials deteriorate with the passage of time. The situation is often aggravated, however, where the materials are in a tropical environment. With the heterogeneous collection of materials and components found in radio equipment, it is not surprising that deterioration is accelerated under tropical conditions unless measures are taken to minimise it. Mould growth rapidly forms on materials that provide food in combination with a high humidity situation. Many insects and micro-organisms also exist on food contained in these materials. Metals which would not generally provide food for such life are liable to corrosion, the reactions being accelerated by high humidities and temperatures. Some insects such as termites do however cause physical damage to soft metals such as lead when used on underground cables. In the absence of natural food, termites are ferocious in their eagerness to sample any readily available materials which they can cut with their mandibles.

Low temperatures are also a problem. Whilst most equipment in cold locations would be operated in a heated environment much of the external plant would be exposed to the elements. High winds can affect the operation of antenna systems including rotating radar scanners, and special design features may be required to take account of these factors. In some cases driving snow has packed radar scanners and prevented their rotation. Build-up of ice on antenna wires, television antennas, towers and guy ropes can cause deterioration of performance, physical distortion, stretch or even collapse.

Very little permanent deterioration has been noted with components operating under very cold conditions but much temporary deterioration, particularly with mechnical components, has been experienced. Potentiometers, switches and relays have been stiff to operate or frozen up; sleevings and hook-up wire have become hard, tough and sometimes very brittle; bitumen and similar substances have become very brittle and easily broken up; some capacitors have shown large increases in capacitance while other types have shown large decreases in capacitance; quartz crystals have failed to operate because of mechanical changes; and plugs and sockets have caused troubles because of differential contraction of the metal and plastic insulating parts resulting in poor contact.

A large amount of field experience has been obtained concerning the deterioration of components, materials and equipment and some of the main deterioration factors are summarised in the following sections.

TEMPERATURE

An increase in temperature has a marked effect on most of the phenomena causing deterioration. These effects may best be considered by classifying the phenomena as chemical, biological and physical. In all biological, most chemical and some physical processes, elevation of temperature intensifies effects promoted by other causes. With certain chemical reactions and with most physical effects, however, increase in temperature acting alone may be responsible for degradation.

The effect of heat on a component or part generally produces at least one of the following:

(a) Disintegration.
(b) Sudden collapse.
(c) Reduction in life.
(d) Temporary change in physical characteristic.
(e) Permanent change in physical characteristic.
(f) Chemical change.

While a temporary physical change will generally result in a temporary change in value and in some situations may not be of much concern, permanent physical and chemical change will result in a permanent change in value. In some hot dry areas polythene coil formers softened causing inductance-change and had to be replaced by Mycalex formers.

The most obvious physical effect of temperature is that of dimensional movement. Examples are expansion of transmission line and antenna conductors and cracking of paint on masts. Also, the fluidity of semi-solid or thermoplastic materials increases as temperature rises and this may result in flow and distortion.

The embrittlement and warping of thermoplastic materials when exposed to high sun temperatures is probably due in part to the loss of plasticiser by volatilisation. Low temperatures, too, present a problem, as at very low temperatures, for instance, electrolytic capacitors lose capacitance, quartz crystals frequently fail to oscillate because of physical change, relay contacts ‘freeze’ and many mechanical components and drive devices fail because of differential contraction.

Changes in temperature also have a deleterious effect on radio equipment. The changes, particularly when they cover a wide range, result in the pumping of air and moisture in and out of materials. The heating and cooling of components resulting from their working condition, also results in this air cycling process, sometimes called breathing, and may even result in the accumulation of water.

With increasing trend towards miniaturisation of radio equipment, the heating problem is often aggravated because the smaller components are frequently too small to act as effective heat sinks and many impregnating or sealing compounds are poor heat conductors. To overcome these problems forced air cooling is, in many cases, necessary. The development of materials capable of working at high temperatures is assisting in overcoming some of the heat problems.

The temperature of bodies exposed to the sun are often very much higher than those in the shade and this is an important consideration where temperature sensitive materials are used in structural applications. As an example, a 75 mm square hollow fibre glass crossarm was erected for experimental purposes as a tension member on a transmission line with a pull of 450 kg but the crossarm collapsed during a high ambient temperature. The crossarm was re-erected after repair and with an ambient of 38 °C the temperature of the material, as measured with a thermocouple, was recorded as 42 °C.

In another instance, a sheet of aluminium covered plywood was exposed to check the effectiveness of certain plywood glues prior to the use of the material in an antenna matrix system, and the measured surface temperature was 45 °C with an ambient of 36 °C. It is of interest to note that the surface temperature did not exceed 40 °C with part of the surface painted with a white matt finish. Although a polished aluminium surface is an efficient reflector of solar radiation its low temperature emissivity is low, and such energy as is absorbed, is not readily re-radiated, so that an increase in temperature of the surface takes place.

The temperature limits for radio equipment should be so chosen that they will result in a satisfactory life under normal operating conditions. In addition, permissible short term temperature limits and corresponding ratings may be established, including the durations and frequencies of operation to which these limits apply. For example, sustained 100% modulation conditions may not occur in normal practice for a broadcast transmitter but test periods of tone at this level for 10 minutes or more may occur during test periods prior to transmission.

Insulating materials in particular are affected in different ways by elevated temperatures. Thermal degradation is the major factor affecting the life of insulating materials. Moisture, chemical contamination and mechanical stress may contribute to failure, especially after the material has been weakened by thermal deterioration.

The main problems are:

(a) Softening and flow may occur. For some materials, this characteristic may occur at a critical temperature, whereas for others it may occur over a range of temperatures.
(b) The electrical properties such as power factor, resistivity etc. may change.
(c) Mechanical properties may decrease even before true softening of the material takes place. Epoxy and polyester resins exhibit this characteristic.
(d) Where elevated temperatures are applied over a long period, several properties such as mechanical, electrical and physical may change. *Table 40.1* shows the approximate maximum working temperature of some selected insulating materials used for radio engineering purposes.

Table 40.1 APPROXIMATE MAXIMUM WORKING TEMPERATURE

Material	*Temperature (°C)*	*Material*	*Temperature (°C)*
Perspex	60–88	Silicon bonded glass	232
Polyester glass	66–204	Polytetrafluoroethylene	260
Polystyrene	66–77	Mica bonded glass	454
Ebonite	77	Plate glass	538
Transformer oil	77	Fused silica	982
Polyethylene	77–127	Mica	982
Polyvinyl chloride	82	H.V. porcelain	982
Nylon	82–149	Steatite	1129
Epoxy glass	93–204	Zirconia porcelain	1204
Permali	93	Alumina porcelain	1371
Polypropylene	93–149		

ULTRA-VIOLET RADIATION

Experience has shown that exposure of materials in a tropical environment produces more rapid decomposition than exposure at higher latitudes and this is frequently attributed to a high proportion of ultra-violet radiation in the sunlight, in the regions near the equator. However, the available evidence does not suggest that the proportion of ultra-violet energy in solar radiation in the tropics is noticeably greater than in higher latitudes.

The accelerated deterioration appears to result from the fact that the tropics receive more ultra-violet radiation simply because of the more sustained exposure to the sun. In general, the average duration of bright sunshine is often greatest in the tropic latitudes.

HUMIDITY

High humidity conditions result in moisture being deposited on surfaces and can be injurious to materials and equipment. The absorption of moisture is one of the chief causes of the deterioration of materials exposed to humid conditions. Moisture may cause not only physical deterioration, such as the corrosion of metals, the swelling of absorbent materials, the rotting of timber etc. from mould growth, but also a serious reduction in the electrical properties of insulating materials. It may reduce the dielectric strength, influence the dielectric constant of the material, and in the case of non-absorbent materials such as vitrified ceramics, increase surface leakage. The problem is frequently aggravated when the water film becomes contaminated by extraneous salts, dirt etc.

The effects of humidity on exposed components can result in major failures. Switches, plugs, sockets, tube and crystal holders will be effected by corrosion. Potentiometer carbon tracks will suffer from penetration of moisture and ferrous metal parts will rust unless protected, wire wound components will become open circuited, insulation materials will develop carbon tracks following flashovers and small components will fail through ingress of moisture.

The problems of high humidity are greatly affected by diurnal fluctuations in temperature. These, although not excessive, are sufficient in some areas to cause frequent saturation of the atmosphere with copious nocturnal dew formation. Moisture deposited in this way is a serious hazard because of its ubiquity and the difficulty of ensuring evaporation from confined spaces, and also because the combined effects of deposited dew and following sunlight encourage rapid chemical and mechanical breakdown. This effect, however, is not confined to the humid tropical environment, although here its effects may be most serious. Dews are also common in dry inland climates on account of their clear atmospheres and low night temperatures.

It is well known that micro-biological activity proceeds at optimum speed where there are no periods of dryness, and it is clear that the condensation phenomenon introduces a serious problem to the preservation of complex electronic equipment where this is not located in a controlled environment. Of the materials used in radio engineering, those of organic origin such as wooden transmission line poles, paint, plastics etc. are the most likely to deteriorate under climatic influence. Inorganic materials such as line and antenna procelain insulators, if properly made, suffer little deterioration, but some metals may suffer corrosion. The risk of breakdown of materials is always somewhat higher in the tropics than it is in temperate regions, and the need for good design, fabrication, installation and adequate maintenance is correspondingly higher.

Climatic zones with very low humidities also introduce certain difficulties with radio equipment. Hygroscopic materials undergo shrinkage as water is evaporated in the process of coming into equilibrium with prevailing low humidities. Timbers may warp severely and in areas where relative humidity fluctuates seasonally over a wide range there may be considerable working of the material. An example of this problem occurred at a broadcast station where a polished wooden control desk was manufactured in a workshop located on the coast in a temperate area and when installed at the transmitting station at a hot inland site of very low humidity, the timbers warped so extensively that the wooden desk was later replaced with a laminex covered steel desk.

Some inland areas of low humidity can be very dusty and this can be a problem with air dielectric capacitors, contacts, insulation strips and air filters. In variable capacitors used in high voltage circuits of transmitters, dust particles are drawn between the plates by electrostatic attraction forming bridges which cause voltage flashover. In external plant activities, low humidity situations can create problems with satisfactory curing of new concrete.

Humidity has also an important controlling effect on the life of materials and spare parts held on the station for maintenance requirements. In a large international broadcast establishment, spare parts of considerable value may be held on the station and proper storage to ensure the minimum of deterioration is essential. The greatest deterioration occurs when the equipment is stored in areas which are damp and unventilated. The least rate of deterioration is realised by frequent cycling in working plant, regular maintenance, proper packaging and by storage in a controlled environment that will ensure maximum life. To meet this environmental storage requirement, it is practice at many stations, particularly in tropical locations, to air condition those storage rooms which contain equipment and components subject to deterioration by a high humidity environment.

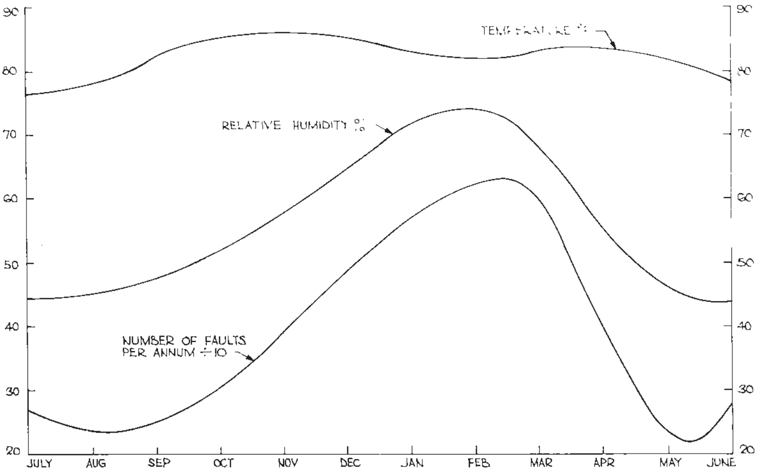


Figure 40.1 Faults in broadcast transmitters in tropical locations

One method of dealing with the humidity problem is to hermetically seal the component or device. Air tightness is the essential requirement for preventing the transmission of moisture by diffusion and breathing. However, several practical difficulties often arise. These include provision for the dissipation of heat generated by the enclosed components, the prevention of moisture leakage through glands and lead-through conductors, and the problems of providing a satisfactory seal for moving devices, such as shafts. Also, some components are difficult to hermetically seal without adversely affecting electrical and mechanical factors in the design, construction or operation of the equipment.

Figure 40.1 shows an interesting relationship between the number of faults in operational radio equipment and humidity. The figure shows the average number of faults which occurred over a five year period in nine 2 kW broadcast transmitter installations located in approximately equivalent tropical environments during the early 1960s. No air conditioning was provided at the stations.

ATMOSPHERIC CONTAMINANTS

Radio stations located in certain city areas may be subjected to an atmosphere heavily contaminated with industrial fumes which may be very corrosive to antenna systems, masts, towers and equipment. Natural sources of corrosive fumes constitute local hazards in certain areas. Severe corrosion of electronic equipment has been reported from stations subjected to volcanic gases and from stations near oilfields where sulphur dioxide and hydrogen sulphide is liberated into the atmosphere.

Atmospheric corrosion of ferrous materials is influenced by the prevailing natural atmospheric conditions. The corrosion rate is greatest for a marine environment and least for a rural environment. The rate for an industrial environment in most cases lies between these two extremes. Industrial pollution has the effect of doubling the corrosion rate. Observations indicate that the zinc on galvanised members of a mast or tower has a corrosion rate which rises sharply with increasing sulphur dioxide content of the atmosphere. The corrosion is worst on the tops of horizontal members and on nuts and bolts where dust settles. It is likely that there is adsorption of sulphur oxides into the dust particles.

A salt laden atmosphere is a problem at many station sites. At some coastal sites where there is heavy surf, high atmospheric salt concentrations are found. The most dangerous effect of the salt is that it directly accelerates the corrosion of metals. Salts together with moisture form electrolytes and the corrosion is both chemical and electrochemical. The corrosive effects of sea winds are rapidly reduced in their passage inland and very few problems from salt have been reported at stations located more than about 50 km from the coast. Frequent rains also tend to diminish the effects of salt corrosion, particularly on structures.

Air borne dust is often a difficult situation to satisfactorily deal with, particularly in the desert regions where fine particles remain in suspension. Under calm conditions this is perhaps not a serious weathering factor although it is a matter of concern with relays and high voltage circuits. When strong winds blow, suspended dust together with larger particles become a potent abrasive. Stations in dry inland regions have experienced abrasion of masts and towers and transmission line fittings. At one station with a 200 m sectionalised radiator a layer of chrome which had been electroplated on to the sectionalising coil was completely removed on the windward side, following a severe dust storm.

CYCLONES

This phenomena is known by different names in different areas. It is essentially a wind which blows in a circle, while the circle as a whole moves forward. A very violent cyclone is called a hurricane or, if its area is very small, a tornado. The damage done by a cyclone of this kind is very great and is sometimes accompanied by much loss of life. The wind speed of one tornado which struck Wichita Falls, Texas, in 1958 was measured at over 400 km/h. The typhoon of the China Sea area is similar in character.

In those areas where occurrence is frequent, it is normal practice to design the station buildings, towers, masts and other external plant to withstand the wind forces which prevail in the area. In some areas of the world, cyclonic type disturbances have a frequency of occurrence of five or more per annum and it is important to have as much warning as possible in order to take appropriate action to safeguard plant and facilities. Radar plays an important role in plotting the path of meteorological disturbances. Weather satellites also now provide an important function in this work. *Figure 40.2* shows an 1800 tonne patrol boat equipped with radar for meteorological observations covering a radius of 400 km from Japan. It is primarily intended to catch the rise of a typhoon in the Western Pacific and to cover its subsequent development. The antenna is three metres in diameter and is fitted with a gyro stabiliser.

Figure 40.2 Radar equipped patrol boat (Courtesy JETRO)

Many radio masts and towers have failed under heavy wind condition. Others have been subjected to severe treatment for many years and are still in service. For example, four 300 m guyed masts erected in 1930 near Shanghai survived many typhoons over a 30 year period.

Figure 40.3 shows the remains of one 160 m top loaded radiator at a broadcast station that did not survive the onslaught of a wind, estimated to have exceeded 160 km/h.

Curtain type antennas because of their construction are often subjected to violent movement of wires, insulators and fittings during heavy cyclonic type winds and practice at some stations has been to provide winch and counterweight systems. The antennas are supported by counterweight catenary ropes which are wound on to electric winches forming part of the counterweights. These winches enable the antennas to be lowered to the ground to avoid damage from high winds and flying debris.

The most common form of wind damage to station buildings and facilities is damage to roofs. In regions where cyclones are experienced, the damage extends

Figure 40.3 Damaged 160 m top loaded mast after collapse

Figure 40.4 Damage to buildings and water supply facilities

from the breakage of windows to the partial or complete destruction of buildings. Buildings under construction are particularly vulnerable to damage, especially while masonry is 'green' or before doors and windows are fitted or if wind strikes before bracing is secured. The rotational nature of the extensive air mass of a cyclone leads to the situation where a building may encounter gale-force winds from any direction, depending on the path of the cyclone. *Figure 40.4* shows damage to power house and water supply facilities at one station following high winds.

THUNDERSTORMS

The most violent storms occur in tropical regions and generally in the summer rather than at other times of the year. Radio construction projects can be seriously disrupted during these storm periods, particularly during work associated with the construction and erection of foundations and steel-work of masts and towers. Tropical seasons are generally referred to as the 'wet season' and the 'dry season'. There are of course many tropical lands in which there is a scarcity of rainfall but there is not very much radio construction activity in these areas compared with the high rainfall regions.

In many of the high rainfall tropical areas, the rain is concentrated largely into a few months of the year and during these periods external plant engineering construction works can be seriously handicapped. Transportation to site of heavy materials is made difficult, excavations for structural foundations fill with rain and groundwater, and working conditions can be hazardous and uncomfortable. The rapid growth of grass on many tropical sites also hinders progress of field works, particularly earth mat laying operations.

As a destructive element, storms, which are essentially products of convection, are of considerable interest in connection with the probability of lightning strokes to masts and towers, power lines and programme lines. These structures and lines are a target for lightning which on breaking down insulation barriers causes serious interruption to radio service. Great destruction of equipment and plant can occur when it is considered that currents or hundreds of amperes can occur in a direct stroke.

Another factor associated with rain storms is the sudden cooling of hot insulators and the consequent fracture. Where standard porcelain insulators are used instead of low loss steatite on high power high frequency transmission lines and antenna systems, the temperature rise can be considerable, especially near the end cap. The power loss or rate at which heat is generated within the insulator is proportional to the product of the dielectric constant and the power factor, and this product known as the loss factor is very much greater for standard porcelain than for low loss steatite. Consequently, the operating temperature of standard porcelain insulators is much higher than steatite types, particularly at the higher frequencies.

WIND INDUCED VIBRATION

Besides the pressure which is created on the surfaces of structures and which may affect the stability, the vibration of structures, conductors and cables is also a problem. Fatigue cracking due to vibration by wind and the subsequent failure by tension can be caused by relatively light but constant winds.

Two types of wind induced vibration can occur, aeolian vibration and galloping. Although they are significantly different in physical configuration and cause different types of damage, both forms of oscillation occur at one or more of the natural harmonic frequencies of the conductor or structure. Of the two, aeolian vibration is by far the more prevalent. Galloping is generally confined to long spans of large diameter conductors as used on v.l.f. antenna systems. A typical v.l.f. antenna may use some 40 km of steel cored aluminium antenna cable up to 37 mm diameter spread between masts covering an area of more than 250 hectares.

Difficulties which have been experienced with aeolian vibrations on radio plant include:

(a) Fatigue breakage of transmission line and antenna conductors.
(b) Severe abrasion and fatigue breakage of tie wires at post insulators.
(c) Loosening of associated line and antenna hardware such as nuts, bolts, pins and clamps.
(d) Breakage of strain insulators. *Figure 40.5* shows the unusual breakage pattern of one large strain insulator which failed as a result of severe aeolian vibrations. The failure occurred at about the mid point of the ceramic rod.

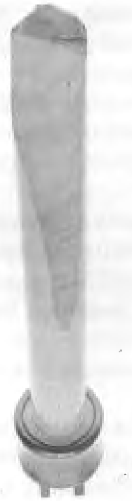
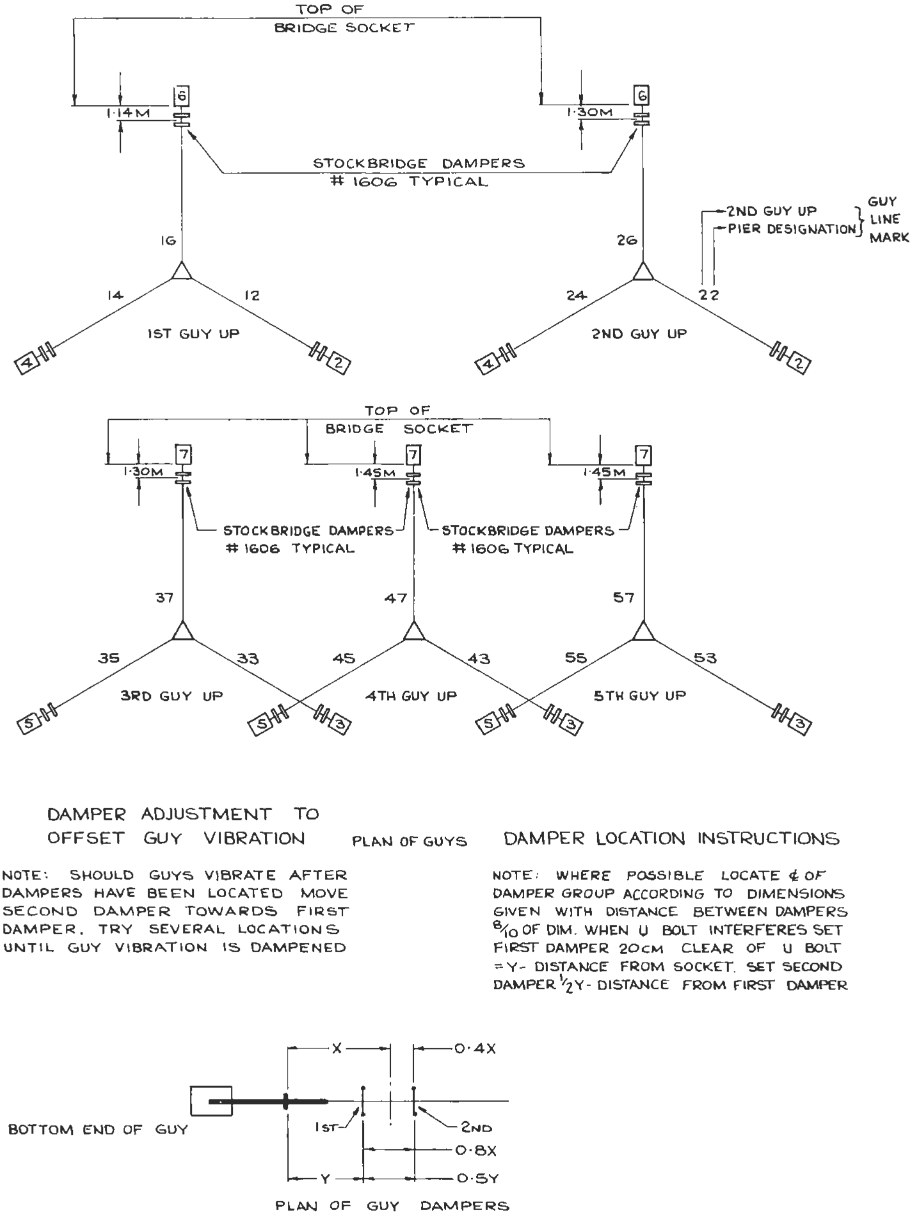


Figure 40.5 Failure of insulator from aeolian vibrations

(e) Fatigue breakage of mast and tower members. This has occurred mainly with lightly loaded members such as ladder cage wires and bars.
(f) Audible mast noises, mainly from loose metal washers on guy insulator assemblies.
(g) Vibration of masts and towers. The energy of vibrating guy ropes is often transferred into the structure which they support.

When severe vibration is encountered, two principal methods of minimising the effect are used. In one, reinforcing devices are employed at the clamping points and in the other vibration dampers are fitted to suppress it. For small size conductors as used at receiving stations or low power transmission lines, the solution is relatively simple as wrap-on plastic dampers and other cheap devices are available. For the large size conductors, including guy ropes, Stockbridge dampers have been successfully employed. When properly installed the Stockbridge damper is an effective and economical means of preventing vibration fatigue. It reduces cyclic stresses in conductors by about 90%, in the normal frequency range. It also prevents the transfer of harmful vibration into insulator strings and steel mast members.



DAMPER ADJUSTMENT TO OFFSET GUY VIBRATION

NOTE: SHOULD GUYS VIBRATE AFTER DAMPERS HAVE BEEN LOCATED MOVE SECOND DAMPER TOWARDS FIRST DAMPER. TRY SEVERAL LOCATIONS UNTIL GUY VIBRATION IS DAMPENED

DAMPER LOCATION INSTRUCTIONS

NOTE: WHERE POSSIBLE LOCATE ℄ OF DAMPER GROUP ACCORDING TO DIMENSIONS GIVEN WITH DISTANCE BETWEEN DAMPERS $^8/_{10}$ OF DIM. WHEN U BOLT INTERFERES SET FIRST DAMPER 20CM CLEAR OF U BOLT =Y- DISTANCE FROM SOCKET. SET SECOND DAMPER $^1/_2$Y- DISTANCE FROM FIRST DAMPER

Figure 40.6 Damper installation for 381 m antenna support mast

Figure 40.6 shows a typical damper installation arrangement for a 381 m television antenna support mast, guyed at 5 levels. In this arrangement, two dampers were fitted to each guy about one metre from the ground end of the guy termination.

FUNGAL ATTACK

Fungus is the most troublesome biological agent and is a broad designation used to describe a group of micro-organisms within the plant area. Most types of fungi grow at an optimum in humid, tropical areas, but that does not preclude growth in the temperate zones. Fungus will not grow below a certain temperature nor will it grow above another certain temperature. For every form of fungus there is a certain temperature at which the most rapid growth takes place. Once established, fungus can survive a certain degree of desiccation but during germination, continuous moisture is needed.

The destructive nature of fungi can be manifested in many ways. Some examples are:

(a) They may attack and reduce the strength of a material causing it to have a reduced life.
(b) They may attack and deface meter scales and similar type labels.
(c) They may produce organic acids that etch or disfigure glass or other polished surfaces.
(d) They may cause malfunction of meter and similar type movements by interfering with moving parts.
(e) They may attack soldered joints, circuit boards, components etc., causing lowering of surface resistance.
(f) They hold water and cause surface leakage from energised components.

The energy requirement of fungus is very small and it is often capable of deriving nutrient from very small quantities of adventitious matter on the surface of components. Growths on plastic wiring, capacitors, resistors and transformers may often be associated merely with some surface contamination such as dust, grease, resin. Finger prints in particular are a real problem with fungus growth on components, circuit boards etc. and have been the cause of many circuit failures.

Many hand creams used by female assemblers provide a very good nutrient for fungi. With the advent of modern insulation materials, lacquers, components and finishes which are highly resistant to fungus the problem with radio equipment is not nearly as serious as it was 20–30 years ago. In the wartime literature on materials and equipment deterioration, fungi occupied a prominent position, particularly for equipment installed in tropical areas.

The attack of pole timbers used for transmission line and antenna systems is also a serious problem associated with fungi at radio stations. The fungus attacks the cell structure of the wood causing complete decay. The installation of wooden poles at most stations is now limited to pressure treated poles or to untreated poles of defined durable species.

INSECTS

While there are numerous insects that menace radio equipment in various parts of the world, there is little doubt that termites and brown ants are the most significant because of their widespread presence and destructiveness. Other insects, mainly the flying type, can however be a problem with air filtering equipment, high voltage apparatus and heat exchanger equipment. At one transmitting station located in a tropical area and operating on standby power plant, the lights in the power house attracted myriads of insects from an adjacent cane field. The insects were sucked on to the engine cooling radiator by the fan draught and after one hour's operation the build-up of insects was so thick that the water temperature rose above the safe level and the plant automatically shut down.

Flying insects also often cause flash-over across capacitor plates, between ballgaps and horngaps of transformers and antennas and whilst little damage may be done, it can be a source of annoyance in programme transmission when the transmitter drops out for a recycle operation.

Although termites are widely found in many regions, they are more prolific in

Figure 40.7 Large termite nest

tropical and subtropical regions, because here their needs for food, warmth and moisture are most adequately fulfilled. Their main foodstuff is cellulose, especially wood, and they can cause havoc with wooden transmission line and antenna poles and crossarms if these are not properly treated and regularly maintained. In addition to their depradations on poles they have become adapted to feeding on or otherwise invading many other materials such as underground cable sheaths as well as the station building materials. At one broadcast station in New Guinea, the studio and control room were separated by a double paned window one metre square and termites found their way to the window wooden framing material and built a nest between the two sheets of glass. Over a period of one week, the termites had reduced the effective viewing area between the two rooms to 25% of its original area.

There are many different species of termites; the largest and most voracious species occurs sporadically in the tropics. The nests of termites may be visible above ground, be completely under the soil or be in a hollowed out tree or stump. A typical nest is shown in *Figure 40.7*.

With the extensive application of buried plastic covered cables for control and communication circuits on stations, brown ants have also made their presence felt. One species produces circular holes of about one millimetre diameter and where the colony is large, damage can extend over a long distance of the cable route.

OTHER PESTS

No account of environmental failure or interruption to the operation of radio station equipment would be complete without mention of some miscellaneous pests such as rats, mice, birds, snakes, frogs, possums, wild horses, grasshoppers and many others.

The stories told by some station engineers of experiences with various local pests would be proper material for a book on humour rather than this work. However, some interesting reported troubles are summarised as follows:

(a) A bird made good progress in constructing its nest inside the sectionalising coil of a 150 m medium frequency radiator operating at 10 kW, until it brought home a 30 cm piece of bare wire and endeavoured to place this across the coil. The bird was electrocuted and the nest set alight.

Figure 40.8 shows one recovered bird's nest constructed largely of scrap wire pieces, metal springs and even a pair of white plastic spectacle rims.

(b) When the station operator proceeded to start up a 2 kW transmitter, he discovered a possum inside the cubicle amidst broken tubes. The animal had entered the transmitter during the night through the 30 cm square hot air outlet duct which terminated outside the building without a grill.

(c) Snakes have been reported in antenna matching huts, on masts and inside transmitter cubicles. In many areas with radiators located on or near swampy land, frogs and snakes abound. The snakes enter huts and climb masts after frogs. The horn gap appears to be a favourite point for the snake to board the radiator and the snake often receives a good cooking when it bridges the gap if the structure is powered.

(d) Frogs are a big problem in many antenna matching huts and boxes. They get through small cracks under doors while very small in size and live on insects

Figure 40.8 Birds nest constructed of scrap wire and miscellaneous items (Courtesy The Sunday Mail, Adelaide)

Figure 40.9 Guard rails for protection of guy

inside the hut. They become a real problem when large, as they bridge turns of inductors and suffer the same fate as snakes attempting to climb the mast.

(e) Rats and mice have chewed cables in chases and ducts, resulting in short circuit conditions. They also constitute a menace to motors and generators as they favour these for nesting places.

(f) Grasshopper plagues have been a problem in Africa and Australia. The swarms bridge horn gaps and block up air intake filters. At one 10 kW station it was necessary to shut the transmitter down for two hours because the transmitter air intake filter was blocked tight with grasshoppers.

(g) Animals have caused damage to external plant at some stations where cattle are allowed to graze. They rub their backs on guy wires near the ground and often cause violent oscillations in small masts. Guards, similar to *Figure 40.9*, and barb wire have been used to keep them away from these areas. Damage from wild horses was reported from one station located on a 3000 hectare heavily timbered site. A buried coaxial cable had been damaged by a lightning stroke on an antenna during a thunderstorm and after repair the cable was left uncovered in the trench pending further tests. Wild horses on the site fell into the trench during the night and their hoofs severely damaged the cable.

(h) Parrots have caused considerable damage in areas where they frequent. Many instances have been reported of damage to waveguide windows resulting in escape of the pressurising gas. Because the window of some systems is generally constructed of a thin plastic material the parrot finds it relatively easy to pierce it with its beak. *Figure 40.10* shows a photograph of two windows which have been damaged by this means.

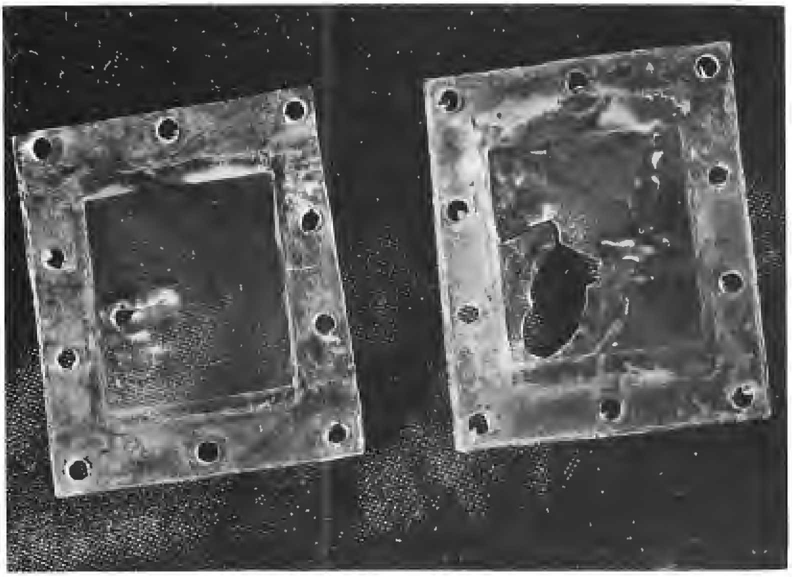


Figure 40.10 Waveguide window damaged by parrots

Many cases have also been reported where parrots perch on antenna wires and make indentations with their beak in the copper wire by swinging around the wire with feet and beak firmly clasped to the wire. *Figure 40.11* shows damage to a balanced coaxial feeder of an antenna system. The outer sheath was extensively damaged for almost the whole of its length. The feeder fell to the ground after being chewed through.

Figure 40.11 Antenna feeder damaged by parrots

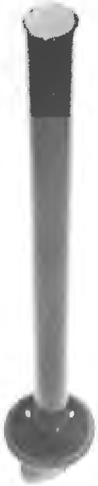


Figure 40.12 Strain insulator damaged by travelling wave

One method which has been found to be effective in dealing with this particular bird problem on antennas and transmission lines is to place over the wire, small lengths of split p.v.c. flexible plastic conduit to form a loose covering. The conduit rotates on the wire and the birds quickly learn that those areas provide an unstable roosting perch and keep away.

It is not unusual for hundreds of parrots to perch on a long wire rhombic antenna resulting in considerable sag of the element. On occasions when the birds are startled and they simultaneously leave the wire, a travelling wave of considerable magnitude is generated and it can cause failure of strain insulators. *Figure 40.12* shows one insulator which failed when the ceramic broke away near the brass end cap.

VANDALISM

In recent years the incidence of vandalism against radio installations and property has increased, resulting in station or system downtime. Actual monetary value of the damage caused is difficult to determine but it is high. The real tragedy, however, is that listeners, viewers, telephone callers and business in general suffer through lost or disrupted service.

Vandalism incidents include bomb blasts in equipment buildings and on masts and towers, firearm damage to waveguides, feeders, dishes and guy insulators, cutting programme and control cables and setting fire to buildings.

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Chapter 41

Performance of Materials and Equipment

PERFORMANCE

Even well designed equipment is liable to failure during its operating life. This tendency to failure can be minimised by ensuring that the components and materials have a high intrinsic reliability under the operating environment. Components and equipment built to very high reliability standards can be costly and in many situations could be economically justified only in exceptional circumstances, such as space flights. In the normal situation encountered, it is usual to employ materials and equipment built to good commercial standards, and then to obtain any required improvement in reliability by the provision of sufficient redundant equipment.

The many types of radio and electronic equipment are constructed of many different materials, each of which may suffer deterioration in different ways. A great deal of work has been done by designers and manufacturers in improving performance of materials and equipment to meet the environmental challenge but there are still many modern components, materials and devices which will not stand up to the normal environmental conditions encountered in some areas of the world. Some examples of performance of selected materials widely used in radio installations are given in the following sections. It must be emphasised, however, that improved materials are always being produced.

PLASTICS

The physical properties of plastics depend more on environmental operating temperature than those of metals. In general as temperature increases, stiffness, strength and fatigue life decrease. The overall effect that temperature has on a polymer depends on both the specific environment and the mechanical load to which the part is subjected. Specific environmental factors include oxidative, hydrolytic and chemical exposure. Therefore the design data used for the material must correspond to the end use requirements of the part.

The variety of plastic materials and detailed accurate information available about them are such that the designer can choose a material for a certain application with a high degree of certainty that he will be able to obtain such characteristics. However, random selection of data will not necessarily enable the designer to choose the right plastic for a particular application. There exists, and always will exist, the need for the exercise of judgement and the use of the accumulated knowledge of the engineer. Tremendous advancement has been made in recent years in the development and use of plastics for radio engineering purposes and there is no doubt that plastics are here to stay. The engineer's task is to determine their limitations and possibilities and to design his equipment accordingly.

Science has not yet come up with an all purpose plastic material for all the conditions encountered in radio engineering. In nearly all cases of application, a compromise must be made between the electrical properties desired and the mechanical limitations inherent in the material. Sometimes there are also optical limitations which have considerable effect on the electrical characteristics. For example, the packaging systems used with many solar cell arrays now finding wide application in radio engineering have been found to experience yellowing, clouding and cracking of the sealant and loss of adhesion between the sealant and the glass or polycarbonate window. In some installations the epoxy-glass laminated board became noticeably darkened as a result of the exposure to the sun. The result was that the electrical output had dropped to 75% of the original value.

Probably the greatest uses for plastics in radio engineering are as solid insulating materials and an important requirement is their ability to resist tracking under adverse environmental conditions. Some plastics produce conducting paths of low resistance relatively quickly compared with others, under the same conditions. A few materials do not decompose, or decompose without leaving a conducting deposit, and are considered to be non-tracking. It would not be possible to detail all problems which have been encountered in the application of plastics to radio engineering, however some of the problems experienced with a few plastics which are widely used are summarised as follows:

(a) Polystyrene.
Polystyrene is probably the oldest synthetic resin known, being discovered in the early 19th century. However, it was not until the middle of the 1930s that cheap methods were developed for synthesising the hydrocarbon. With the capture of the rubber supplies in Malaya in 1942 by the Japanese, the use of polystyrene was rapidly expanded and because of its good electrical properties has been used extensively in radio applications ever since. Its light weight, compared with porcelain, has resulted in its use as feeder spacers for transmitting and receiving antennas. Many installations carrying powers of up to 50 kW for rhombic and curtain antenna feeders are in existence. However, polystyrene has poor weathering properties when used for these external applications. Irradiation by ultra-violet light leads to breakdown of reactive groups in the polymer. This causes the material to yellow and craze. The extent of discolouration depends on the amount and characteristic of the impurities in the polymer. Heat accelerates the rate of degradation and mainly for this reason it is gradually being superseded in tropical areas by polytetrafluoroethylene. *Figure 41.1* shows an application as coil supports in a 50 kW dual frequency antenna matching network.

(b) Synthetic Resins.
The use of materials compounded from resin bonded glass fibre has found wide application mainly because of their ease of fabrication and working. However, there have been many reports of poor performance from both internal and external applications. Electrical failures have been reported with antenna matching hut coil spacers, tube support air ducts, oil filled capacitor insulating frames, high voltage terminal strips and stand-off insulators. In these particular failures, tracks or trees formed on the insulation

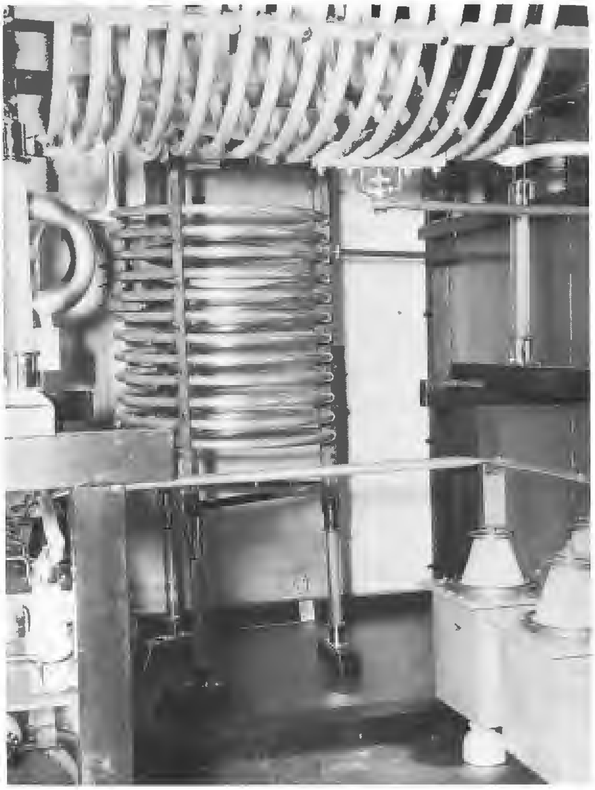

Figure 41.1 Polystyrene rods as coil supports

and resulted in voltage flash-over. A point of interest was the appreciable difference in breakdown voltage for a.c. and d.c. The d.c. breakdown was a great deal higher than the a.c. but it was discovered that after a short period of stress at d.c., slightly below the estimated breakdown voltage, reversal of the polarity would result in an immediate failure at a substantially lower voltage. One of the major problems in using fibre glass for external applications is the comparatively short life, particularly in tropical areas. Ultra-violet light causes rapid deterioration and at some stations, mechanical failures have occurred after three years of exposure. Various treatments have been proposed, from painting to the use of synthetic varnishes known to absorb ultra-violet light. While some surface treatments may be reasonably satisfactory where electrical considerations are of little concern, the problem is not easily solved where high voltages and high frequencies are involved.

Many instances of failure have been reported of fibre glass transmission line spacers at stations located near the sea. Some samples showed a tree like growth of copper which spread rapidly across the surface and gave rise to an arc which carbonised the surface of the insulation and caused its breakdown. At one 50 kW broadcast station, standard silica filled epoxy resin cast insulators were provided as standoff insulators on a transmission line but were removed after 2 years service. Brush discharge, humidity and ultra-violet light had a detrimental effect. In particular, the ultra-violet light caused crazing of the surface in which particles of dust and moisture lodged. This accelerated breakdown by tracking.

Problems have also been experienced with fibre glass in transmitter units. In one transmitter polyester styrene copolymer resin reinforced with fibre glass cloth failed in a switch mechanism. An examination showed that it failed in two different ways by charring and shrinking causing the switch contacts to become loose, and by breaking down electrically.

The charring was due to excessive heat being dissipated in a small volume of material resulting in too high an operating temperature for the resin in the insulation to stand. Forced air cooling of the area was reported to have effected some improvement in one installation but a redesign of those portions of the circuit where excessive heat was being generated was found to be the only suitable long term cure.

The electrical breakdown across the surface of the material was considered to have been caused by the chemical breakdown of the surface resulting in increased conductivity. Chemical changes in polymer surfaces are known to be caused by many factors including excessive heat, a combination of moderate heat and moisture as would be experienced in a hot humid climate, corona and arcing in the surrounding air due to transient voltage surges.

These processes can gradually cause the current flow across the surface between electrodes to increase to a point where surface sparking and carbon formation occur and an electrical track is formed. To avoid this the electrical creepage distances between charged conductors separated by polymer insulating surfaces should be several times greater than the distances used for the same voltages between conductors separated by ceramic surfaces.

Epoxy resin has been tried as a base insulator for broadcast radiators but one trial was disappointing. Cast silica loaded epoxy resin insulators were installed as base and sectionalising insulators of a 50 kW radiator. After only six days operation, partial failure of the mast occurred with fracture of both base and sectionalising insulators.

Epoxy resin has also been considered as a substitute for lead-through porcelain insulators used to connect the capacity hat of some top loaded broadcast radiators. The use of these insulators has resulted in flashover troubles when operating at 50 kW and above. The loss factor of many epoxy resins is relatively poor and on high frequencies considerable heating of the material occurs.

Many components in radio equipment fitted to aircraft operate under severe environmental conditions including ionization and corona. The high voltage applied across some components make total insulation mandatory to prevent external breakdown. One approach has been to completely encapsulate the unit with a proprietary brand resin, a clear two part silicone material that is heat cured to form a tough, electrically stable coating about one centimetre thick. This treatment has been successfully employed with high voltage capacitors.

For high power units complete encapsulation may not be practicable. In one 250 kW high frequency broadcast transmitter the main vacuum tuning capacitor operated in a highly charged radio frequency field and close to other components and considerable trouble was experienced with flashover.

The capacitor had a capacity range of 100 to 1600 pF, a peak test voltage rating of 50 kV at 2-30 MHz and a current rating of 600 A r.m.s. at 2-30 MHz. To overcome the problem two L shaped rings moulded from silicone rubber were used to increase the length of the arc path at the sharp corners of the unit's ceramic seals thus effectively nullifying corona. Insulating silicone adhesive/sealant was pumped under the corona retardant silicone rubber rings to bond the rings to the capacitor. It also formed a large fillet in the corner stress area.

(c) Polytetrafluoroethylene.

Polytetrafluoroethylene (p.t.f.e.), the two most widely known trade names of which are Teflon and Fluon, has in recent years been finding wide application in radio engineering. Its main features include the ability to withstand high temperatures, low losses, high insulation resistance and linear temperature coefficient.

Experience at several stations indicates that the material is not deteriorated by weathering, moisture, mildew, fungus, ultra-violet rays, insects, rodents, salt spray or tracking. In high power external plant installations the antistick characteristics of the surface discourages deposit build up and will not form a carbonaceous track. In the event of a discharge across the surface, the arc merely ablates the surface. No charring or burning is evident. The material will not support combustion even in the presence of an arc.

At high frequencies most insulator materials are subject to dielectric heating. The dissipation factor of many ceramics and polymers increases with a rise in operating frequency resulting in thermal expansion and contraction cycles which leads to surface cracking and eventual insulator failure. Polytetrafluoroethylene has a very low dissipation factor and there is very little heat build up in the material.

One interesting application of p.t.f.e. is in coaxial cables used in high power broadcasting. The ability of coaxial cables to handle high powers at high frequency depends mainly on the properties of the dielectric and how well the cable is manufactured. Service is limited by the dielectric's thermal performance and resistance to ionic bombardment. Imprisoned air in the insulating material has been a major problem in the past. When air is subjected to a sufficiently strong electric field, it ionizes and creates a corona discharge which will attack and eventually degrade the dielectric. At one station employing 500 kW transmitters some 53 km of cable using p.t.f.e. spacers was used to connect the antennas to the matrix switch. The cable consisted of an inner conductor of radially corrugated copper tubing 99 mm in diameter with a wall thickness of 0.6 mm and an outer conductor of spirally corrugated aluminium 246 mm in diameter with a wall thickness of 2.5 mm. Spacers of p.t.f.e. were located at 25 cm intervals within the cable to keep the inner conductor centred. Each spacer was made up of three elements spaced 120 degrees apart on an open ring of copper plated steel. The elements were injection moulded simultaneously on the ring. The maximum temperature of the inner conductor was estimated to be 140 °C in normal service with the operating frequency being 26 MHz and an environmental ambient temperature of 35 °C.

Under these conditions the outer conductor temperature was 75 °C. The cable was pressurized at 4 atmospheres to improve the heat transfer from the inner conductor.

(d) Ebonite.

For many years ebonite was used in the construction of coil formers and spacers for inductors in antenna matching networks. Although many new synthetic materials are now being used for this purpose, ebonite has not been entirely displaced. The electrical properties of a well made unloaded ebonite such as dielectric strength, power factor and permitivity are very good. The power factor is lower than that of some of the thermo-setting synthetic resins which are more heat resistant, but is not as low as that of the best synthetic resins, polystyrene and others. However, its chief weakness is its tendency to deform at high ambient temperatures. This may not cause serious difficulty if the material is not heavily stressed mechanically but serious softening may occur in some grades at temperatures of about 75 °C or for high voltage applications where there is a high frequency field, in which case dielectric losses can raise the material to a temperature considerably above ambient level.

Another well known disadvantage of ebonite is its tendency to form an acid surface under action of light. However, loaded ebonites, i.e. ebonites loaded with fillers, are usually much less liable to form acid surfaces on exposure to light than unloaded materials.

PLASTIC CABLES

Plastic covered cables buried in the ground are soon damaged by termites and brown ants where these insects are prevalent. The insects eat holes in the plastic sheath then in the plastic insulation covering the wire so baring the conductors. If water then enters the cable, it will cause short circuits or leakage between the wires and may put the cable out of service.

The use of insecticide placed in the cable trench has been used with success at some stations but its effect rapidly disappears in areas of heavy rainfall. Insecticide or repellant incorporated in the sheath has been tested by cable manufacturers but has not proved entirely satisfactory. A nylon jacket has recently been developed to counter insect damage and field tests have given encouraging results, particularly against termites.

The most common method of protection generally used is screwed galvanised iron pipe. Care has to be taken at pits and manholes to ensure that termites and ants cannot enter the pipe. Another method which does not require a duct is to provide an integral copper or aluminium sheath or copper tape barrier. This technique has been used successfully for nearly 100 years on submarine cables and is also the standard technique for coaxial cables used to feed the antenna systems. The cables are generally covered with a plastic jacket as part of the standard cable and although insects may eat the plastic jacket, the copper or aluminium sheath prevents further damage. Damage to the plastic jacket is often of little consequence except in those soils which may contain substances which are corrosive to copper or aluminium.

Cables however are not all buried in the ground. Often they may be exposed to scorching sunlight, wind, rain and coastal salt sprays. For the cable to serve its proper function it must, under these environmental conditions, retain its physical attributes, the essential electrical qualities and have no corrosive effect on the conductors or other components of the cable. Incorporation of suitable substances, such as carbon black, are essential to obtain the best resistance to sunlight for polythene and polyvinyl chloride cables.

Troubles have been experienced with the corrosion of copper conductors in p.v.c. compounds of inferior stability. In one case there was reported fading of the red dye, decomposition of the p.v.c. by ultra-violet light and general stress corrosion of the copper conductor. In a second, a black p.v.c. compound containing chlorinated plasticisers also caused corrosion in a section of exposed cable where water had entered due to a bad termination seal.

Heat and light stabilisers must be employed to avoid rapid actinic degradation. Among these are ultra-violet absorbers and active plasticisers. Substances are also frequently added to neutralise the hydrogen chloride which is formed when p.v.c. is heated.

CERAMIC AND GLASS INSULATORS

Ceramic insulating materials find wide application in radio engineering but have the one important disadvantage that their electrical surface leakage increases considerably with increasing relative humidity. The rate of change is shown in *Figure 41.2* and it can be seen that the performance of an insulator is very much worse when installed at a station situated in an environment of high humidity than one in a dry inland locality. This is the main contributory reason why transmission line and antenna insulators flash over during wet weather conditions when insufficient factor of safety has been built into the design.

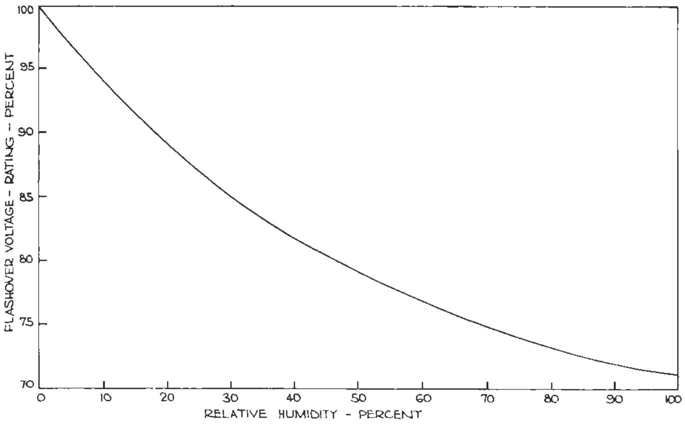

Figure 41.2 Flashover voltage of ceramic insulators in air as a function of relative humidity

The flashover is due to the formation of a surface layer of absorbed water which at high relative humidities may be many molecules in thickness. The electrical conductivity of the aqueous layer is increased by the presence of ions resulting from the solution of substances such as salt spray, carbon, and the like which may be on the surface of the insulator.

Figure 41.3 shows the calculated relationship of flashover voltage and arcing distance for three generalised types of surface conditions for rod insulators, and

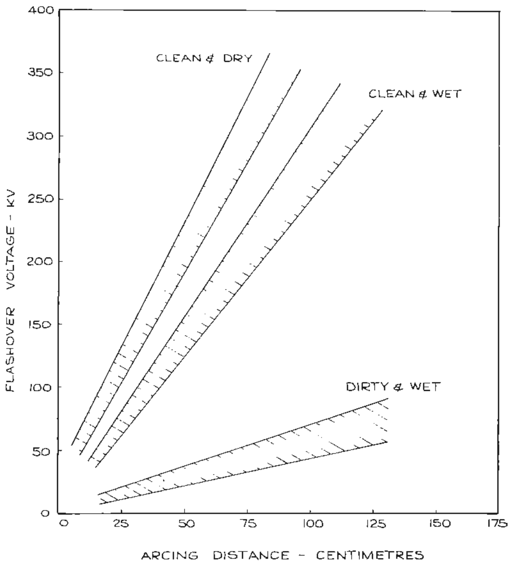

Figure 41.3 Arcover distances of ceramic insulators as a function of surface condition at 50 Hz

clearly shows the need to maintain a clean surface, particularly where high voltages are concerned. A standard 37 cm transmission line strain insulator will have a wet flashover rating five times greater when clean, than when dirty.

Under dry conditions, the flashover voltage of most types of ceramic insulators is determined by the mounting arrangement and quality of workmanship. Sharp edges and imperfect working of the cementing compound between ceramic and fitting reduces the discharge voltage level. The dielectric strength is almost independent of frequency but during periods of rain the influence of the frequency of the working voltage is much larger.

Glass also suffers from the same surface leakage problems as ceramics. Glass insulation has found wide application as a lead-through insulation material for connecting antenna matching hut equipment to the antenna. In the case of some medium frequency and very low frequency transmitter installations, the lead-out glass window is built into the wall of the matching hut building. The rim of the glass is bedded into an earthed lead or copper flashing which is connected to a large sheet metal rain shield hood extending over the outside of the window in order to keep the rain off the surface of the glass. At the centre of the glass sheet a ground hole carries a brass bush bedded to the glass with a conducting graphite paste. The lead-out conductor which may be up to 7.5 cm diameter for a high power v.l.f. installation runs closely but freely through this bush again bedded by graphite paste. Various types of varnishes, greases and waxes have been tried from time to time to overcome deterioration in the insulation resistance of these plate glass windows because of absorption of moisture on the surface, but with little success. The application of most readily available compounds, gives only temporary protection, since water vapour diffuses through coatings of the usual thickness within a few weeks and forms a conducting layer on the surface. It is evident that in order to prevent this deterioration, the material used for the surface treatment must possess adhesive properties to the glass, greater than that of water for the same surface.

The electrical performance of insulators is affected by their operational environment and problems may be encountered if the choice of insulators is based purely on theoretical considerations. This applies particularly to the choice of insulators for external use. Also, proven field trials in one country may not necessarily be a guarantee of their satisfactory operation in another. In some installations, insulators designed for severe icing conditions in northern Europe were found to be unsatisfactory in a tropical site location with a heavy salt laden atmosphere.

At one station located in a tropical environment close to the sea and in an area of high dust, the conductivity of iron ore dust and salt was high enough to cause tripping of the transmitter when switched on early in the morning for the beginning of the days transmission. It became necessary to keep the transmitter operating continuously in order to maintain a degree of warmth in the base and guy insulators. The insulators were subsequently coated with p.t.f.e. to reduce dust build up.

INSULATING OILS

The deterioration of insulating oils used in transformers, chokes, circuit breakers and capacitors may be caused by:

(a) The increase of foreign substances such as moisture and dirt. Moisture finds its way into the oil by inadequate maintenance of breathers or by oil which has been improperly stored or filtered on the station.

The replacement of oil in transformers at a large transmitting station is a frequent occurrence, particularly during initial testing when faults may develop and in later years when the oil has deteriorated. Oil should always be stored in sealed drums and passed through a suitable filter before being placed in the tank. The presence of moisture is a common cause of failure and a relatively small percentage will substantially lower the breakdown strength of the oil.

(b) The formation of impurities.

The formation of sludge is the result of chemical action and a rise of 10 °C in temperature may double the rate of formation of sludge. Sludging is associated with an increase of acidity and an improvement can be affected by increasing the ventilation of the transmitter vault room or by attention to other points which will cause the transformer or choke to operate at a lower temperature. Many high power transmitters used for international broadcast purposes employ speech clipping techniques and this imposes a high load on transformers when high levels of clipping are employed. Some installations employ forced air cooling units which are automatically switched into service when continuous high levels of modulation cause transformer oil termperatures to rise above a predetermined level. Deterioration of the oil can also be caused by the formation of carbon and by cracking. Both these result from arcing or a limited but sustained fault rather than environmental situations.

The deterioration of oil resulting from excessive acidity is a serious problem at some large stations and many organisations have installed oil

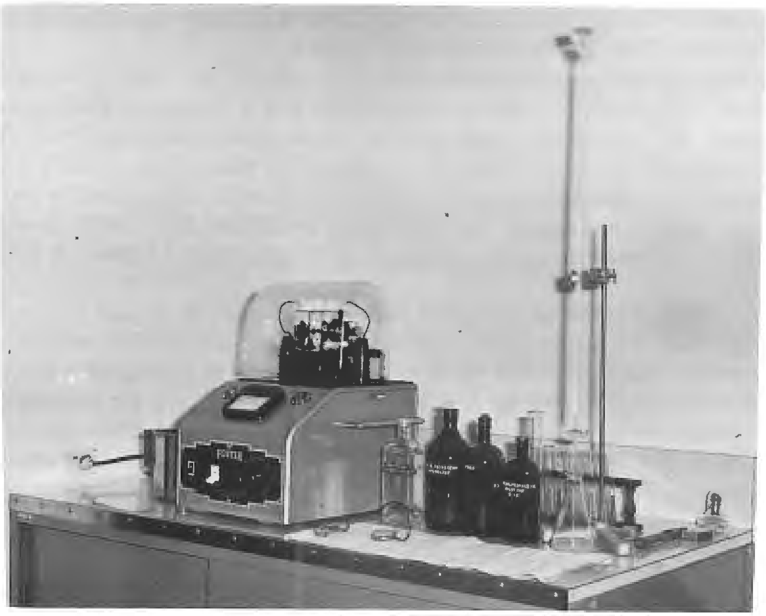

Figure 41.4 Typical station oil testing facilities

testing equipment to enable checks on the condition of the oil to be carried out at regular intervals. It is usual for one station to act as the test centre for all other stations in the network. *Figure 41.4* shows the testing facilities provided at one large centre for this activity.

Excessive acidity may cause corrosion, deterioration of insulation and blockage of cooling ducts, leading to overheating. The symptoms of high acidity may be classified as follows:

(i) Smell: A pungent acrid odour which in many cases can be detected without removing the cover of the transformer.

(ii) Colour: Discoloration of the oil, from its normal transparent and almost colourless state, to dark brown.

(iii) Sludge: The presence of a deposit of dark brown or "treacly" black appearance on the core windings and other parts. If the deposit is difficult to remove it will most likely be an indication of high acidity condition.

(iv) Embrittlement of the insulation: Acid products of oxidation have a deleterious effect on the mechanical properties of cellulose insulation. The electrical properties are not generally affected provided that the insulation is not mechanically damaged.

(v) Corrosion: Corrosion appears in the form of conductive flakes which might fall and cause electrical leakage across terminals, wires etc.

(vi) Other indications: Gas collected can give information as to the process going on inside the transformer.

Field experience by some engineers has indicated that transformers provided with oil conservators give far less acid trouble than non-conservator types.

Nevertheless there are many examples of non-conservator transformers, installed at radio stations in situations with good ventilation and cooling, and not subjected to prolonged overloads, which have given long service without acidity troubles.

SILICA GEL

It has been the practice for many years to include bags of silica gel with equipment in transit to radio stations in order to absorb moisture which may penetrate the packing covers. However, experience has recently shown that silica gel has a corrosive effect on nickel silver and several other metals, particularly in a moist atmosphere as often happens with faulty packing or poor storage arrangements. Because of these corrosion problems with relay and jack springs some organisations have discarded silica gel and are using the slightly more expensive activated alumina which has about two thirds the moisture absorbing capacity of silica gel, but is non-corrosive.

CONTACTS

High claims are made on performance and life of modern contacts but environmental conditions can introduce many problems. Impurities in the air can cause a lot of troubles. Then there are chemical combinations which produce thin films on the contact surfaces. These films have to be cracked by the contact pressure and removed by the sliding motion of the contacts. The films may not always be troublesome where very high pressure sliding contact is in use, as for example in a high power matrix switching system, but they are frequently a problem with relay contacts in low level circuits.

Silver is used extensively for contacts but is subject to sulphide tarnishing. The sulphide film grows relatively slowly, changing colour as the thickness increases and has a very high resistance. The growth of the film is dependent on the availability of free sulphur atoms and in a clean environment the tarnish thickness will increase very slowly. The biggest problem occurs when materials containing sulphur are associated with equipment in close proximity to the silver. Rubber and ebonite are materials which should not be used near silver. At one 50 kW transmitting station a motor driven rotating switch, *Figure 41.5*, was provided to switch the output of the transmitter to either line or artificial antenna. To stop the rotary action of the switch in the desired contact position, a brake was applied to a rubber tyred wheel. The braking action wore away the rubber and minute particles were thrown throughout the switch during each operation. The silver contacts soon became black but did not affect performance because of the high scraping pressure of the switch arms. However, silver relay contacts controlling the stopping and starting operations of the switch and carrying only 48 V d.c. became highly resistive. Measurement showed a resistance value of more than 5000 ohm. The silver sulphide tarnish film was extremely tenacious and could only be removed with great difficulty.

Another substance that has caused much contact trouble is silicone. Silicone greases have been used on insulators in an attempt to improve their flashover characteristics in a high humidity environment and silicone liquids in pressure pak form have been used to spray wiring and terminal blocks in order to minimise leakage problems. Because of their low surface tension properties silicones used in this manner soon spread to contacts. Silicone is a first class insulator and

Figure 41.5 Rotary switch with rubber tyred wheel

extremely difficult to break down even with high contact pressure. A station engineer reported that an operator after suspecting surface leakage across a bias supply contactor surface, following several days of continuous rain, sprayed the contactor surface and wiring with a silicone spray, after shutdown of the transmitter. It was found at start-up the following morning, that the contact surfaces of the contactor presented an open circuit condition, even though the surfaces touched with the normal pressure.

A further problem that has been experienced with silicone is when it finds its way on to contact surfaces which arc after breaking a circuit. The silicone is decomposed to silica, an extremely hard glassy type material which fuses on to the metal surface, and can only be removed by vigorously filing away the contact surface. Once silicone has found its way into jacksprings, relays and contactors, it is extremely difficult to remove and many engineers have prohibited its use on their station.

CONTACTORS AND RELAYS

The failure of contactors and relays is not reported as frequently as it was in transmitters 10 years or more ago due mainly to the improved heat resisting properties of synthetic or plastic enamels, and solid insulating materials such as polytetrafluoroethylene. However, in dry areas where the filtering arrangements of the transmitter air intake are inadequate or filters are not properly maintained, moving parts of contactors and relays will wear excessively and if contaminants are present, armatures may stick.

Corrosion is still a problem at some stations. The magnet wire should be protected against electrolysis. The insulating materials must be pure and free from chemical combinations which form electrolytes in the presence of high humidity. Otherwise corrosion will attack free points of the copper wire, especially when wires have a potential difference to earth or other parts. The problem is often aggravated at installations close to the sea where salt laden air may be allowed to circulate through the equipment.

SILVER MIGRATION

Silver is used extensively in radio equipment because of its high conductivity but silver migration can be a problem in environments of high humidity. In certain conditions, the use of silver leads to the development of low insulation resistance or even complete breakdown of an insulating gap. Although hygroscopic surfaces readily permit migration, even in an environment of low relative humidity, some of the more stable surfaces such as mica can also show this effect in high humidity situations.

This migration phenomenon may be defined as a process by which silver when in contact with insulating materials under electrical potential, is removed from its initial location and is redeposited as metal at some other location. Although an inspection sometimes gives the impression that metallic silver migrates as if it were a kind of whisker growth from one of the electrodes, this is not so. The process is rather like that of an electro plating set-up.

The silver migration problem has been detected at several stations including some installed in tropical areas. It is not an easy problem to solve because of many complicating factors involved. The rate of growth appears to be enhanced by a high d.c. potential, a low surface resistivity of the insulation material and an environment with a high relative humidity.

No insulation material has been found which will give complete freedom from migration problems, but polystyrene appears to be the least affected of those insulating materials generally used at radio stations. Fibre glass laminates have given considerable trouble, due mainly to the effects of ragged cut edges. The control of dust and humidity in equipment areas will often do much to minimise troubles from migration.

An interesting problem has arisen in recent years with wet-slug capacitors widely used in space and military radio equipment. The problem has been traced to the silver case. The capacitor has a sintered tantalum slug as anode and a fine silver case as the cathode. The electrolyte is a gel of either lithium chloride or sulphuric acid in water. Under certain operating conditions the silver case deplates forming silver whiskers which pierce the tantalum anode slug. An all-tantalum wet slug capacitor has been developed which has overcome the problem.

PRINTED CIRCUIT BOARDS

Modern printed circuit boards manufactured under controlled factory conditions are generally very reliable when used in the environmental situation for which they have been designed. However, many units are built locally by station installation and maintenance staff and considerable trouble has been experienced with many boards because they were not properly cleaned after assembly or after maintenance. Residue from plating baths, soldering, etchants and grease from fingers all help to reduce reliability of the installed product. Resin residue from soldering operations has resulted in many failures. Although resin when dry is a good insulator and therefore of little concern to performance characteristics, the residue will decompose and become conductive under conditions of heat and high humidity.

Cleaning the board is not an easy operation where facilities are restricted. At least two types of cleaners are required to remove the harmful substances. Several proprietary brands are available and if used in accordance with the maker's instructions satisfactory results should be obtained. Some cleaning fluids can be hazardous if used improperly. Chlorinated hydrocarbons will damage electrolytic capacitors by attacking the insulating material at the positive terminals. Polystyrene parts of capacitors and other units should be protected, otherwise they may be dissolved by some substances e.g. trichlor.

TRANSFORMER BOXES

At many stations it is often necessary to install small equipment boxes externally to house for example, off-air pick up alarm equipment, field strength monitors near directional antennas, matching transformers and balanced to unbalanced transformers as in *Figure 41.6*. Equipment failures in these small boxes or cabinets is a problem particularly in areas of high humidity.

The relative humidity measured inside some boxes has reached nearly 100%

Figure 41.6 Balanced to unbalanced transformer boxes

for long periods and condensate often collects in the bottom of the box. The use of epoxy sealed units and plastic insulation has done much to relieve the problem but leakage still occurs across the face of terminal and tag blocks. This leads to corrosion and poor circuit crosstalk characteristics. Connectors are very difficult to seal properly, and in fact the ineffective sealing of coaxial cable connectors to television antennas, mast lighting distribution boxes and balanced-to-unbalanced line transformers has been a source of trouble at many stations.

There are two schools of thought among engineers on enclosures. One considers that box and cabinet enclosures should be hermetically sealed and the other considers that they should be well ventilated. It is not an easy job to achieve a perfect hermetically sealed box in practice, particularly if the box has to be frequently opened. An imperfect seal is undesirable as moisture enters the enclosure by breathing but is not purged out, and an appreciable build-up of liquid occurs. Full ventilation is reasonably effective with some pole mounted balanced-to-unbalanced transformer boxes and rhombic resistance terminations, although frogs and insects particularly wasps have been found to be troublesome.

ROPES

Prior to the introduction of synthetics, the most commonly used rope for radio station work was made of natural fibres, usually manila. This was a general purpose rope used in practically all applications. With the introduction of synthetic ropes it has been found that because of the peculiar characteristics of the various synthetics, many of the ropes can be used only for a specific job and so their general acceptance has been slow.

Nylon was one of the first synthetics introduced but it was found that the rope had a very high elongation and elasticity, and because of the stretch had limited application.

Dacron has characteristics more closely resembling manila than most of the other synthetics. It does not stretch appreciably but due to its relatively high cost and weight has not been readily accepted.

Polyethylene has a very light filament and in fact will float in water, but because of an extremely slippery surface it is sometimes difficult to handle. Polypropylene has a higher coefficient of friction than polyethylene and is consequently easier to handle. However, both polypropylene and polyethylene have a comparatively low melting point. It has been found that when used as a working line, some ropes tend to melt when a heavy strain is applied to the line and to stick to the fitting to which they are attached, then suddenly give way.

In order to obtain the advantages of the higher melting point of dacron with light weight polypropylene, composite ropes are now available with internal polypropylene filaments and an outer covering of dacron. *Table 41.1* shows the melting point of fibres of some commonly used plastic ropes.

Natural fibre ropes are weakened by mildew and rot and there have been several different treatments used to impregnate the ropes during their manufacture. Most of them are copper compounds and are satisfactory as long as they last, but they all wash out in water after prolonged use and it is difficult to replace the treatment. Synthetic ropes do not rot and the mildew that attaches itself to them is seldom detrimental. Manila ropes should be stored in a cool dry

Table 41.1 MELTING POINT OF PLASTIC ROPE FIBRES

Material	*Temperature (°C)*
Polypropylene	165–170
Polyvinyl alcohol	215–225
Polyamide	250
Polyester	260
Dacron	250
Nylon	250

Figure 41.7 Plastic ropes used to maintain antenna stability

room with plenty of ventilation to avoid dry rot and mildew. Synthetics should be stored out of direct sunlight.

In addition to their use for rigging and other lifting purposes, synthetic ropes are finding use in antenna systems because of their insulating properties. *Figure 41.7* shows one application of polypropylene ropes on a log-periodic antenna system to maintain stability during very high winds. The application however proved disappointing. Less than 18 months after installation, the outer covering disintegrated and the separate strands then became exposed to the elements. Some of the covering can be seen hanging from ropes in the photograph. *Figure 41.8* shows in more detail, the extent of deterioration. The rope was approximately 18 mm diameter.

Polypropylene appears to be adversely affected by ultra-violet radiation. Stabilisers provide some protection, but carbon black is effective in preventing ultra-violet damage.

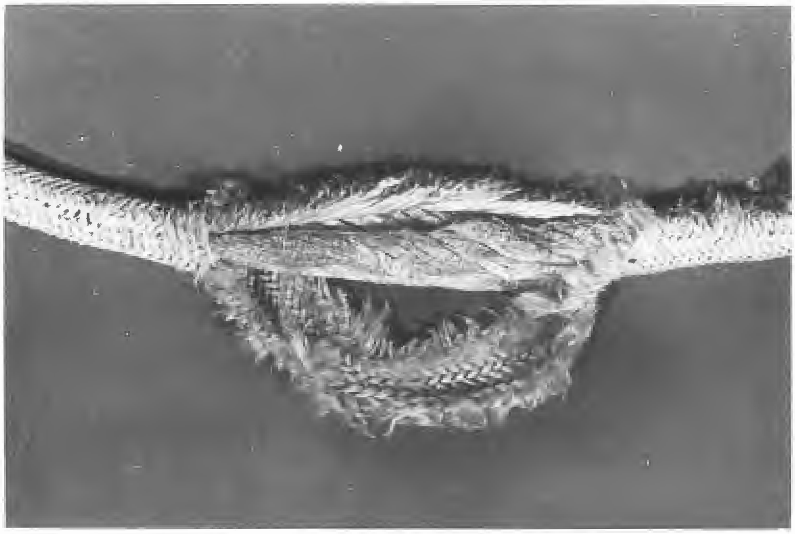

Figure 41.8 Deterioration of polypropylene rope

WOODEN POLES AND DRUMS

Wooden poles used for transmission lines and antenna systems have a long life in many temperate areas, even when untreated, but under a wet tropical environment the same pole would soon become part of the soil.

Wooden poles are subject to attack from several agencies, of which the two main ones are:

(a) Decay fungi.

Wood destroying fungi live mainly on cellulose and lignin and the presence of starch does not increase the susceptibility of wood to fungal attack. Infestation of the timber will not occur unless the moisture content is above about 20%. However, once the initial attack has taken place, the water produced as an end product of the decay will generally be sufficient to maintain the process, unless evaporation is very rapid. In the process, the cellulose is oxidised into carbon dioxide and water.

Conditions essential for fungal growth are food supplies, adequate moisture, suitable temperatures and oxygen supplies. The optimum temperatures are generally in the region 18 °C–33 °C and it is evident therefore that the greatest problems exist at those stations in the temperate and tropical regions.

To counter soil decay problems many tall poles used to support antenna systems are mounted on a concrete thrust block above the surrounding ground level. To secure the butt, some engineers set vertical steel sections in the concrete and strap the base of the pole to those sections. Others have set the base loosely in a hole about 30 cm deep in the concrete block and filled the space with pitch. Transmission lines are as a general rule set directly into the soil and decay is most pronounced about 30 to 40 cm below the ground line.

It is generally in this area that there is sufficient moisture, adequate air supply and small temperature variation—conditions ideal for fungal attack. In tropical areas with high humidity and high temperature, attack also occurs above the ground level, generally at crossarm points, stay attachment point and other areas where moisture is easily retained, such as knot holes.

(b) Insects.

Termites are by far the most troublesome of the insects. The strength of a pole infested with termites may be seriously impaired and wooden poles should be suitably treated as soon as the presence of these insects is oberved. The termites attack the timber in contact with the ground and may extend their attack to a considerable distance above the ground. They retain their soil connection by their internal workings in the wood or by the covered runways which may extend over durable timber sections to make contact with more suitable food material.

Borers and beetles also attack poles and crossarms. Auger beetles and powder post borers confine their attack to sapwood and although they seldom seriously damage a large pole they have caused failure of crossarms which have been cut from timber with a large sapwood content. The holes they make also become focal points of fungal decay.

For transmission line and antenna support poles, many of the denser eucalypt timbers such as ironbarks, boxes, river and forest red gums, jarrah, wandoo, ironwood, turpentine and bloodwood show considerable resistance to termite attack.

Superficial coatings of creosote oil or other preservative applied to poles and crossarms by brushing or dipping them will not give permanent protection against termites although they may act as temporary deterrents. Termites

Figure 41.9 Pressure treated transmission line poles

often cross over creosote brushed timber to reach unprotected timber or cracks which form in the pole.

Poles and crossarms that have been pressure treated with creosote oil, a fixed waterborne preservative of the copper-chrome-arsenic type or other recognised preservative, can have a very high resistance to termite and fungi attack, regardless of the natural resistance of the untreated timber. It is now common practice to pressure treat the poles by full immersion under pressure inside a closed cylinder. It has been estimated that an average life of 40 years can be expected from a treated pole compared with 20 years for an untreated one. *Figure 41.9* shows a group of pressure treated transmission line poles erected as anchor poles near the matrix switch of a high frequency broadcast station.

Coaxial cables and flexible waveguides are supplied on large diameter wooden drums and when stored in an unfavourable environment the drums will deteriorate very rapidly. The drums may be up to 3 m in diameter and some have collapsed after a year or two in the open. The recovery and redrumming of the cable or waveguide is a difficult operation when the drum becomes unfit to handle. Only the most durable timbers should be used for construction of drums which are to be stored at sites for long periods. The advice of timber experts should be sought in the specification for suitable timbers.

Plastic covers have been provided over some drums where these have had to be kept on site in the open for long periods, as emergency station spares.

MASTS AND TOWERS

Practically all masts and towers are now galvanised, and unless required for aircraft warning purposes, it is not usual practice to paint a structure. Painting new galvanised steelwork for protection purposes is unnecessary and uneconomical in most areas.

The rate at which a zinc coating weathers away varies primarily with the degree of corrosiveness of the atmosphere to which it is exposed. Atmospheric corrosion, however, requires promoting and controlling factors and neither of these is able to induce corrosion unless the other is present, also at an adequate level. The main promoting factors normally encountered are sulphur dioxide and air borne salt. The important controlling factor is the atmospheric relative humidity. In general, atmospheric corrosion becomes serious only at relative humidities above about 70%, provided that a promoting factor is present.

Except for salt-spray atmospheres, serious atmospheric corrosion is rarely due to any natural constituent of the air but to extraneous impurities of which sulphur dioxide is the worst. If this contaminant is eliminated or not present, atmospheric corrosion largely ceases to be a problem. Although there are exceptions it has been found that marine atmospheres existing at radio stations near the coast do not generally constitute as serious a hazard in promoting mast and tower corrosion as the polluted atmospheres of heavy industrial areas. The same pattern applies to the corrosion of copper and brass conductors and fittings of transmission lines and antenna systems.

The life of a zinc protective coating on a steel mast or tower depends on the extent of corrosiveness of the atmosphere and the thickness of the zinc. An examination of the history cards of some radio masts and towers located in

Table 41.2 LIFE OF GALVANISED COATING ON STRUCTURES IN VARIOUS ENVIRONMENTS

Type of Structure	*Atmosphere*	*Life to stage of rust show (years)*
Broadcast Mast Radiator	Dry rural, sub-tropical	> 35
"	Coastal, tropical	27
"	Coastal, temperate	> 30
Radiocommunication Tower	Mountain, tropical	> 20
"	Railway-yard, temperate	8
"	Mountain, temperate	> 22
"	City, tropical	18
"	City, temperate	20

various environmental situations and with the same approximate original zinc coating thickness, showed average life figures at the stage when rust was first observed, as set out in *Table 41.2.* In the case of the first, third, fourth and sixth structures rust had not appeared at the last time of inspection.

Guy wires have to be closely watched in corrosive atmospheres. At some stations located close to the sea, guy wires have been replaced within three years of erection. Some tests have been carried out with plastic sheathed guys but problems have been encountered in properly sealing the wire when egg type insulators were used to break up the guys. Sealing of the wire when using standard compression type insulators presents no problems. However, objections have been raised against sheathing on the grounds that it is difficult to detect any start of corrosion when the wire is covered with a defective sheath.

At least three large v.l.f. stations have been erected on sites where guy corrosion resulting from salt spray is a problem. When it is considered that there are many very tall structures supported by a large number of long guy wires, proper maintenance of external plant is an essential requirement if a satisfactory economic life is to be obtained from the plant.

At the time of treatment, the coating thickness of zinc on structural members may vary from 3 to 4 mils to as much as 8 mils. It is, however, not easy to determine the point at which protective painting becomes necessary as a result of weathering or corrosion of the zinc. Some administrations have a requirement that painting be carried out for protection purposes when the zinc coating has been reduced to $1\frac{1}{2}$ mils.

It is important to commence treatment before base metal rust appears, as the cost of preparation climbs sharply once rust has appeared, particularly at nuts, bolts and gusset plates. The thickness of zinc remaining can be determined by using an instrument which measures either the attractive force between a standardised magnet and a zinc coated specimen or the reluctance of a magnetic flux path through the zinc coating. Either the attracting force or the reluctance as measured is a function of the thickness of the zinc coating.

Occasional corrosion of galvanised steel transmission line poles has been experienced and it is the practice of some stations which are located close to the sea to coat the poles with a tar epoxy before embedding he pole in concrete, at about 15 cm above and 15 cm below the finished concrete level. Steel poles are preferred in many areas because of the absence of suitable local timber and also because of trouble with termites and dry rot.

Corrosion of stay rods associated with the transmission line poles has been experienced at some stations. At one broadcast station erected on a tidal salt flat, about 60% of all stay rods had been severely weakened by corrosion within three years of installation. In similar areas, engineers have successfully overcome this problem by slipping an oversize plastic tube over the stay rod and filling the space with a bitumastic compound during the installation of the stay.

Metal shapes require careful selection where environmental conditions are severe and in many cases require constant maintenance. Masts and other structures made of tubular steel must be closely inspected at regular intervals to check for signs of corrosion on the inside. Holes bored in the tubular members for galvanising purposes often allow water to enter and also allow condensation of moisture on the inside walls, unless properly sealed. The detection of internal corrosion is a difficult maintenance problem and the collapse of a member can have serious consequences. During an annual inspection of one mast the inspector struck one leg with a small hammer and the head of the hammer disappeared inside the tubular leg. The thick skin of paint had covered the section which had corroded right through one side of the member.

Threads of guy anchor installations should be closely watched for corrosion, as the action during adjustment of tensioning will remove the soft zinc from the screw thread. Some engineers coat the complete rod threads regularly with grease but others go for much more effective protection. The thread is coated with a thick layer of white lead and tallow compound and covered with several layers of bound canvas stripping, followed by two or three coats of white paint. The covers and compound are removed every two years during a thorough inspection and replaced with fresh material. *Figure 41.10* shows this principle applied to the guy anchor rod of a 180 m mast radiator.

Modern satellite stations employ massive antenna systems which involve a large amount of structural steelwork. The total surface area of steelwork for a typical 33.5 m diameter dish and the supporting structural members is about 950 m^2 and great care is taken during the manufacturing and installation stages to ensure that high quality protection is provided to ensure low maintenance during the life of the system.

Although structural steelwork at one station was supplied with a galvanised finish, additional factory protection was provided to give on-site long term protection. In order to achieve good adhesion prior to treatment, all members were washed with a proprietary brand solution to clean the surfaces. Four coatings were then applied. The first comprised a coating of zinc chromate primer. This was followed by a coating of epoxy micaceous iron oxide undercoat of natural steel grey colour. When this had thoroughly dried, a top coat of epoxy micaceous iron oxide of bridge grey finish was applied followed by a finishing coat of epoxy micaceous iron oxide of silver grey colour. The steelwork received further treatment on-site with a final coat of epoxy micaceous iron oxide.

Antenna feed arm corrosion has been a major problem at many radio communications station sites. The worst area of corrosion is under stainless steel clamps which hold the corrugated aluminium feed arm to its supporting member. Sites close to the sea have been affected more than those at inland areas. An effective cure has been to seal the pits and holes with epoxy resin prior to the application of a thin aluminium tape and then to wrap the feed arm with Denso tape and plastic sheet to separate the aluminium and the stainless steel clamp.

Figure 41.10 Guy anchor rod thread protection

PAINT FAILURE

The two main purposes for which paint is used on radio plant are for preservation and for functional reasons, such as identification for air navigation purposes.

Paint on internal equipment presents very few problems but on external plant, regular treatment is often necessary. Wooden poles and crossarms are generally treated with creosote or other preservative and most steel structures are galvanised and do not therefore require painting for protection purposes. However, painting of masts and towers for aircraft warning purposes may be required. The cost of painting tall masts and towers is high, so it is desirable to keep repainting operations to a minimum. The decomposition of paint is due to oxidation, erosion, weathering etc. and the rate of decomposition is dependent on its constituents and the environmental conditions the main defect of paint work is cracking in all its forms, including checking, crazing and alligatoring which produces such effects as flaking, scaling and peeling.

An examination of paint failures on external plant has shown that the most important causes of failure are due to inadequate surface preparations, application of the paint under unfavourable weather conditions, use of inferior or unsuitable paint materials, adhesion difficulties, and the nature of the environment.

Tropical conditions, in general, contribute to faster paint breakdown owing to high temperatures, moisture laden atmosphere and the longer exposure to ultraviolet radiation or to a combination of some or all of these effects.

Observations of painted structures in the tropical regions indicate that fading, discoloration, matting, chalking and cracking, followed by peeling and generally embrittlement, can take place rapidly.

When painting is required for aircraft protection purposes it is often necessary to paint the structure immediately after erection. In some cases, painting of individual members is carried out on the ground before the erection, but many engineers do not permit this practice. This introduces the problem of paints on new galvanised steel. Most paints do not readily adhere to new galvanised surfaces and it is frequently necessary to apply an etching solution. Normal practice is to follow the etching procedure with three coats of paint. The first or primer coat is a zinc chromate iron oxide base and is followed by two coats of micaceous iron oxide based undercoat and topcoat of the appropriate colour to suit aircraft warning requirements. The recent introduction of calcium plumbate has solved the etching problem, but care should be exercised in its use, as several cases have been reported where animals grazing near the structure have consumed sufficient of the material from wind blown deposits on pastures to kill them.

Considerable work has been undertaken in recent years on exposure trials of orange and white gloss acrylic emulsion paints to evaluate their possible use as aircraft warning colours on masts and towers. These paints have many advantages over other types including ease of application and rapid drying characteristics. Early trials with acrylics in wet tropical regions were disappointing but with the introduction of acrylic emulsion galvanized iron primers, a more durable acrylic paint system is expected to give good results in the long term. In hot dry inland areas acrylic paint films are vastly superior to alkyd paint. They have excellent resistance to ultra-violet light degradation and the paint on some test structures was still in good condition after eight years exposure.

Experience has shown that surface coatings which are of the highest quality should always be used. Good supervision, careful working and common sense can contribute a great deal to reduction of paint failures and the wasteful work which is necessary to repair or strip down a structure before a reasonable time has elapsed.

Paint finishes are also widely used for internal equipment components, racks, cabinets, brackets, equipment covers etc and provided they are properly applied and maintained they will give long service. New types of finishes are being continually developed for different environmental situations but very few have a general application.

One recently developed finish of particular interest is a process called electrostatic powder coating. It has the special quality of combining the properties of polymers with the rigidity and strength of metal as well as giving a high quality finish. It is a spraying technique whereby fine polymer particles are coated on to metal surfaces and fused to give protection against abrasion, impact and corrosion.

The power is fed from a reservoir to a special spray gun where it is charged at the gun's nozzle to a high static voltage. The metal part to be coated is connected to earth and the technique uses the principle that positively charged particles are attracted to an earthed object. Coating thickness is controlled by varying the applied gun voltage.

The dry coated object is passed into an oven and heated to a temperature of 200 °C for about 10 minutes causing the powder to fuse into a coherent and tenacious coating. Some care therefore needs to be taken in selecting articles for coating in order to avoid heat distortion.

CONCRETE

Special care is required for concrete work, particularly in remote areas where difficulty may be experienced in obtaining suitable aggregate and water and also where expert supervision and testing facilities may not be readily available. First class concrete work is essential for the safety of masts and towers and also many other works.

In humid tropical areas, cement is particularly prone to deterioration by premature hydration and proper storage is necessary. For construction works a long distance from the supply source, special water-proof storage sheds may have to be provided where large quantities of cement are required for mast and building foundation works. Storage of cement in paper bags is inadequate in most humid tropical regions and where it cannot be used quickly it should be stored in airtight containers, such as large lidded drums fitted with rubber gaskets.

In a large project where thousands of tonnes of concrete may be required, the cost of cartage of sand and gravel to a remote site may be prohibitive and it may be necessary to explore for local supplies. *Figure 41.11* shows a local sand-pit used to supply the needs of one large station complex. The sand was excavated

Figure 41.11 Sand pit for remote station construction

with a front end loader and passed through a screen to remove loose matter such as sticks, bark etc.

The supply of good quality water for concrete work can also be a problem in some areas. In many cases, sea water, sand from the beach and local coarse aggregate were used in the construction of radar stations during the war years and although inspections have shown severe corrosion of reinforcing rods in some installations, there are many, about 40 years old, which are still in good condition. However, modern designs call for strict control over the quality of the water used in thrust blocks and anchor blocks of masts and towers. During the survey of a long haul radiocommunication system it is usual practice to examine the quality of local aggregates and water at the various sites and to include details in the Tender document. *Table 41.3* shows typical figures obtained at 21 sites along one proposed route.

Table 41.3 CHEMICAL ANALYSES OF SOURCES OF CONCRETE MIXING WATER

Water Source site		*pH*	*Total dissolved solids (mg/litre)*	Cl^- *(mg/litre)*	SO_4^- *(mg/litre)*	HCO_3 *(mg/litre)*
A		7.0	3150	1075	540	703
B		8.6	2400	564	379	405
C		7.1	3350	1421	620	285
D		7.6	800	262	74	256
E		7.8	4790	2000	780	442
F		7.0	950	1195	1112	414
G		6.8	3240	1210	490	348
H		7.4	3060	979	550	567
I		7.6	4070	1581	780	736
J		6.1	3059	2008	400	236
K		6.5	5140	11	62	107
L		7.0	1290	2384	1162	316
M		8.3	3200	1220	660	449
N		7.1	1480	355	168	743
O		7.4	1790	1476	345	387
P		7.6	2040	660	342	359
Q		7.6	1320	362	226	456
R		7.8	910	270	87	303
S		7.1	1110	249	1184	365
T		6.9	4000	1171	740	441
U		7.7	2370	1485	224	179
V		8.2	1450	1510	284	283
W		6.9	1600	518	215	375
Limits set in South African text 'Concrete Technology'	Reinforced concrete	4.5–8.5	15 000	6000	3600	720
	Plain concrete	4.5–8.5	30 000	18 000	3600	720

Where a station is being constructed at a location where only coral aggregates are available, grading deficiencies are often encountered but these can be corrected. With improper grading, the concrete will have high porosity and permit moisture to reach and corrode reinforcing material. Coral usually has a salt residue and often under conditions where only coral aggregate is available, good quality fresh water will be in short supply. Porous concrete allows oxygen bearing moisture to penetrate and come in contact with the steel. Corrosion of the reinforcing steel increases its diameter and causes the surface concrete to break away. This, of course, may have a serious effect on the stability of a structure.

There are many types of failure of concrete work but the two most common encountered in radio engineering construction work are:

(a) Failure to meet the specified strength.
This failure has often been traced to the cement itself. It may be hydrated due to poor storage arrangements or it may be stale. A check should be made to see that the cause is not something too obvious to be noticed, such as unusual weather conditions or the concrete test tubes being produced or stored in the wrong manner or some error in the batching arrangements.

(b) Structural failure.
Structural failures from honeycombing, sandy patches, crumbly concrete, cracking etc. usually arise from one or other of two causes, failure to ram or vibrate the concrete in position properly or incorrect grading or mixing.

To ensure sound concrete, experience has shown that the following rules should be observed:

(i) Use only clean, well graded aggregate, salt free water, fresh and properly stored cement.
(ii) Keep the water-cement ratio as low as possible.
(iii) Compact the mix thoroughly.
(iv) Cure the concrete well by keeping it damp.
(v) Provide adequate cover of concrete for the reinforcement.

OUTDOOR TRANSMITTING EQUIPMENT

The outdoor mounting of some equipment associated with transmitters is not new. Water cooling plant and power supply equipment have been mounted in a fully exposed environment for many years at some broadcast stations. The satisfactory record in temperate and hot climates has encouraged its use particularly in high power installatins. There is a considerable economic advantage in that building costs are reduced. However, there are conditions affecting its application which differ from indoor installation of the equipment and warrant special consideration.

Temperature limitations for enclosed equipment such as control equipment, switchgear, crowbar circuits and other equipment which may form part of a transmitter vault or high voltage power unit installation, should be established at a value which will ensure satisfactory life of insulation and other temperature sensitive components. Operation of the equipment at higher temperatures than the design value may result in shortened life, but if the temperature of some types of insulation, for example the oil in transformers, goes above the design figure for a few hours on isolated summer days during a year, the effect on total life may be generally very small. In good design, the hazard of immediate breakdown of insulation will not be reached unless extreme temperatures are involved.

The techniques adopted in assembly of the outdoor installation components of a transmitter vary from one manufacturer to another. Some have the units, including busbars, completely exposed as in *Figure 41.12* while others provide a

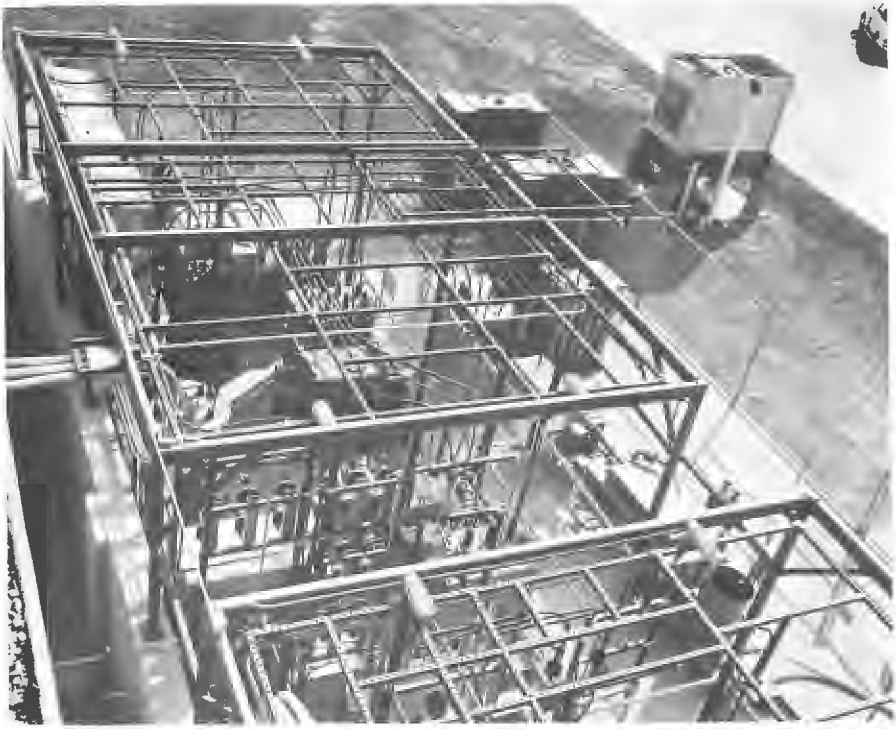

Figure 41.12 Rockwell-Collins 250 kW heavy equipment installation arrangement (Courtesy Rockwell International)

weatherproof metal clad unit with all busbar, cabling and auxiliary equipment enclosed, but with transformers exposed and fitted with a throat, through which connections are made into the unit. The result of enclosing equipment is a tendency toward somewhat increased internal temperatures compared with indoor installations with equivalent exposed busbars and components. With restricted ventilation of the enclosed system, the effect of solar radiation on the top of the enclosure will cause the air immediately under the roof to be very hot. Components located close to the top of the unit will be exposed to an environment much more severe than those located near the floor.

The sources of heat which bring about temperature rise in externally mounted equipment are from electrical losses within the equipment itself and from solar radiation. The maximum temperature which will be taken up by a unit exposed to the sun depends on several factors:

(a) The radiant energy from the sun.
(b) The characteristics of the surface of the unit.
(c) The conductivity and heat capacity of the unit.
(d) The rate at which heat is lost by the body.

The radiant energy from the sun, as it would be measured at the earth's mean solar distance but outside the atmosphere, is called the solar constant and has a value of about 1350 W/m^2. In practice, it varies from zero at sunset to about

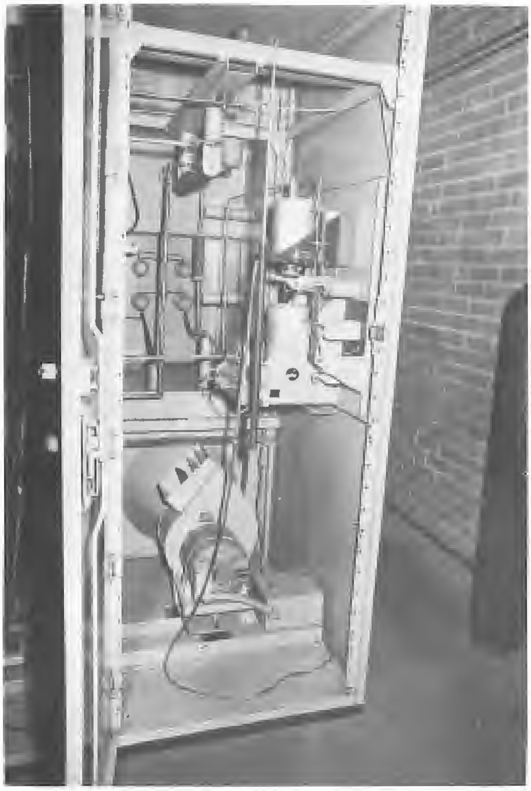

Figure 41.13 Enclosed vault equipment cubicle with transformer entry at rear and forced air cooling

1000 W/m^2 at noon for a typical inland site. Wind of course has an important influence on the heating effect and it has been estimated that a wind of about 16-20 km/h would offset a great part of the heating effect of the sun. However most external units are generally located close to walls of the transmitter building or near enclosures and in many cases the effect of wind could have negligible cooling effect. This would apply particularly when the equipment is located on the leeward side of the prevailing winds and it is therefore practice in a well engineered design to neglect any cooling of the equipment by wind. Measurements at one station on modulation and e.h.t. oil filled transformers, indicated a rise of 8 °C on a sunny day compared with night time. The effect of the colour of the transformers was found to be quite small. A black painted case was 2 or 3 degrees better than one with a matt white finish. An aluminium case was 1.5 degrees hotter than the white tank. Some installations with metal clad cubicles for vault equipment provide forced ventilation to remove heat build-up from solar radiation and equipment losses. The ventilation also assists in minimising condensation problems in tropical installation. *Figure 41.13* shows one unit with rear transformer entry.

An environmental problem encountered at one station with a fully exposed high voltage plant installation in a tropical location was caused by heavy rains, birds and insects. The horn gaps provided across the modulation transformer and the reactor, frequently arced-over during rain, mainly because of shedding of water from busbars which connected to the terminals of these units. Insects and frogs also caused arc-over at these points and it became necessary to enclose the horn gaps with a Perspex shroud to prevent these troubles. Also, because of the relatively close spacing of interconnecting busbars, birds attempting to perch on the unprotected conductors caused several short circuits. This trouble was cured by slipping split plastic tubing over the horizontal busbars. These particular environment troubles are of course not experienced with the cubicle type of external installation, as all protective gaps and busbars are fully enclosed.

A lot of stainless steel has been used in some exposed installations in order to reduce corrosion problem but it has not proved as satisfactory as the designer had hoped. For stainless steel to be effective, oxygen must have free access to the surface. If oxygen starvation occurs and at the same time the steel is subjected to an applied force, a condition known as stress corrosion can occur. A lot of problems have been experienced with stainless steel bands and components, particularly bolts or power cable supports and runways, on coaxial cable brackets, standoff insulation holding down bolts and metal housing for switches.

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Chapter 42

Corrosion

RATE OF CORROSION

Many metals and alloys used in radio engineering suffer oxidation when exposed to the atmosphere. In the majority of cases such oxidation is not damaging and is itself protective. An unprotected steel tower will rust because of oxygen and moisture in the atmosphere. This rusting process is damaging to the structure and must be prevented. Copper transmission line and antenna conductors, on the other hand, acquire a coating of basic copper carbonate (verdigris) in ordinary atmospheres and is not damaging to the mechanical properties of the line. However, where the line carries high voltage, corona will occur at a lower voltage with such coating, than for a new polished conductor.

Marine and industrial atmospheres are more corrosive than ordinary atmospheres because of the presence in them of more active chemical constituents. These promote corrosion in two ways: firstly, by direct chemical combination with the materials with which they come in contact, and, secondly, by speeding up electro-chemical corrosion.

The major factors which influence the rate at which atmospheric corrosion takes place may be summarised as:

(a) The amount of moisture in the atmosphere.
(b) The presence of dust, carbon and other air borne particles.
(c) The presence of acid gases such as sulphur dioxide.
(d) The presence of air borne salts such as sodium chloride.

DISSIMILAR METALS

Bi-metallic corrosion is a process essentially similar to the rusting of unprotected iron. When two different metals are in contact, and bridged by a suitable electrolyte, current flows through the electrolyte. In the electric cell so formed, the two metals constitute the positive and negative poles. The cathodic metal tends to be protected but the anodic metal may suffer greater corrosion than when it is connected to a metal similar to itself. The degree of corrosion depends on the voltage difference which exists between the dissimilar metals.

Table 42.1 shows some commonly used metals and alloys listed in order of the voltages they develop while freely corroding. The lower the metal or alloy is listed the less likely is the metal to corrode. The table is most useful in predicting the metal which will corrode in any bi-metallic couple and the likely degree of the corrosion. The metal or alloy closer to the upper end of the scale will corrode while the other will not, and the further apart on the scale the metals are the greater will be the corrosion.

Table 42.1 ELECTROCHEMICAL SERIES OF METALS AND ALLOYS

Anodic end (Corroded end)	−1.05	Zinc plating on steel
		Cadmium plating on steel
		Aluminium
		Iron and steel
		Lead
		Lead–silver solders
		Tin–lead solder
		Chromium plating on steel
		Tin plating on steel
		Brasses
		Copper and its alloys
		Silver solder
	0.00	Silver
		Gold
Cathodic end	+0.15	Platinum

No dissimilar metals should be in contact in an external environment unless their voltage difference in the electro-chemical series is less than 0.25 V. Even then the interface should be coated with a suitable inhibitive material before assembly.

CORROSION PROTECTION

Methods of protection against corrosion include the following:

(a) Protective coatings.
The main purpose of a protective coating is to separate the metal from substances which would cause corrosion.

Many metals such as zinc, chromium, cadmium and nickel are used for such protective purpose. The electro-chemical behaviour of the metallic coating is generally similar to that of the same metal in the massive state if the coating is of adequate thickness and is not porous. Where discontinuities exist in a coating, a corrosion cell may be formed which can cause attack on the basic metal if the coating is more noble, or undue wastage of the coating metal if that is a less noble metal than the basic metal.

Paint is also used as a protective coating. It is relatively cheap and easy to apply in the field. Bituminous or black epoxy coatings are often used for ironwork in a corrosive environment where aesthetic consideration are unimportant. Paints used for protecting metal should be compatible with the metals they are intended to protect. For example, paints used on aluminium should not contain lead, graphite, copper or mercury fungicides.

(b) Sacrificial protection.
When the corrosion of a base metal is accelerated by contact with a noble metal the corrosion of the latter is usually decelerated and may be prevented altogether. This phenomenon is known as cathodic protection or sacrificial protection. A common instance of sacrificial protection is that which occurs when the coating on galvanised steelwork is broken. The zinc corrodes in preference to the steel, but in the process cause a greater area of the steel to be exposed. As the sacrificial protection is restricted to the area

immediately adjacent to the zinc coating, the steel will rust. It should be mentioned that zinc has a comparatively poor resistance to acids and irons such as chloride and sulphates which do not produce impervious films but tend to penetrate deep down. Because of the absence of these substances, the galvanising on a tower will last much longer in the rural environment than in an industrial environment.

(c) Use of compatible metals.
It would be almost impossible in any radio installation project to avoid contact by dissimilar metals. For instance, mild steel because of its strength, stiffness and economy finds wide application in fixing devices such as nuts, bolts, screws, nails etc. whereas aluminium and copper would be unsuitable in many cases. Because it is frequently necessary to use the electrical properties of aluminium in conjunction with the mechanical properties of steel and as these two metals are somewhat removed in the electro-chemical series, some form of protection is necessary. A common practice is to plate the steel with cadmium or zinc. These metals are adjacent to aluminium in the series and do not themselves suffer serious corrosion in a mild atmospheric environment.

On antenna and transmission lines where aluminium and copper are frequently encountered, care should be taken in the termination arrangement. The connection should be such that water droplets do not fall from copper to the aluminium, as copper ions may be deposited on the aluminium surface causing severe pitting and perforation.

Another aspect which has to be watched is the termination of copper bonding wires provided on galvanised mast radiators used for broadcast purposes. Copper is a much more noble metal than the zinc coating on the structure and the flow of water down the copper bonding wires on to the zinc often leads to corrosion of the zinc.

Many coaxial lines are constructed of aluminium outer conductor and copper inner conductor but corrosion is seldom experienced because the materials are electrically isolated by the insulator spacers which may be teflon, polystyrene, porcelain and the like. Where the feeder is attached to a galvanised structure such as would be used to support a television antenna, the direct attachment of the outer aluminium conductor to the steelwork will be satisfactory, as long as the zinc coating remains effective. However, where the installation is located in an environment where the life of the zinc is short, attack by the underlying steel may cause deterioration of the aluminium conductor. The sealing of such joints under these situations is a wise precaution.

Because corrosion between dissimilar metals requires electrical contact, a conducting electrolyte and a potential difference between the metals, it is obvious that the attack can be controlled by the elimination of at least one of these factors. This can be most effectively done by:

(a) Good design.
The avoidance of contact by metals of wide potential difference, adequate ventilation and drainage, the avoidance of pockets and crevices, and the use of protective measures.

(b) Metallic coatings.
Dissimilarity may be avoided by coating one of the metals with the other

metal or one compatible with it. The coating may be applied by metal spraying, hot dipping or electro-plating but must be non-porous.

(c) Insulation.
An insulating material will prevent current flow and so prevent corrosion.

(d) Cathodic protection.
Cathodic protection is particularly applicable to immersed corrosion but can sometimes be applied to atmospheric corrosion, for instance zinc washers may be useful when steel bolts are used on an aluminium structure.

(e) Painting.
Painting of metalwork is suitable, provided that the environment is only mild. The painting should include a primer pigmented with an inhibitor and a waterproof high quality finishing coat.

Metal equipment shelters have been finding wide application in recent years for housing broadcasting, television and radiocommunications equipment. They have however resulted in considerable maintenance requirements as a result of corrosion of metal members. Whilst many shelters showed only moderate corrosion after four years exposure, at some sites accelerated corrosion within two years occurred between untreated mating galvanised surfaces and at unsuitably treated welds because of attack by condensate, saline dust and zinc corrosion product. Other contributing causes were inappropriate paint finishes on ventilation louvres, unsatisfactory after treatment of welds and unsatisfactory drainage and ventilation of cavities.

The causes of corrosion of shelters may be summarised as:

(a) No barrier protection between galvanised to galvanised or galvanised to aluminium mating surfaces during fabrication, unit assembly or field erection.
(b) Unsatisfactory drainage and venting of cavities in roof and wall insulated panels.
(c) Ingress of moisture and dust.
(d) Unsatisfactory painting system on the original galvanised louvres, the R.S.J. base frame for the inner shelter, and the diesel generator sets enclosure and stand.
(e) Unsatisfactory post-treatment of welds on galvanised steel members.
(f) Absence of a protective coating to inside of roof gutters and unsatisfactory fall thereto.
(g) The random aluminium foil surface contacting the inside of the outer galvanised cladding of the wall units rather than being 'bonded' to the polyurethane insulation.

Although there have been minor corrosion attacks on exposed members, the unventilated galvanised interfaces where driven rain or condensed moisture lies have been found to be the worst areas for corrosion. At some sites where fine dust has a high content of chloride ions, and is strongly alkaline and contains chlorides, carbonates and sulphates, these combine with the hygroscopic zinc carbonate/zinc oxide corrosion product to form a strong electrolyte so increasing the corrosion rate.

In construction which uses a shade house and an inner shelter, the inner shelter is usually relatively free from corrosion, no doubt because it is protected from most rain and dew and thus with the internal heating from the equipment, experiences far less temperature differential and hence condensation and corrosion than the exposed shade shelter.

Paint failure on louvres develops from the cut edge of the louvres. Here there is no zinc on the face of the cut edge and the paint film tends to be of minimal thickness because the sharp corners effect the surface tension of the paint. Because of the non-uniform permeability of the film at those places and differential aeration, zinc corrosion products form there, leading to under film creep and spreading attack. To prevent this the cut edges need added protection by either hot dipping the whole louvre frame after fabrication or grit blasting then metal spraying followed by a suitable etching and a compatible paint system.

There is a big difference in the corrosivity of sites varying from temperate to tropical, coastal to inland and industrial to rural. Economies can be achieved by constructing shelters to two or more standards rather than making them all to the most corrosion resistant standard. The construction form, and fittings of the shelters are common but the sheet material, finishes and assembly technique differ. As well as galvanised steel other materials are frequently used for the whole or parts of the shelters. These include corrosion resistant aluminium, glass reinforced plastics, asbestos cement, and various patented surfaces and coatings. Direct zinc to zinc contact assemblies or fabrication should be avoided. Precoated material should be employed or interfaces should be coated with an inhibitive compound or heavy paint before assembly or fabrication.

In the assembly of shelters, aluminium foil insulation should be kept clear of direct contact with galvanised steel panels because condensate in the interface will cause corrosion. In cases where corrosion had occurred the aluminium foil was not bonded to the polyurethane insulation but bulged out and contacted the outer lining of the insulated wall panels.

Cavities, pockets and sills should all vent and drain fully but prevent field mice, snakes etc. from entering the insulated cavities.

All welds of pregalvanised members should be chipped, ground clean, wire brushed, degreased then coated with three coats of inorganic zinc rich paint or hot coated with eutectic zinc-tin-lead stick or powder.

Zinc coated screws or other types of fasteners are unsatisfactory in joining aluminium sheeting or members as there is a danger of bimetallic corrosion between steel and aluminium once the zinc coating has worn. In many cases the problem has been overcome by using tin cadmium coatings which have a longer life and have minimal electrolytic corrosion action with aluminium.

AERATION CORROSION

A particular problem, sometimes referred to as differential corrosion, has been observed on stranded aluminium conductors used in long wire rhombic and flat top antenna systems. It appears to occur also in other situations when moisture is trapped between two closely separated metallic surfaces. The corrosion results from the difference in oxygen concentration in the electrolyte between the inner surfaces of the adjacent wires and the external faces in contact with the fully circulating air. Some pitting occurs and this can lead to corona troubles with high voltage conductors but the noticeable effect is the relatively large buildup of oxidation between the strands of the cable.

Differential aeration corrosion can also be observed at a paint surface which has been damaged. The exposed metal becomes cathodic while the part underneath the paint becomes the anodic section and liable to corrosion. This accounts for the phenomenon of rust creeping underneath damaged paintwork of ungalvanised ironwork.

Probably the most widely known effect of differential aeration is associated with corrosive damage to copper earth mats of medium frequency broadcast radiators. Since many of these radiators are erected on soils which tend to be clayey as well as saline, in order to take advantage of a high conductivity situation, the poorly aerated conditions of the soil result in differential aeration being responsible for a major part of the corrosion of earth mat radial wires.

The chemical composition of the soil on a site does not indicate definitely whether the particular soil will be corrosive towards copper wires of the earth mat of the same type and after two years severe corrosion had occurred over a corrosive towards copper. Also, soils having a high concentration of sulphides or chlorides tend to be corrosive. In all these cases the corrosion is associated with poorly aerated soil conditions.

At one broadcast station using an earth mat of 120 copper radials 3 mm diameter and 160 m in length buried about 20 cm, the earth mat became ineffective after eight years service due to corrosion. It was replaced by another mat of the same type and after two years, severe corrosion had occurred over a large area. Samples of the soil and wire were sent to a laboratory for analysis and results of a chemical examination revealed that there was a wide variation in the specific resistance of the soil.

The variation was due mainly to the differing concentrations of sodium chloride which was by far the major soluble inorganic component in several of the soil samples. The potentials assumed by pure copper wire when immersed for several days in the laboratory in a slurry made from the soil samples indicated a difference of more than 80 mV between copper/soil potentials for two of the soil samples. Construction of a corrosion cell using these two soil samples confirmed that the current produced was sufficient to destroy the wire within seven years, if continuously maintained.

The general corrosion of the copper appeared to be mainly due to salinity gradients in a partially aerated soil, producing concentration cells and metal oxidation along the copper earth wires.

In attempts to overcome corrosion of copper wire earth mats, engineers have used polyethylene jacketed copper wire and aluminium wire. Aluminium wire has only been used at a few installations and its behaviour over a long term period in different soil environments is not yet known.

TRANSMITTER WATER COOLING SYSTEMS

The choice of a coolant for high power transmitting tubes depends on many factors but on the basis of economics and heat transfer efficiency, water remains the most acceptable of all coolants currently available. The cooling process presents several difficulties, the most important of which are the electro-deposition of metals on plates and insulating hoses, the formation of scale on plates, power leakage due to low resistivity of contaminated coolant and the high voltage applied to the plate of the tube. A typical water cooled installation showing heat exchangers and storage tanks is shown in *Figure 42.1.*

Aeration is a problem which has occurred with many installations. It occurs

Figure 42.1 Heat exchangers and storage tanks of large water cooling system

when water is exposed to the atmosphere or if spraying takes place in the system. It also results from the electrolytic decomposition of the coolant by the leakage current flowing in insulating sections such as hoses, coils or tubes. Liberated oxygen from the heated coolant has a strong corrosive action, particularly on ferrous parts of the system.

Although the majority of recent installations utilise copper tanks, copper piping and other non-ferrous parts, many early systems used iron or concrete tanks and ferrous piping and pumps. The presence of iron in the coolant of a ferrous system had one major advantage in that it assisted in de-aerating the coolant. However, the rust in time caused a decrease in the resistivity of the coolant and was also extremely difficult to remove when it became deposited on hoses and fittings.

WATER QUALITY

Generally, distilled, demineralised or de-ionised water is used in order to minimise sludge and scale formation of the plate surface and also to reduce the possibility of electrical breakdown of the water. Distilled water usually refers to water supplied through the normal domestic distribution system and which has been distilled from glass apparatus. De-ionised water refers to domestic water which has been purified by passage through ion exchange columns both cationic and anionic, so that all heavy metal ions such as iron, lead, copper and all mineral acid anions, such as sulphate and chloride, have been removed. Experience has shown that a pH value of 7.0 is acceptable and dissolved solids should be less than 10 ppm.

If the normal domestic water supply were used as a cooling medium, calcium compounds and other solids of low thermal conductivity may be deposited on the plates and so result in excessive plate temperature rise. Regardless of the quality of water used, the system should be kept free from the accumulation of foreign material. Oil or other contaminants in the water from faulty pump seals etc will reduce the heat transfer considerably and may also produce carbonaceous scale deposits on the plate of the tube. Oil contaminant should be kept below 1 mg/litre.

The conductivity of water used in a typical system will be found to be of the order of 20 to 60 micromho per cubic centimetre and should be replaced before it reaches 100 micromho although some tube manufacturers recommend that replacement of the water take place before it reaches 70 micromho for klystrons and power grid tubes. The water as taken from the station distillation equipment should be better than 10 micromho.

REMOVAL OF SCALE

The accumulation of scale on water cooled tubes should be avoided. Scale hinders proper transfer of heat from the plate to water as it is a poor conductor of heat, although some engineers are of the opinion that for vapour cooled tubes it slightly enhances the transfer of heat from the plate. The scale is a matt block formation of copper oxide which is formed when dissolved oxygen in the water contacts the hot plate. Overheating and distortion of the plate may result if build up of scale is excessive. Water whistles are often heard with high velocity water cooled systems and this is generally a sign of an overheated plate. Therefore, the whistle should be used as a guide to improving maintenance operations of the system.

The main cleanser used for the removal of scale from the plate jacket is a

Figure 42.2 Sediment in copper piping of water cooling system

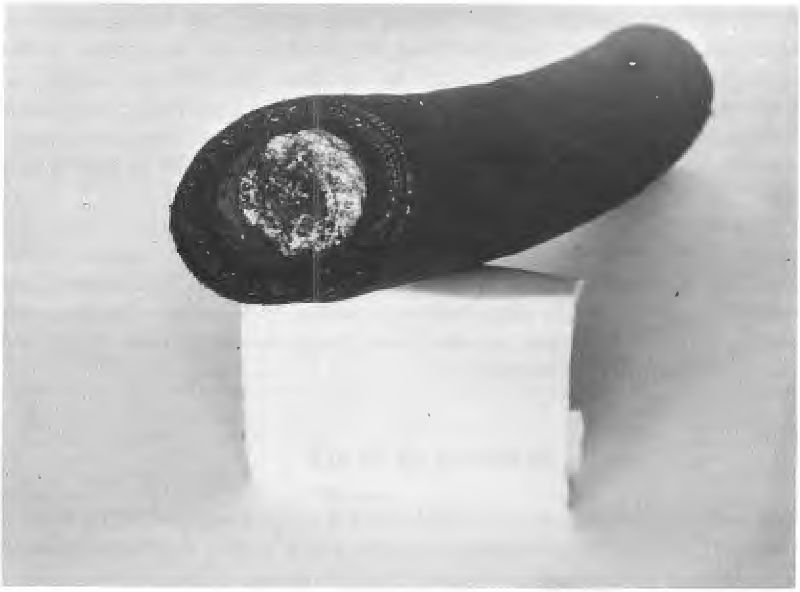

Figure 42.3 Sediment in insulating flexible hose

10% solution of hydrochloric acid. When cleaning the tube, the solution should be kept clear of the metal-glass seal and the plate should be thoroughly cleaned with distilled water after treatment.

To clean the complete system with tubes *in situ* is a difficult problem. The procedure which was adopted at one large transmitting station for many years involved the use of tri-sodium phosphate. After the water in the system had reached a temperature of 70 °C, two tubes, generally the power amplifiers, were removed and a kilogram of the chemical was poured into the sockets and dissolved with boiling water. The tubes were replaced in their sockets and the chemical solution then circulated throughout the entire system for at least an hour with filaments on to keep the water temperature at about the 60 °C point. This procedure resulted in the removal of an amazing amount of sludge and residence from rubber hoses and other parts of the system. The complete system including tank was finally thoroughly flushed with distilled water and then refilled with new water.

Examples of water and vapour phase cooling installations that had been inadequately maintained are shown in *Figures 42.2, 42.3* and *42.4*. The copper pipe of *Figure 42.2* was almost completely filled with sediment and it is surprising that the tube received sufficient water flow to remove the heat. In *Figure 42.3* the effective diameter of the insulating tube had been reduced to less than 6 mm. An examination of the log of this particular station showed that the water flow meter had indicated a falling volume over a period of 6 months, the alarm had operated but still no action had been taken. To stop the transmitter from shutting down, the operator had bridged out the water flow control circuit. *Figure 42.4* shows the scale build-up on the plate of a vapour phase cooled tube rated at 100 kW of plate dissipation.

The purity of the water is important for all types of systems but it is a

Figure 42.4 Scale on plate of vapour phase cooled power tube

particular requirement in the case of vapour phase cooling where higher temperatures are experienced. In a typical 250 kW transmitter using four vapour phase cooled tubes, the total maximum dissipation is approximately 300 kW. The system uses distilled and/or de-ionised water having a minimum resistivity of 200 000 ohm/cm^3.

Research and study have resulted in selection of materials for the system that minimise the degradation rate of the resistivity. The water and steam flow lines connected to the boiler are of pyrex, polypropylene, and Kel-F material. The water lines are equipped with expendable targets that protect the boiler from electrolytic deterioration. *Figure 42.5* shows a new target and one which had been in service for about 500 h. Mechanical pumps in the system employ a ceramic-to-carbon seal to ensure high reliability.

Care should be exercised to ensure that no contamination enters the water system. The coolant will be soon contaminated if any lead bearing alloys such as brass or soft solder are used in the fabrication and assembly of the system because the steam will leach out the lead. Contaminated coolant will result in a fall in resistivity and leakage current power will cause water to boil in the lines, interfering with proper operation of the system.

Some corrosion of collectors of television amplifier klystrons has occurred and this has indicated that the level of chloride ion concentration in the water in

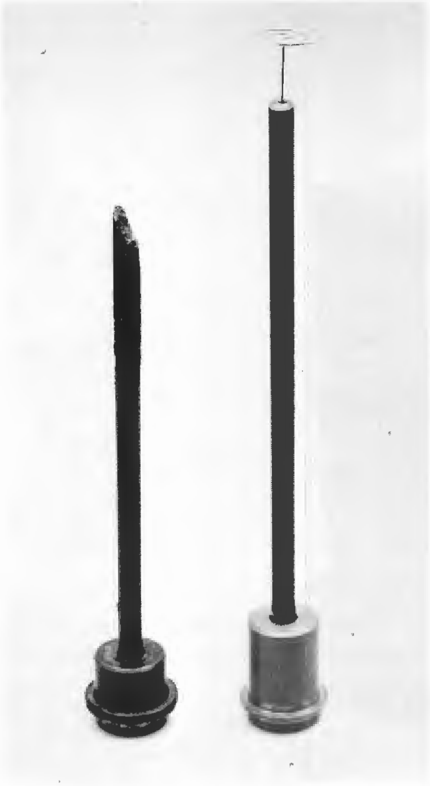

Figure 42.5 New and used targets of vapour phase cooling system

the boiler is of considerable importance. The magnitude of the galvanic current flowing between the klystron collector and the copper baffle determines the rate at which corrosion takes place and this can be related to the extent of chloride contamination in the water. Workers who researched the problem have recommended that the chloride content of the water in the boilers should be maintained below 30 ppm[1].

CORROSION OF METALS

Because most metals have higher free energies than most of their common compounds, metals exhibit a tendency to achieve greater chemical stability by reacting to form oxides and other compounds. This natural tendency is observed as corrosion of the metal, and water provides an excellent medium for such reaction to take place. In time and given a sufficient supply of water practically all metals will dissolve. An important factor, therefore, to be borne in mind when selecting metal components for an application such as in a tube cooling system is the solubility of the metals concerned.

In a study of corrosion due to the solubility of various metals in water under static sealed conditions, Clark[2] has made the following observations:

"Mild steel suffered greater corrosion in aerated than in de-oxygenated solutions. In 'pure' water corrosion of this metal was at least six times less than in tap water. In the stagnant solutions tested even ethylene glycol solution corroded steel less than did tap water.

Brass corroded more in 'pure' water than in tap water (in which corrosion products are adherent and form a barrier against further attack) dissolving to a greater extent in de-ionised water than in distilled water.

In both 'pure' water cases corrosion apparently took the form of dezincification.

Copper samples gained weight in most solutions, corrosion being only slightly greater in 'pure' water than in tap water.

The solubility of lead in aerated distilled water gave by far the greatest weight loss of all the metals studied. Oxygen adsorption in the distilled water system gave rise to an uneven electrode potential distribution over the surface of the lead which became cathodic at its upper end and anodic at its lower end. As a result lead was corroded from the lower end and re-deposited at the upper end in the form of loosely adherent crystals of the metal. Ethylene glycol lowered the solubility of lead in tap water.

In terms of changes in weight, aluminium appeared comparatively un-corroded in all systems, and, in most cases corrosion products took the form of adherent oxide films. On one or two samples, particularly in aerated tap water and ethylene/glycol solution, corrosion took the more serious form and localised attack which, after the 'oxide' had been removed, left fairly deep pits.

Zinc corrosion differed from that of most other metals in that it was invariably worse in the absence of oxygen than in the aerated solutions (in which a protective film of insoluble zinc hydroxide is rapidly formed). However, except in tap water, corrosion of zinc was not very marked.

Chromium and nickel were almost totally inert in all the solutions studied.

Stainless steel was remarkable in exhibiting almost exactly the same degree of corrosion in each solution, irrespective of its composition. Some of the corrosion was at what were probably non-austenitic phases formed at the edges of the samples where they were overheated during handsawing.

Cadmium, like aluminium, had a high percentage of adherent oxide-type corrosion products. On the whole, corrosion of this metal was less in 'pure' water than in tap water.

Tin, unlike lead, was no more soluble in distilled water than in tap water. This accounts for our previous findings, in this laboratory, of lead only in samples of distilled water from transmitting cooling systems of soldered construction.

We see then that, where conclusive results obtain, only two metals, tin and lead, corroded less in de-ionised water than in distilled water; i.e., de-ionised water is, in general, the more corrosive. In most cases de-oxygenation reduces corrosion by water, especially with ethylene glycol solutions (an average 60% reduction in corrosion) and distilled water (40% reduction)."

One interesting type of corrosion associated with brass components used in many cooling systems is known as dezincification which has been referred to previously. Many brass alloys particularly those containing in excess of about 15% of zinc fail prematurely due to dezincification. This phenomenon of de-alloying has been known for many years but the mechanism of failure has not been adequately explained. One explanation is that the zinc dissolves preferentially in the environment leaving behind a porous copper deposit. Another is that the complete alloy is dissolved and that the copper is reprecipitated close to its point of dissolution. However, regardless of the mechanism, the end result is the same, i.e. a component which was previously a strong brass alloy is reduced to a weak porous copper one, with very poor mechanical properties.

Of two station engineers who had had long experience with this problem, one considered that fittings made from cast brass invariably gave longer life than those made from machined rod. The other considered that greater life was obtained by using brass with a lower zinc content that had been inhibited by an arsenic addition.

THE USE OF TARGETS

Corrosion in cooling systems can be restricted by turning some of the mechanism of corrosion to protective ends. A good everyday example is galvanised iron where the zinc coating serves as a sacrificial anode which itself corrodes instead of the underlying steel. The same technique is used to protect vital metal parts of tube cooling systems, by providing a suitable sacrificial anode or target. An advantage of such an arrangement is that the spent target can be replaced quite easily. The target can be replaced at a fraction of the cost of replacing some other parts of the system. In some installations it is usual practice to inspect the target after 1500 h of transmitter operation and to replace it when it has been reduced to a stipulated minimum size. Care should be taken to ensure that the target is always securely held in its fittings, as several cases have been recorded with high velocity water systems where the target has broken away and found its way into the circulating system, with serious consequences.

The successful use of targets in a cooling system is dependent on:

(a) Sufficient space in the system to accommodate the target without interference to the coolant flow.
(b) Adequate target life to allow co-ordination of replacement with the normal quarterly, half yearly or yearly maintenance programmes.
(c) Appropriate positioning and shape of the target to avoid producing local turbulence and thereby accelerating cavitation corrosion.

CARE OF WATER COOLING SYSTEMS

A log should be kept of the leakage current as read on the leakage current meter and the water changed when this leakage current reaches a predetermined figure. In addition, a routine weekly check should be made on the condition of the water in the tanks with regard to foreign matter content and sediment. Even though not indicated by leakage current or foreign matter content, it is practice at many stations to change the water every six months. The level of the water in the tank should be checked daily and kept well above, at least 15 cm, the top of the return pipe.

The transmitter operating log should show the range of temperature of the cooling water and this should be used as a guide in determining the condition of the coolers. With water-to-water coolers, a deposit will accumulate from the raw water in the tubes of the cooler and periodically the heads of the cooler will have to be removed and the deposit removed. The frequency at which cleaning

Figure 42.6 Roof mounted type steam condenser

Figure 42.7 Ground mounted type steam condenser

will be necessary will have to be determined at each station, as it will depend upon the purity of the raw water. Once each year the cooler should be opened, inspected and cleaned.

Each time the water in the cooling system is changed, the entire system should be cleaned thoroughly, including hand cleaning of the tank, flushed out and drained before adding clean water.

Cooling equipment associated with vapour cooling systems requires far less maintenance than high velocity water systems. With gravity feed type systems with the condenser mounted on the roof as in *Figure 42.6* no pumps are required. In the case of floor mounted units such as in *Figure 42.7* small pumps will meet the need for returning water to the boiler.

Fin corrosion has been a problem at many stations particularly with steam

Figure 42.8 Tests with copper-aluminium contact

condenser units. The trouble has been evident with both aluminium and copper fin units. At one station near the sea the problem was pin pointed to salt laden air and regular hosing with fresh water reduced the rate of corrosion. At another station aggressive elements in the soil accelerated corrosion when dust was drawn up through the fins by the fan. Insects have also been a nuisance at some stations and a spacing greater than 2.5 mm between fins is necessary to prevent clogging. For a typical 250 kW transmitter installation in the tropics the steam condenser unit must be capable of condensing 440 kg/h of saturated steam at 100 °C with ambient air at 50 °C. Although many units have been constructed with electro-tinned copper tubing and copper fins and fitted with brass and plates, there are units in service with electrotinned copper tubing and plate type aluminium fins. However, corrosion at the copper-aluminium junction has resulted in considerable maintenance effort particularly in a high humidity environment. *Figure 42.8* shows the results of one test carried out during the investigation into copper/aluminium corrosion. Severe corrosion occurs unless the junction is adequately sealed from moisture.

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Chapter 43

Failure of Structures

FACTORS INVOLVED IN FAILURES

If structural failure is defined as total collapse, then the number of failures of radio masts and towers is relatively few, particularly when account is taken of the great number in use and the rapid increase in their number. If, however, failure includes those cases where the structure has not conformed with the design, then the number of failures is very large. Unwanted twists, excessive head displacement, humming noises and failure of concrete samples to meet specifications are a few, but it can be questioned whether they are failures, or normal but unexpected variations.

In many cases of failure there is a simple explanation, but in others it may be a combination of many factors, such as incompetency, poor supervision, carelessness, insufficient knowledge of new materials, misunderstandings, environmental factors and others. These factors have been classified by McKaig[1] as follows:

(a) Ignorance.
  (i) Incompetent men in charge of design, construction or inspection.
  (ii) Supervision and maintenance by men without the necessary intelligence.
  (iii) Assumption of vital responsibility by men without the necessary intelligence.
  (iv) Competition without supervision.
  (v) Lack of precedent.
  (vi) Lack of preliminary information.
(b) Economy.
  (i) In first cost.
  (ii) In maintenance.
(c) Lapses or carelessness.
  (i) An engineer otherwise careful and competent shows negligence in some certain part of the work.
  (ii) A contractor takes a chance, knowing he is taking it.
  (iii) Lack of proper co-ordination in production plans.
(d) Unusual occurrences.
  (i) Cyclones, aircraft collision, earthquakes and the like.

Other factors which have been recognised include:

(a) Pressures and tight schedules of a high volume straining the limited supply of technical personnel and lowering standards of shop and field inspection.
(b) Use of new materials and combinations of materials before adequate engineering knowledge has been accumulated.

(c) Premature loading of the structure before all work has been properly finished.
(d) Use of defective materials.
(e) Design oversight.

It is generally accepted that it is impossible to eliminate all engineering failures completely but engineers must seek to keep them to an acceptable level and that level is determined by the incremental cost of reduction and the incremental benefit of failures averted. There is some level of cost at which further expenditure on improvement of safety of a structure is not warranted. For example, a structure erected in a rural situation for use as a medium frequency broadcast radiator would not justify the same level of expenditure on improvement of safety as a communications tower erected in a residential area or on top of a city building.

With the 553 m Canadian National observation and communication tower in Toronto, the world's tallest free standing structure which supports a 102 m tower for television, f.m. broadcasting and other transmissions, considerable expenditure was involved in ensuring that corrosion would not unnecessarily reduce the life and impair the safety of the structure. The radio tower became virtually inaccessible after removal of erection facilities and a long range approach to corrosion protection was adopted during the design and specification. It combined workshop treatment of steel and field application of high performance vinyl coatings after erection on site. After painting, a reinforced plastic cover was installed to prevent ice accumulation.

PROBABILITY OF FAILURE

During the design of the structure the engineer must ensure the achievement of an acceptable probability that the structure will not become unserviceable for the use for which it is required during the period of its specified life. The choice of the probability of failure will depend considerably on the cost and importance of the structure as well as the consequences and cost of failure. In the case of a structure designed for a heavily populated city centre and which is to be a terminal for tens of thousands of telephone channels as well as television channels, then a probability of failure of zero is a highly desirable objective to be sought during the design.

The failure of a structure to serve the purpose for which it was designed may arise in many ways. The main ones may be categorised as follows:

(a) Complete collapse.
This occurs when the applied load exceeds the load carrying capacity of the structure or there is failure of the guy system.
(b) Excessive elastic or permanent deflections which may result in interference with the proper use of the structure or which may influence aesthetic considerations.
(c) Development of local defects.
This may occur when there is damage to surface finish or by cracks or local deformations.
(d) Vibrations.
This occurs due to aerodynamic instability and leads to fatigue failures.

When a structure has been rendered unfit for use by any of these four causes, it is said to have reached a limit state. Hence in his design process the engineer must provide acceptable probabilities that these limit states will not be reached, and this should be done to ensure maximum economy with regard to the total construction and maintenance cost of the structure. The economic approach is based on the assumption that the cost of failure or of unservicability of the structure can be considered as a charge equal to the capitalised total cost of failure or of unserviceability multiplied by the probability of its occurrence. As the cost of failure and to alesser extent the cost of unserviceability are necessarily functions of the probability of failure or of unserviceability for which the structure has been designed, the optimal economic probabilities of failure or of unserviceability should make the sum of the initial cost of the structure and the capitalised cost of failure or unserviceability a minimum.

Alfred Freudenthal[2] in discussing the choice of decision rule with regard to probability of failure says,

"The acceptable probability of failure or of unserviceability can be specified arbitrarily, in relation to the expected number of load applications, or on the basis of an economic balance between the cost of increasing the safety and the cost of failure. The choice of the specification of the probability of failure depends on the importance and cost of the structure, as well as on the consequences and cost of failure.

It is evident that the probability of failure of an important structure or of a structure the failure of which would endanger human life should be practically zero, It can, however, never be theoretically zero, unless the design could be based on an absolute upper limit of the load intensity and on a distribution of the significant strength parameter known to be definitely limited at a minimum value; structures design on such a basis would, however, be inefficient and uneconomical. It is, moreover, not quite logical to attempt to design for zero probability of failure or unserviceability as other risks to a structure, such as fire or earthquake, are accepted as inevitable.

Although all measures are taken to reduce their incidence or the damage associated with their occurrence, the risk remains real—however small—and its magnitude finds numerical expression in terms of insurance rates or of that part of the rates that represent the pure risk. Hence, comparison of the risk of failure or unserviceability with other risks of similar consequences may provide a first rough rule for the specification of an acceptable probability of failure or of unserviceability".

FUNDAMENTALS OF SAFE CONSTRUCTION

The fundamentals of safe construction which could be satisfied to a reasonable degree of probability for any mast or tower may be summarised briefly as follows:

(a) The structure should retain throughout its designed service life, the characteristics essential for fulfilling adequately the purpose for which it was constructed, without failure or abnormal maintenance charges.

The integrity of the structure will be assured by the integration of first class engineering with the correct application of sound construction materials, plant, methods and proper professional supervision during the design, fabrication and construction stages, and the subsequent service life. The life of a mast or tower is not an easy matter to determine. From a weathering or corrosion point of view, the life of a structure located on a site close to the sea would in general be about 20 to 35 years depending on the nature of the environment whereas in rural inland location a life of double this period could be expected.

There are, of course, many situations where very short lives have been obtained. One galvanised pipe radiator of a medium frequency broadcast station located within 100 m of the surf required the complete replacement of the guy ropes after four years, and of the radiator after ten years.

However, the main reasons for the end of the life of a structure are very seldom due solely to weathering or corrosion but rather to changes in the use, need for a more efficient structure, blanketing or interference reasons.

Broadcast transmitting and receiving stations in particular are affected considerably by residential build-up and are subjected to a persistent process of retreat, with a resulting comparatively short life for structures.

(b) The structure should retain throughout its life an appearance not disquieting to the user and the general public, and should neither have nor develop during its lifetime service, characteristics leading to concern as to structural safety.

To prevent the structure being misused during its lifetime, it is important that the design loading conditions be properly documented and be readily available to engineers proposing a change of purpose, increase in the loading or structural alteration.

Very frequently the design engineer responsible for the original calculations, studies and work has retired, or transferred to other duties or his calculations are not available due to inadequate documentation.

Many cases are known where decision was made to install additional facilities which added considerably to the static and wind loads without proper studies being undertaken. To partially overcome this problem it is the practice with some organisations to attach a metal plate to every major structure summarising the maximum load conditions, the design guy tensions, maximum peak design voltages in the case of insulated structures and other critical data.

(c) The structure should be so designed that adequate warning of improper loading etc. is given by visible signs and none of these signs should be evident when the structure is working within the design limits. Typical of warning signs of radio structures are abnormal deflections, slack guy ropes, broken or cracked insulators, elongated anchor pin holes and the like.

Regular inspection of structures by competent and experienced people is essential as some warning signs may not be evident to the untrained observer. The early recognition of warning signs will allow a greater chance of remedying defects and hence preventing total collapse of the structure. The assessment of the factor of safety with corrosion is an important example and there are many instances where steel cylindrical type masts have been covered with reinforced concrete to extend their life.

LESSONS TO BE LEARNED

The performance of a structure as erected does not always meet the desired of the designing engineer. Some of the reasons why this is so have been covered previously but no lessons can be learned from failures, to prevent a recurrence in subsequent designs and erection procedures, unless adequate information on what caused the failure is made known. Unfortunately a lesson is not always learned by all those associated with the design, construction and maintenance even though important lessons may be learned by those directly associated with the particular failure. This is brought about by the general reluctance of individual engineers and organisations to publicise failures. In many cases, the only information about the failure is often a sketchy report with bold headlines in the newspapers.

No major structural failure should be allowed to pass without a detailed investigation. The investigation should lead not only to remedies for the kind of structure concerned but should also be of benefit to other related types of structures.

There are a number of general lessons concerning design, construction and operation that can be drawn from structural failures. These may be summarised as follows.

Design

(a) Consideration should be paid to ensure accessibility of the structure and associated plant mounted thereon to enable a full and proper inspection to be carried out at regular intervals during the life of the structure.

Some early 100 m high tubular steel plate structures were barely sufficient in internal diameter to allow internal inspection of the structure. Those of the bore casing type which are too small to enable direct inspection of the condition of the inner walls require close attention. In several cases of these types used for medium frequency broadcasting, failures have occurred without warning. In the case of one known structure an inspection from ground level with binoculars indicated no signs for concern but the structure collapsed in the night during a light breeze. In the case of another which had been in service for about 10 years on a hill site near the sea, a climbing step fell out at the 38 m level when the Inspector placed his foot on it.

Methods which have been used with varying degrees of success to minimise the internal corrosion problem include drilling holes at regular intervals, completely sealing the structure and pressurising the inside with dry air.

(b) Design calculations should be based on reliable materials characteristics and properties, environmental and soil patterns and sufficient data to enable accurate calculation of loading figures.

Many factors have to be taken into account during structural analysis exercises. These include variations in material strengths, properties of various materials including insulating materials, variations in the load and imperfections in theory. Accuracy is important as it is pointless to press the accuracy of other factors when one of these is known to be inaccurate. On site investigations may be necessary in order to obtain some of the data. Foundation design is one area where on-site data would be necessary. Large self supporting towers require massive foundations and accurate information on the bearing capacity of the site is essential. A 600 m high tower may require a thrust block of some 17 000 m^3. In some studies bore holes have been taken to depths of 50 m and supplemented with a detailed analysis of seismic soundings.

A material problem which from time to time has plagued engineers and metallurgists is embrittlement in structural steels. One of the aspects of this problem is strain age embrittlement and is observed as a change of properties of cold worked steel. The extent of strain age embrittlement is influenced by steel quality and fabrication procedure. Strain from workshop fabrication procedures, which includes reaming, punching or bending is a pre-requisite for strain age embrittlement.

One of the most important factors in the design of tall structures used for radio purposes is the force applied by wind to the antenna systems and the members comprising the structure. Wind loading on tall slender structures has always proved to be a controversial subject. The assessment of probable wind conditions has yet to be confirmed by precise observation and no one pressure curve has yet been adopted as a universal standard. Recent research into improved techniques for design of the very tall and slender structures has revealed that wind is not a steady load, so resulting in a flexible structure responding dynamically to this load. It has also been revealed that wind loading is a statistical problem because gusts occur randomly.

In areas where the formation of ice is a problem, a lattice structure may become packed with ice and it is not unusual to treat the structure as having a wind area equal to that of a solid face.

Construction

(a) Only experienced people should be permitted to work on a mast or tower, particularly those above about 70 m in height. They should ideally have previously worked together as a team. The use of locally hired non-professional riggers should be discouraged. If this cannot be avoided they should be confined to non-critical duties such as painting and general support duties.
(b) All work on the structure should be under the constant close scrutiny of an engineer and experienced foreman. All moves should be planned in detail by the engineer and supported by drawings and erection methods. The engineer should be fully briefed about the design principles and about calculations involved in the design of the structure. Procedural decisions should not be left to riggers as experience has shown that their techniques are not always consistent with safety.
(c) Absolutely no procedural short cuts should be permitted.
(d) Full information should be available to field staff and all construction personnel briefed regarding devices and techniques being used on the project.
(e) Where appropriate there should be seasonal cut-off erection activities. In the United States, two 700 m high masts collapsed within eight weeks of

each other as a result of wind conditions which should have been expected at the particular time of the year that the erections were taking place.

(f) Care should be exercised in working under conditions that are unduly pressing either politically, or in time, in order to complete erection before a scheduled or seasonal cut-off date.

(g) The erection of masts and towers suffer more delays from inclement weather than any other radio engineering activity. Structures for television and radiocommunication purposes are frequently erected on mountain tops and winds and cold weather make rigging work difficult and hazardous. In order to complete the job as quickly as possible because of impending worsening weather conditions, staff may resort to undue haste or unsafe practices, perhaps with disastrous consequences.

(h) Materials delivered to the construction site should have been fabricated in a workshop under efficient supervision and strict quality control conditions. A large international broadcast transmitting complex with curtain antennas would use up to 12 000 tonnes of structural steel for masts and 3000 tonnes of steel wire rope for guys and hoists. The fabrication of a steel structure calls for a high degree of accuracy and workmanship. Rigid shop control of fabrication work is essential otherwise erection difficulties will be experienced or a bent or twisted structure will result. The removal of a twist from a pivoted structure is a difficult exercise. The requirements of the riggers must always be kept in mind and they should not be expected to perform workshop type activities while aloft. Some specifications do not permit drilling, reaming, cutting or any other activities which would destroy the galvanised protective coating.

(i) Inspection and control of materials used on site for the construction of foundations should be strictly in accordance with the specifications and design code.

(j) A great deal of trouble has been experienced with some projects in meeting specified concrete tests at remote sites where high quality aggregate and water have not been readily available. Disputes have arisen concerning the interpretation of the results of tests on concrete samples taken during pouring of the foundations and anchor blocks. Factors which have contributed to the variability of results obtained from sample cube tests are, non-uniformity of cement and aggregate used to make cubes, differences in mixing techniques, and variability of curing conditions, and errors introduced by the characteristics of the testing machine. The amount of concrete required varies with the facilities to be provided but can reach a level of 35 000 m^3 for thrust blocks, counterweights and guy anchorages at a large high power international broadcasting complex.

(k) All structure/ground communications should be routed through a slow speed audio tape recorder for documentation.

Many tall masts have permanent telephone facilities installed but during the construction phase temporary wiring is frequently employed. Small walkie-talkie type radio transceivers are also used as these do not have the restrictions of a wired circuit.

(l) A time lapse camera should maintain a documented history of the work in progress for future reference. If this facility is not readily available camera slides or photographs should record important phases of the work.

(m) The technique used in construction will depend on the type of the structure.

In the 533 m Ostankino tower in Moscow the tower was constructed of concrete for the first 385 m and of steel for the remainder. In constructing the concrete trunk the hoisting of the framework, installation of the scaffolding and casting of the concrete, was not done in the open air, but in an enclosure with a roof, walls and floor and even central heating. After the pouring of each stage of the tower, the machine would lean on the hardened side of the tower with its powerful claw and hoist itself further up. The other claw lower down would dig into specially arranged bays and the process would begin again.

The task of making this enormous self-supporting structure absolutely vertical was not an easy one. The calculation even took into account the daily rotation of the earth. Measuring equipment was fixed above and below the machine, and about 1500 m away from the structure an invisible plumb-line was detected at the intersection points of light beams. The deviation from the axis of the structure and the axis planned is 5 to 6 times less than the allowed margin.

Operation

(a) Operation and maintenance aspects should be fully considered during the design stage and, on completion of erection, a planned periodic inspection programme should be implemented.

(b) The use of the structure should be controlled to ensure that additional equipment is not provided which would overload it beyond the design limit.

The provision of one additional horn antenna could result in an increased loading of the structure by about 5 tonnes during a high wind gust.

(c) The specific purpose of the structure should be known before completion of design details.

The effect of the wind on antennas is an important design consideration. For some structures the antennas may contribute up to about 80% of the overturning moment at ground level.

Also, with structures used for television and radiocommunication purposes the sway or rotation will cause a deviation of the transmission beam and for this reason the movement of the structure may have to be restricted to fine limits. For some radiocommunication purposes, the permissible rotation at the point of attachment of the antennas has been limited to one third of one degree.

DESIGN CONSIDERATIONS

The design as well as the fabrication and erection of radio masts and towers represents a specialised branch of structural engineering and, because of the relatively small demand for these structures, only a few organisations have been able to acquire expertise in this field.

The design of radio structures involves consideration of many factors not normally encountered with other types of structures such as buildings. Some important factors are:

(a) Radio masts and towers are as a general rule tall and slender and sensitive to lateral stresses caused by winds, and to ice loading.

(b) The characteristics of winds vary considerably according to local conditions, height above the ground level and with climate. Actual on-site measurements of various kinds may be required for analysis purposes.

(c) In the case of structures required for radio communication and television purposes, antennas of shapes most likely to suffer damage from wind pressure and ice may be mounted at the top of the structure.

(d) The precise stresses imposed on a loaded lattice steel structure by wind forces is very difficult to calculate accurately for every wind speed and direction and can often only be properly assessed by experiments or actual measurements.

(e) There are critical limitations in the permitted movement of the structure at the point where high gain microwave antennas are fitted. A typical restriction figure is a maximum rotation of one third of a degree and this is a major factor in the development of the detailed design of the structure.

(f) The tall cylindrical self-supporting structures now being erected to heights in excess 500 m require analytical studies which call for the use of considerable experimental data. In fact there is much to be learned about the behaviour of the wind and other external factors which influence the design of tall structures, from those already erected. To this end, it is common practice to build-in extensive instrumentation at critical points for the benefit of future designs.

Tall structures in particular call for considerable experience and exceptional ability on the part of engineers and others associated with the structural design and erection.

Structures of 300 m are now commonplace, at least one exceeds 600 m and designs have been prepared for 800 m structures. Considerable skill and experience is required to design an economical structure which can be effectively translated

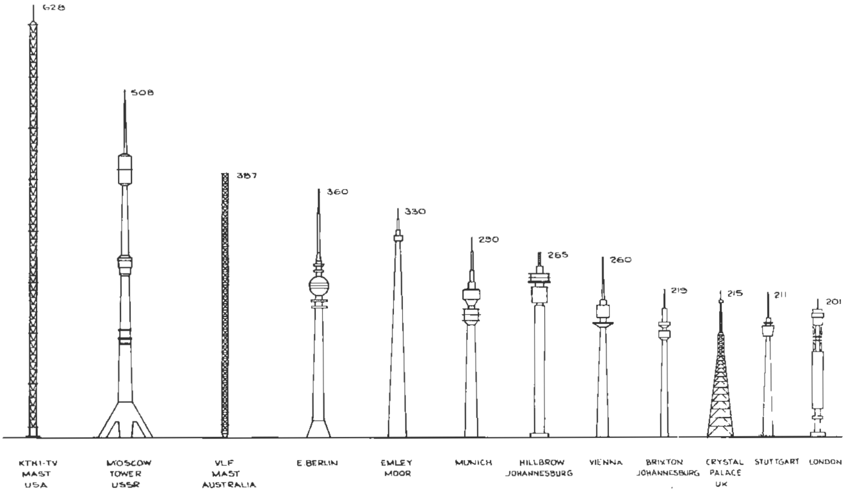

Figure 43.1 Comparative outline of some tall masts and towers

from the drawing board sketches into steel or concrete. In this connection, the requirements of the erectors cannot be ignored because their work at great heights imposes limitations on the shape, weight, size and configuration of the individual parts which have to be hoisted into position to form the complete structure. *Figure 43.1* shows comparative outlines of some tall masts and towers erected throughout the world. The KTHI-TV mast at Fargo, North Dakota, is of particular interest being the highest man-made structure in the world. It is 628 m high and is a lattice steel type structure. The legs are formed from solid round steel about 24 cm in diameter reducing to 14 cm at the top. The width is 3.35 m at the base and continues up to the eighth guy level where it tapers in to 2.6 m for the purpose of a wrap around channel 2 antenna. The channel 11 antenna at the top of the mast is 34.4 m high and weighs more than 4 tonnes. The total weight of this triangular structure including the antenna and guy ropes is more than 513 tonnes and this is supported by a thrust block 10 m across, standing on massive piling. All concrete below ground is covered with one centimetre copper mash which is tied into ground rods and bonded to the tower and the guy ropes. This system provides an effective lightning earth. There are 14 levels of lighting on the mast, seven levels have flashing code beacons spaced 91 m apart and the remaining levels have three obstruction lights at each level, one on each leg of the mast. A two man lift capable of hauling 386 kg is provided for maintenance purposes. The lift comes to within 6 m of the ground and goes to approximately 590 m.

The design of a structure for radio purposes is generally a two stage process involving firstly the selection of an appropriate type of structure and secondly the detailed design of the various parts of the structure. The engineer must consider all steps necessary to prevent failure of components of the structure such as members, guys, insulators and foundations by estimating the effects of impressed forces, by determination of optimum cross sections, by selection of proper materials and by studying the effects of the environment, surface treatments, voltages, soil conditions and the effects of shape.

Throughout the design process, the following points have to be considered for each section, component or member:

(a) The function it has to perform in the operating or static mode.
(b) The arrangement by which it must perform the function within the section and the structure as a whole.
(c) The conditions and environment under which it must function in service.
(d) The degree of accuracy with which the acting mechanical and electrical forces can be determined by calculation or measurement.
(e) The accuracy with which the properties or performance of the materials to be used in the fabrication and assembly are known.
(f) The manner in which a part of the whole is likely to fail and the effects of that failure.
(g) The capacity to withstand the working loads and voltages to be applied in service.
(h) Whether the proposed design is the most economic way of performing the desired function within the specification.
(i) The method of erection.
(j) Whether aesthetic factors are involved in meeting environmental considerations.

These points form the basic factors in value analysis, the determination of factors of safety and in suggesting the methods of tackling the mechanical and electrical calculations.

SAFETY ASSESSMENT

The failure of any element of the structure can occur by yield, buckling or fracture on the application of a load of sufficient magnitude. Failure may also occur by time dependent modes such as fatigue, creep, corrosion and embrittlement. Where a structure is used as a radiator, for example for medium frequency broadcast purposes, mechanical failure can occur as a result of the effect of the working voltage on the structure. Internal heating of insulators due to dielectric loss or formation of a crack may be sufficient to bring about mechanical failure of these elements. Also arc-over to a wire guy rope section can result in burn-through and collapse of the guy. Grass fire will quickly burn through a plastic guy rope if the rope is close to the ground.

The information on which the safety of a structure must be assessed during the design stage will in general include:

(a) The dimensions and strength of the materials to be used and the standard of workmanship and supervision during fabrication and on site erection.
(b) Particulars of the design and actual physical and electrical loadings, arising from any cause, to which the structure will be subjected during its life.
(c) Design calculations and relevant performance tests.
Care is necessary in the interpretation of the relevant specified tests, for example the strength of concrete foundations and anchor blocks of the finished work can vary considerably from that indicated by the test samples.
(d) Material strength deterioration due to time dependent modes such as corrosion and fatigue and in particular to vibration.
(e) Conditions of the site and foundation where the structure is to be erected.
The main body of evidence regarding the safety of the structure will usually take the form of design calculations which should have standards of accuracy and completeness at least equal to the standards set by the relevant current codes of practice. Also, to ensure that risks of failure are acceptable for any given design, considerable emphasis may need to be placed on a statistical treatment of both the strengths of materials and the various types of loading which may be placed on the structure due, for example, to wind and ice conditions and changes in type of equipment from one kind of antenna to another.

An important factor which has to be taken into consideration is the factor of safety. It is an objective value of correlation between actual strain and potential resistance. With the application of computer techniques in recent years the element of ignorance in structural design methods has been almost eliminated in the case of straightforward designs but the element of uncertainty, because it is caused by circumstances which can be changed, can not be removed. Hence, the factor of safety can be considered to be a measure of uncertainty rather than ignorance. The reduction in the numerical value of the factor of safety in many of the separate structural, foundation and antenna design areas has been due mainly to improved quality control in fabrication and manufacture, stringent controls in the standard of workmanship and improved acceptance testing techniques rather than as a result of improved design methods. Evidence of this can be seen in comparing modern day structures with those erected in the 1930s. Dead weight has been considerably reduced, guy ropes have smaller diameters and anchor blocks have reduced mass.

In summary, the value and reasons for the factor of safety are based upon consideration of the following:

(a) Variations in the quality of materials.
(b) Variations in marking-up and fabrication of structural elements.
(c) Uncertainties in determining loading figures.
(d) Variations in stresses during transport to site and in the erection process.
(e) Deterioration of components and members as a result of service e.g. corrosion and fatigue.
(f) The degree of importance of the facilities requiring the tower, the loss of life or damage to property should the structure collapse.
(g) Unknown stresses not taken into consideration during the design and also those likely to occur under dynamic conditions.

AERODYNAMIC STABILITY OF STRUCTURES AND ANTENNAS

Practically all radio type structures, including masts, towers and antenna systems, are aerodynamically unstable. Considerable attention has recently been focused on this problem because of damage to guys, tubular members of television antennas, continuous wall reflectors of microwave antennas, rigid waveguides, transmission lines and the supporting masts and towers, particularly those with tubular trunks.

The absence of wind excited vibrations in some structures and elements is due either to high natural frequencies or to high damping characteristics of the structures or elements. However, the number of recorded heavy vibrations of structures and equipment mounted on them, and reported metal failures, are increasing with the use of taller structures and some unconventional structural shapes necessary to meet mechanical and radio requirements. In December 1976 the 80 m mast at the Pic de Nore transmitting station in France collapsed when winds of up to 260 km/h hit the structure. The mast supported television antennas for the Paris-Madrid link. It was thought by the investigation team that the mast was driven into severe oscillation by the effect of two particularly violent gusts of wind that coincided with the natural period of resonance of the structure.

The most common cause of aerodynamic instability is vortex excitation which tends to excite oscillations or vibrations in a direction transverse to that of the wind stream. The peaks of disturbance become a maximum when the frequency shedding of vortices coincides with the natural frequency of oscillation or vibration period of the structure or element. In at least one installation severe vibrations were observed in a structure after a cylindrical fibre glass protection sheath had been fitted over the television antenna because of ice problems. The structure was a 100 m selfsupporting lattice steel type and there was no evidence of vibration before fitting the protection cylinder.

In the case of a cylindrical form, instability is caused by its cross sectional shape, and aerodynamic stability can usually be introduced by alteration to the shape, in the requisite direction. The air flow can be controlled by the attachment of protrusions mounted on the external wall of the cylinder. Spiral interceptions such as helicoidal fins have been used to good effect in reducing vibration on tubular television masts and cylindrical ice protection sheaths. However, care is essential to ensure the interceptor system is properly designed and engineered, because an interceptor mounted at an incorrect angle may increase the instability, rather than reduce it.

As a typical example, helical straking was successfully employed on a 1.5 m diameter fibre glass cylinder which enclosed an antenna system on top of a concrete tower. The tower was 274 m high and supported a v.h.f. antenna system 30.5 m high and a u.h.f. antenna system 24 m high above the v.h.f. system. The v.h.f. antennas were enclosed inside a 3.6 m diameter fibre glass cylinder and the u.h.f. antennas inside the 1.5 m diameter cylinder.

The strakes were applied to the top third of the cylinder to prevent oscillation of the cylinder under vortex shedding conditions. The need for this was shown up during investigations of the aerodynamic behaviour of an aerolastic model of the mast in a wind tunnel.

In the final design, the strakes comprised sections of 12 mm thick fibre glass projecting 150 mm from the cylinder forming a three start helix. Subsequent experience showed that the design provided the required aerodynamic damping by acting as an effective spoiler.

The vibrational energies of thin walled copper or aluminium tubing used for parasitic type antennas and log periodic antenna elements are small and can be damped by filling the tubes with oil of high specific vibrational loss, or by a thin steel wire mounted inside the tube so that the vibration is damped when the moving tube and the wire collide. The steel wire also often serves as a mechanical bearer to support long horizontal tube elements. Wooden dowelling placed inside tubular elements of Yagi and rotating log periodic type antennas has also been used with a high degree of success to minimise vibration.

Parabolidal dishes used for microwave antenna purposes have also been found to be aerodynamically unstable as they tend to oscillate in pitch about a diameter for certain angles of wind flow. In very large dishes such as radio telescope where this may introduce inaccuracies, a mesh reflector is often used in place of a solid type reflector.

The galloping of stranded long wire antenna conductors, transmission lines and guys has been attributed to aerodynamic effects in quartering winds due to the lay of the strands. Galloping has also occurred on ice covered antenna wires and conductors due to the resulting unfavourable aerodynamic shape. The cross-section shape has often a quasi-elliptical or airfoil profile.

In the case of an ice covered conductor, motion may be initiated by ice dropping, or strong gusts of wind. Lift and drag forces are established on the conductor by its motion through the air. If the resultant of the lift and drag forces is in the general direction of conductor motion, aerodynamic instability will exist and the motion will be sustained by the movement of the conductor iteself. Galloping on long spans of v.l.f. antenna conductors has been observed to persist for several hours, even in unsteady wind conditions. Oscillations with amplitudes as large as three metres have been observed at some installations. The conductors are usually steel cored aluminium cables of 2.5 to 4 cm diameter in order to prevent corona rather than for its current carrying ability.

The main damage which has been attributed to galloping on long wire antenna conductors and guy ropes may be summarised as follows:

(a) Breakage of strain insulators, particularly long rod ceramic types.
(b) Excessive sag being introduced as a result of overstressing by the large elastic forces developed in the conductor during the galloping motion.
(c) Fracture of strands, particularly at points of termination or anchorage.
(d) Breakage of hardware fastening pins and shackles.

Another type of wind induced vibration which causes problems in radio engineering is aeolian vibration. Aeolian vibration is more prevalent and generates a great deal more damage than galloping. Depending on the conductor or structure characteristics and environmental exposure, the vibration may vary from a very severe level to one barely detectable. The amplitude of vibrations, however, is very small compared with the galloping phenomenon; the peak to peak displacements rarely exceed a conductor diameter in magnitude.

It has been found that the most severe cases of aeolian vibrations are associated with constant wind movement. Long wire antenna systems erected in mountainous or heavily timbered country have not recorded any significant number of failures from aeolian vibration, because in these areas the irregular contours cause turbulence, changes in wind direction and speed to the uniformity of the air mass movement. On flat open country, where unfortunately many long wire installations are situated, the problem can be of considerable concern to station maintenance engineers. Few obstacles exist to break up the uniform wind flow and the air is allowed to move constantly across long spans of conductors for extended periods. Experience has shown that vibration is generally more severe at night time than during day time, mainly because in many areas there are more uniform wind speeds during night time and also the lower atmospheric temperatures during this period result in an increase in the tensions applied to conductors which are not terminated with counter weights.

The factors which contribute to aeolian vibration and the resultant damage may be summarised as follows:

(a) Aeolian vibration is most prevalent in flat open country areas which offer few features to cause sufficient turbulence to interrupt the laminar air flow.
(b) Stranded conductors are more prone to aeolian excitation at high tensions. Interstrand friction is an important factor in attenuating the vibration. Also, the co-efficient of friction of the material itself has a considerable influence on the attenuation of the vibration. Aluminium has a higher co-efficient of friction than copper and this is one of the reasons why stranded aluminium conductors are favoured for high power rhombic and v.l.f. antenna conductors. The weight per unit length of aluminium is also much lower than copper and consequently the applied tension necessary for the same sag is much lower.
(c) The damage resulting from aeolian vibration is mainly fatigue, although abrasion has also occurred where conductors have been insecurely clamped. Breakages from fatigue have occurred at strain insulator terminations and at feeder line connection points. Damage from abrasion has occurred at loose clamps and tie-ins.
(d) Aeolian vibration has resulted in the loosening of nuts and bolts on hardware, and also on some structures. Part of the annual inspection of structures

> should include checking the tightness of nuts. Loose or lightly loaded redundant structural members and washers on guy insulators have often been a source of high level audible noise and have resulted in complaints from nearby residents.

At one transmitting station using 40 m self-supporting towers for a three wire rhombic antenna system, a gap of about two centimetres occurred between the concrete anchor blocks and the surrounding dry sandy soil of one tower as a result of excessive vibration being transmitted to the tower from the conductors. An inspection of the three 12 mm stranded conductors showed abrasive damage at clamps and one wire had vibrated about 5 mm out of its friction type terminal fitting.

The effect of wind on conductors and cables generally, must be taken into account during the system design. Many examples are available where resonance effects resulting from wind have caused damage to antenna wires, cables and guy ropes, even though they had adequate safety margin to withstand the normal static loads of the system. Long wire antenna systems with heavy insulator and other hardware assemblies require particular care. Given the right conditions, even winds of relatively low velocity can bring about resonant vibration of intensity sufficient to destroy the support structure of the system. Vibration dampers of the Stockbridge type have been used successfully to control this problem. These dampers tend to dissipate the energy and in effect reduce the Q of the mechanical resonant system. Where several long conductors or guy ropes terminate at a common section of the structure, it is important to ensure that they have different resonant frequencies.

SHAPE OF MATERIALS

There is very little to choose between the various shapes of materials used in the fabrication of steel masts and towers. All shapes have their particular advantages and disadvantages. Different designers have different preferences for shapes and also different fabricators have different shape fabricating facilities.

The most commonly available shape is the structural steel angle. Because the legs make 90 degree angles, masts and towers fabricated from these materials are four sided. The main advantage of structural angle shape is its ready availability, comparatively low initial cost, ease of fabrication, ease in shaping, ease of galvanising and ease of assembly on site. The most significant disadvantage is that the angle increases the wind load and consequently the overall loading of the structure, particularly where tall structures are involved. Very few modern masts above 250 m use structural steel angle members. Most use cylindrical shapes.

Structures of triangular cross-section use a steel strip which is rolled into a 'V' or some such shape approximating this. The strip forms a 60 degree angle and so makes it relatively simple to fabricate a three sided structure. The advantages and disadvantages of this section are about the same as those of structural steel angles.

Many masts are constructed of solid round steel bar members, particularly the taller masts. The advantage of a solid bar is that it has low wind resistance for a given cross-section area. Its base price is also relatively inexpensive. However, the solid bar is heavy for large cross sections and the weight of the structure can rise steeply if the design is not properly controlled.

Structures employing tubular section are very popular because the tube has a circular shape which keeps the wind load down and gives the designer the most efficient distribution of material to carry a column load. Tubular structures are usually more efficient and have fewer parts than those of other shapes. The greatest disadvantage of the tube is that it has a relatively high initial base cost price for the material.

WIND AND WIND LOADING

Some damage to masts and towers from storms of cyclone, hurricane, tornado or typhoon intensity is to be expected, although even the pressures from these forces can be successfully resisted by proper design procedures. However, winds of pressure well below design level should not be the cause of so many failures which have occurred in practice. Many masts and towers have failed during winds pressures which were well within their design limits. Resistance to forces created by winds requires appreciation of the fact that wind forces are not

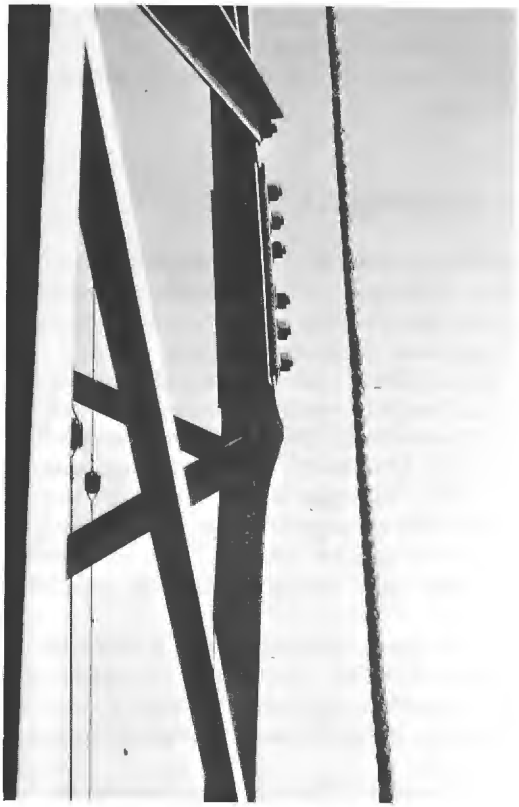

Figure 43.2 Buckled leg of mast when counterweight jammed

uniform horizontal pressures as is commonly believed by some engineers. Investigations have indicated that uplift, buckling and torsional effects have been responsible for many of the failures, particularly where the structure is used to support antenna systems. *Figure 43.2* shows one leg of a 50 m mast which buckled when the mechanism of a six tonne counterweight associated with the catenary jammed during a strong wind, the intensity of which however was well below the maximum level used for the design of the structure and the antenna system.

The basis of design of the wind loading on a structure depends on the geographical area and a detailed analysis of local meteorological data covering a long period should be made in order to ascertain the wind velocities likely to be encountered during the life of the structure. The following should be taken into consideration by the designer:

(a) The basic and peak wind velocities recorded at or near the proposed site by government meteorological authorities.
(b) Probable times of recurrence over selected periods, for example, 10, 25 or 50 years.
(c) Observation of other structures in the area.
(d) Procurement of design data used for existing structures in the area.
(e) Meteorological publications of data dealing with weather patterns in the area.

The great heights to which many masts and towers are now being built is largely beyond the range of application of some current conventional design rules and wind conditions assumed in many designs have yet to be confirmed by measurement. The present approach is to select a basic wind speed at ground level and modify this value by a factor which allows for higher wind velocities as height is increased above the surface. Since air is a viscous fluid, the ground slows the wind to a certain degree due to frictional forces. The resultant velocity gradient is neither constant nor is it easy to express; one reason being that the characteristics of the boundary layer near the earth's surface depends upon the features of the local terrain. An accurate assessment of the wind velocity at various heights is important, particularly for those structures designed to carry microwave dish and horn type antenna systems, because of the large drag effect of these devices.

In addition to this wind gradient there is the gust problem. On top of the average maximum wind velocity, there may be superimposed gust velocities for short durations. Much work has been done studying these gusts and there are some empirical estimates. There is no sure prediction of gusts, but it is reasonable to assume that gusts are possible which exceed the maximum wind velocity by a factor between 10% and 30%. However, the geographical location and also the period over which the gust is taken play an important part in the gust velocity data. For periods of one second, a particular location may indicate gust velocities of more than twice that of the five minute mean value. The choice of the effective gust period is a most important factor in the design of a tall structure and one of the most imprecise. The assumed period must be the minimum to which the structure is sensitive. It is likely that some very short impulses may not coincide simultaneously over the full height and may be too irregular to impose a consistent influence on the deformation of the structure.

Figure 43.3 shows a rolling counterweight system employed at a v.l.f. station to take account of wind and ice loading on the antenna system. The insulators of

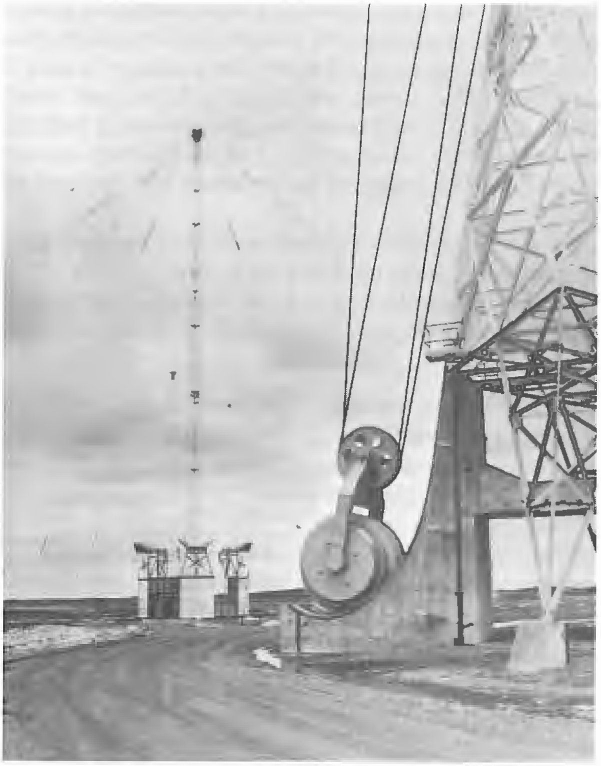

Figure 43.3 V.L.F. antenna counterweight system.
(Courtesy US Navy)

the antenna elements terminating on the masts are attached to halyards which pass through sheaves at the mast head and down to rolling counterweights, near the ground. Some of the counterweights are 220 tonne wheels made of special dense concrete and ride on roller-coaster tracks. In high winds the counterweights may move up and down the tower faces 50 m or more. At other stations automatic winches serve the same purpose.

ICING

Where antenna systems are located in areas subjected to severe icing, some form of protection is desirable for many types of antennas. Not only does the ice cause impedance mismatch with some antennas but it can cause physical damage by breaking or displacing elements and cracking tube elements so allowing water to enter. At one site on a mountain covered with snow during winter, an inspection revealed that a main tubular member of the support framework for a 6 m x 5 m passive reflector had burst. It was considered that this was due to the action of water which had seeped into and filled the tube and expanded in freezing.

Common practice with many television antenna panels is to enclose dipoles and feeders within a cylindrical cover or radome made from fibreglass. The diameter of the cylinder is proportional to the dimensions of the antenna system and hence to the wavelength. Some cylinders exceed 7 m in diameter and are constructed in the form of bolted half rounds or quarters.

Heating is an alternative where mechanical protection is impractical. The technique has been used satisfactorily on long wire antennas, earth station dishes, superturnstile and spiral antennas. For a typical superturnstile array with six radiating bays giving a power gain of about 6, some 18 kW of heating power is required. For the spiral antenna heat is provided by using copper tubing with internal resistance heating elements. Tubing giving 15 to 20 W per 30 cm length is commonly employed.

A zone of protection should be established at each site where falling blocks of ice occur. Although the formation of ice takes place mainly on the side from which the wind blows, ice may during the thaw, fall in any direction. The protection area should therefore not be confined only to the direction of the prevailing winds. The dimensions of the area depend on the height of the structure or elements on which the ice is formed and on the maximum wind velocity which occurs during ice falls.

Buildings require special protection for the roof and for windows near ground level where ice blocks burst on impact with the ground and scatter large splinters of ice. For a flat roof, a layer of gravel about 10 cm thick has been found to be effective while an iron grid arrangement has been satisfactory for a sloping type roof. Special roofing over staff access roads is required and walls may also be a requirement to prevent injury where ice blocks crash to the ground and break up.

During periods of thawing, ice falls away in large pieces from steel work and antennas. The high thermal conductivity of the metal causes the ice to melt on the inside and so severing its bond to the surface. On a concrete tower the ice usually melts slowly from the outside and is seldom dislodged in large blocks.

With satellite earth stations, the ice problem is handled by the use of a radome or by heating the dish. The Raisting earth station in Bavaria is an example where both methods were used on the same site. The first antenna commissioned in 1965 employed a 25 m dish and this was protected against the effects of the weather by an inflated radome. The second antenna dish erected in 1969 was 28.5 m in diameter and was designed for operation without a radome. The reflector was heated at the rear by infra red radiators to prevent ice and snow collecting on it in the winter. The maximum heating power was 400 kW. A third antenna commissioned in 1972 also used heating facilities.

STRUCTURAL FAILURE EXAMPLES

Although records show that many structures failed as a result of bad design or human error or incorrect procedure during erection and also by inadequate maintenance during service life there is nothing like a natural phenomenon such as high wind, lightning, heavy snow or earthquake for highlighting errors in design, construction and maintenance practices. There are, of course, others such as damage by collision, vandalism and fire and there is a continuing process of learning from these lessons.

Because a good deal of material associated with the failure of masts and towers lies unpublished in the files of engineers, contractors, government departments etc., complete coverage of the subject is not possible. However, the following case records are typical and cover the majority of situations. They supplement similar case studies of structural failures in other chapters.

Failure of Components

EXAMPLE 43.1

Among the earliest structures erected specifically for radio purposes were the antenna systems constructed by Guglielmo Marconi in connection with his trans-Atlantic tests. They also are among the first known major structural failures of radio masts and towers. Marconi erected two identical antenna systems, one at Poldhu, Cornwall, in England and the other at South Wellfleet, Cape Cod, Massachusetts in USA. Each system comprised a large skeleton cylinder of 20 wooden masts and wires. The cylindrical system was about 60 m high and 46 m in diameter. The antenna comprised 400 vertical wires which were suspended in an inverted cone. Only the radial stays of the wooden masts were taken to anchor blocks. Circumferential staying was accomplished by cables which linked each support to its neighbour.

The employment of these cables had the obvious disadvantage that should one fail, the safety of all 20 masts could be jeopardised. Technically, however, the system had the advantage that the horizontal wires absorbed little energy from the antenna wires within the circle of masts, because they were virtually at right angles to them. The danger was appreciated, but as the advantage in

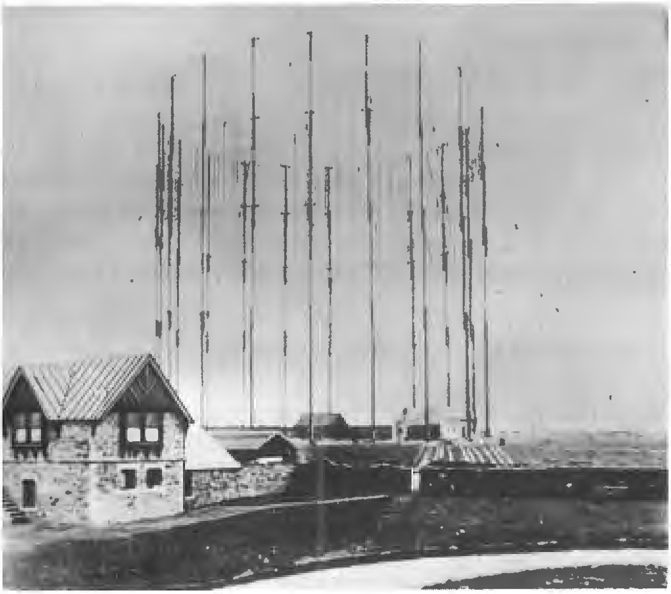

Figure 43.4 Marconi's cylindrical structure 1901 (Courtesy Marconi Wireless Telegraph Company)

Figure 43.5 Damage to antenna (Courtesy Marconi Wireless Telegraph Company)

technical performance of the antenna system was a major factor, those in control decided to take the calculated risk.

With hindsight it was an ill advised course of action. On 17 September 1901, high winds struck the antenna. A lug failed, so breaking the retaining circle of the cable and the structure collapsed. *Figure 43.4* shows the structure before the wind struck. The resultant damage can be seen in *Figure 43.5*.

Marconi also had his problems at the Cape Cod station. Some two months later on 26 November the antenna there also collapsed.

EXAMPLE 43.2

On 13 November 1946, a 155 m mast fitted with a large armature top collapsed at Lawrence, New South Wales, during a violent windstorm. The structure was at the time the first of its type in the southern hemisphere and had been in service 11 years prior to the collapse.

At the height of the storm, the winds were estimated to have reached 160 km/h. The noise created by the storm was so loud that the station operator did not hear the collapse at 6.48 pm. When the transmitter automatically shut down, he looked outside and saw the mast wreckage on the ground. The structure collapsed towards the river alongside the station property and came to rest on the ground in the shape of a letter 'U' as shown in *Figure 43.6*.

The main feature of the mast was that it was surmounted by a large armature mounted on insulators. The armature was electrically connected to the vertical structure via a tuning inductor housed in a cabin just below the armature. The radiator therefore consisted of two sections coupled together via a tuning inductor. The inductor was fitted with a wiper arm to permit adjustment for correct location of the current mode on the mast.

The structure was triangular in section and guyed at four levels in three directions. It stood on a group of six tubular insulators and the guys were sectionalised throughout their length by porcelain insulators of 12.7 cm diameter and 16.5 cm length. Mounted on top of the mast was the 18.3 m diameter armature supported by stand-off insulators. These insulators were tubular type 76.2 cm in length, 4.4 cm thick and tapered from 20 cm diameter to 25.4 cm diameter. They were each subjected to a vertical load imparted by the weight

Figure 43.6 U shaped distribution of mast wreckage

of, and downward wind pressure on, the armature, and a bending moment and shear caused by the side wind on the armature under wind conditions. The lead-through insulator to the armature whilst not subjected to any severe mechanical stress also deserves mention. It was 106 cm in length and 40.6 cm in diameter at the centre flange position.

In the design of the structure, a general factor of safety of three was used throughout for the steelwork and guys. The horizontal wind pressure on which calculations were based was 97.6 kg/m^2 at ground level, increasing by 4.8 kg/m^2 for every 30 m of height. This was equivalent to a wind velocity varying from 131 to 145 km/h. The pressure was assumed to act on the full projected surface of the mast, normal to the direction of the wind. The armature was designed on the basis of the same horizontal wind pressure as well as a vertical pressure of 24.4 kg/m^2 on its projected area.

An allowance for screening of wind pressure was made in the armature construction owing to the close fabrication of the members. Because of the large physical size of the armature and the great height above ground, excessive deflection of the mast had to be guarded against during periods of wind. The deflection was limited to 1% of the height in the design, when the wind impacted on the structure face between two sets of windward guys. This required close attention to guying details. Each windward guy was assumed to hold against the pressure of the wind, firstly, its section of the mast; secondly, the wind on the set of guys themselves; and finally the pull of the opposing guys on the lee side of the mast.

Top guy ropes were 4.75 cm diameter compared with 2.7 cm diameter for those at the first, second and third levels because they were also required to hold the wind pressure on the armature. The maximum calculated working loads ranged from 8.5 tonnes in the lower guy to 31 tonnes in the top guy. The guy

Figure 43.7 Bulldog guy terminations

ropes were terminated at the anchor block fittings and sectionalising insulators by bulldog grips. These grips together with the insulator fittings can be seen in *Figure 43.7* which shows the wreckage above the second guy level point. The subsequent investigation into the collapse indicated that the failure of one of the bulldog grips was the likely cause of the collapse. Similar structures which followed this pattern were provided with socketed guy ropes.

Sea Storm

EXAMPLE 43.3

A $US20 million manned radar tower situated in the Atlantic Ocean, some 130 km off the coast of the United States, in 56 m of water, collapsed in the night during a hurricane on 15 January 1961 resulting in the loss of 28 lives. The tower, known locally as Texas Tower Four, was one of three manned radar towers positioned in the Atlantic Ocean as part of the early warning air defence radar system.

The tower erected in 1957 was plagued with construction and installation problems from its very beginning and the Preparedness Investigating Sub-committee of the Senate Committee on Armed Services which probed the collapse sought answers to possible deficiencies in repair in attempts to restore the integrity of the structure after it had been damaged prior to erection on site, and later by storms. A brief history of the main damages[3] is shown in *Table 43.1* and the investigating group concluded that an unbroken chain of error and mistakes of judgement had ended in stark tragedy.

Table 43.1 HISTORY OF DAMAGE TO TOWER

Date	*Damage*
July 1957	Two bracing members lost on site prior to erection and a third damaged
August 1957 (approx)	All three legs badly dented during erection of platform
October 1958	Collars fitted on site following loss of bracing members, worked loose due to failure of bolts
February 1960	Badly worn pin connection holes on braces at 7.62 m and 22.86 m levels. X bracing later installed above waterline as emergency measure
September 1960	Under carriage inspection bridge badly damaged by high waves (Hurrican Donna)
November 1960	Diver reported the following, which probably resulted from Hurricane Donna: Diagonal brace connected to centre of 7.62 m level brace fractured at gusset plate Pins very loose on diagonal braces connected to centre of 22.86 m level brace Cracks found in above water X bracing
January 1961	Diver reported, diagonal brace connected to centre of 38.1 m level brace, fractured
15 January 1961	Structure collapsed into the sea during a storm

The towers derived their name from their resemblance to off-shore oil drilling rigs erected off the coast of Texas in the Gulf of Mexico. However, whereas typical oil drilling rigs were supported by four tubular legs, the radar towers used only three legs. Five towers were originally planned but only towers Two, Three and Four were built. Plans for the others were scrapped. Following the experience with tower Four, towers Two and Three were later demolished.

The design of each tower was based on the need to support a wedge shaped triple decked steel platform on three hollow columns fixed into the ocean bed. The platform housed radar and radio equipment, engine power generating plant and living quarters for up to 100 staff. Tour of duty for the operating and support staff was 16 months, comprising 45 days aboard the tower and 15 day intervals ashore. The staff learned to live with the continual movement of the tower, the constant reverberations when waves crashed against steel plate, the noise of power generating plant and one of the loudest fog horns in the world.

Tower Four was similar in design to tower Two, an aerial view of which is shown in *Figure 43.8.* Tower Two was the first of the off-shore stations erected for the US Air Force and was located 175 km off shore on George Bank in 17 m of water. The platform stood on large diameter unbraced columns. The three plastic and fabric covered domes housed radar antennas. Below deck was the supply and utilities deck and also the crews living quarters. Topside can be seen the operations and plotting rooms where shift crew's watched for early warning of aircraft approaching from the sea. The helicopter landing pad can be seen at the rear of the operations room. Both towers Two and Three differed from Four in that they were installed in much shallower water and their support columns or legs were not braced.

Storm action and the maximum known wind velocity in the area were major factors taken into consideration during the design of the structure. Meteorological records showed the maximum wind velocity in the area to be 205 km/h over a 20 year period and maximum wave heights of 18 m. Following experience

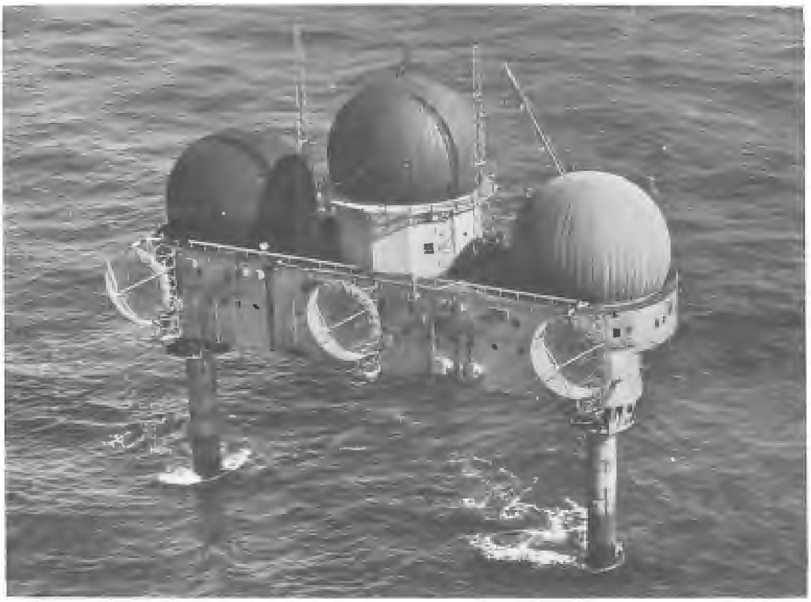

Figure 43.8 First off-shore radar station (Official US Air Force Photo)

with oil drilling structures in the Gulf of Mexico, a 20.4 m clearance above mean sea level was adopted and it was expected that this would have given sufficient clearance to allow all waves to pass underneath the platform.

It is interesting to note that investigations carried out after erection of the structure indicated that more tower motion was caused by waves of only three to four metres than those of greater heights. This is because these smaller waves have a wavelength of about 47 m and so allowing two waves to break simultaneously on different sections of the structure. The bigger waves having longer wavelengths caused the structure to be battered by only one wave at a time.

A three legged structure was evolved in order to reduce the wave forces and although extensive bracing was provided between the vertical support legs in order to minimise lateral deformation and drift, motion studies on the tower showed that there was a plus or minus seven centimetres sideways movement and a twising rotational motion of 1/10th degree of the platform on which the radar equipment was mounted.

Figure 43.9 shows the main features of the tower. The total weight imposed on the structure by the deck and equipment was about 5500 tonnes. Fuel oil for power generating plant was installed in two of the hollow legs. Each leg was 3.81 m diameter, fabricated from 20 mm plate and embedded in a concrete footing, 7.62 m in diameter and about 5.49 m long, in the ocean bed. As shown in the sketch, each leg was lined internally with a 0.68 m thick concrete fill from the top to about 15.24 m below sea level mark. This resulted in an effective leg internal diameter over this section of 2.41 m. The concrete actually filled the annular space between two steel pipe shells and was placed in position on site after erection of the steelwork.

Large horizontal pin connected pipe bracing was located at three levels below

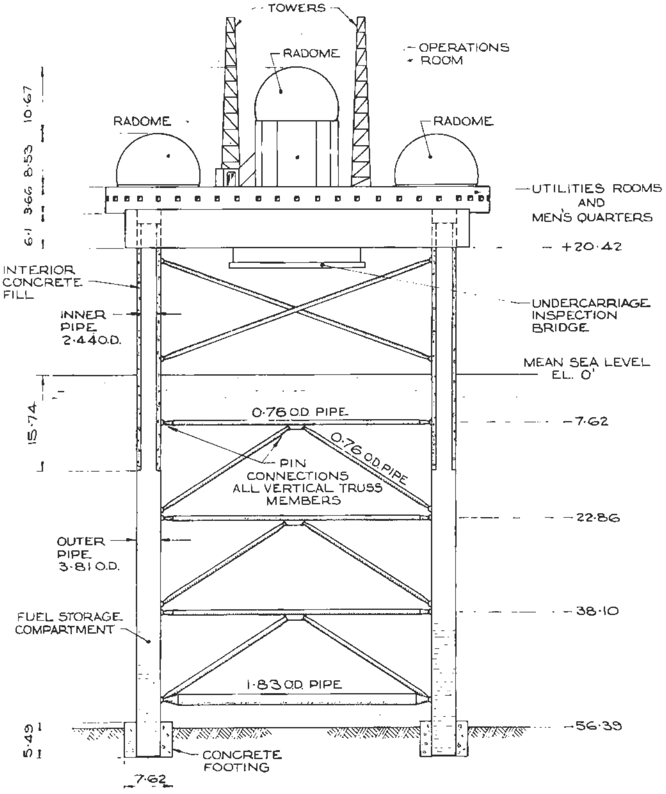

Figure 43.9 Main features of the tower

the surface of the water with tiers of K bracing in each plane of the triangular base, connecting the mid points of the horizontal braces with the support columns. The X bracing above the water level was installed as an emergency measure, three years after the initial construction on site. *Figure 43.10* shows how the horizontal leg braces were themselves braced at their midpoints by welded members and pinned to the three main legs.

The construction procedure called for the building of a tower tripod on its side, floating it to the ocean site and up-ending it by controlled flooding of the cylindrical steel legs. The tripod weighing 1800 tonnes was towed some 800 km from the coast by tugs to its destination but a storm developed before commencement of the installation activities. The storm raged throughout the night and it was noticed next day that large diagonal bracing pipes on two of the legs had broken free and were lost and a third damaged. Decision was made to proceed with the erection and attempt to repair the damage later, rather than return the structure to shore for repair. Massive steel collars were later fitted around the vertical legs and braces tied thereto by divers working in water up to 19.8 m deep.

After fixing of the steelwork, the platform on which the station was to be built was towed into position between the three legs. A swell caused an unexpected movement of the platform, resulting in damage to all three legs. Large

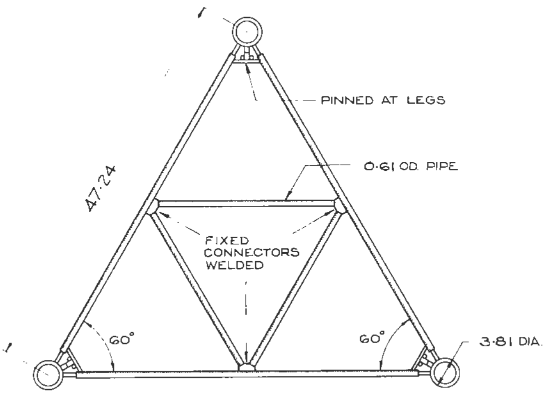

Figure 43.10 Sectional plan of leg bracing arrangements

dents up to 25 cm deep covered the surface for about half the circumference and 2.7 to 3 m in height, of each leg. After jacking up and fixing the platform in position, the concrete stiffening was placed between the inner tube and outer casing of each leg.

Soon after the Air Force took possession of the structure for installation of the equipment and facilities it was discovered that the tower began to heave and vibrate even under relatively small swells and the integrity of the bracing system was questioned. Although calculations indicated that the structure was still theoretically capable of withstanding gale force winds of 200 km/h and high waves, the tower was nevertheless evacuated in the interests of safety of the crew when hurricane Daisy swept through the area in August 1958.

Measurements and studies carried out after the hurricane indicated that the natural tower frequencies were about a third of the calculated values and that the bracing was not functioning as designed. Hydrophone measurements indicated that some joints were loose and that considerable movement of steel members was taking place below the surface of the water. Divers sent down to investigate reported that a repair collar was so loose that the sliding action up and down the leg had worn the metal and some bolts were also broken. Repair work was carried out between several storms and the tower restored to a reasonable state of stability by May 1959.

In the winter of 1959/60, the tower was reported to be swaying with an alarming rocking and rotating motion and banging noises could be heard from below. Divers were again sent down to investigate and reported that the constant rocking of the tower had worn loose the steel pins connecting the braces to the vertical legs. In some cases the holes had worn as much as 2 cm resulting in considerable slap. An analysis of measures necessary to stop this action resulted in the recommendation for the fitting of X bracing above the water line as an emergency measure. This modification had been considered some time prior to this but ruled out on the basis that the increase in loading on the structure from the waves was beyond the additional strength which the bracing could be expected to provide. The additional bracing was completed in August 1960.

Before the worn pins could be fixed, a second hurricane, Donna, lashed through the tower on 12 September 1960, bringing with it winds of 208 km/h and waves 15 m high. The tower was almost engulfed by the high waves smashing against the steelwork. The undercarriage inspection bridge under the platform was almost destroyed by the high waves, pin connections were loosened on the X bracing and on the bracing members at the 7.62 m and 22.86 m levels. Following the damage, the structure was partially evacuated with only a small crew remaining.

By 16 November the rolling and jolting motion was so alarming to the crew on board that some considered it hazardous to life and further evacuation of staff took place. Only a skeleton staff remained to provide heat and power for repair workmen. On 17 January, divers discovered a broken brace at the 38.1 m level but the staff remained.

On 8 January a supply ship arrived with more civilian divers and steelwork, bringing the total number of people on the tower to 28. On 13 January, the meteorological experts predicted gusting winds 70 to 112 km/h for the area and the supply ship, which had returned to port, left and proceeded to the tower with the object of removing certain equipment and to stand by to take off the men in case decision came to evacuate. Equipment was loaded in cargo boxes on to the supply ship using the tower crane on 14th and after all cargo had been stowed aboard, the ship cast off and took up a position some two or three hundred metres away while the tower staff remained on the tower. During the afternoon there was only a gentle swell and visibility was excellent but the barometer was falling and the gale warning was still being issued.

During the night the winds increased and by dawn on Sunday the 15th the supply ship, which was now about 5 km off, was plunging heavily through the fierce gale. Visibility was very poor with snow, sleet and rain falling. The deck of the tower was covered with ice and it was too hazardous for the ship to approach the tower because of the high pounding waves.

Just after 10.00 am the tower crew heard a very loud noise and from the changed motion of the tower it was evident that some major damage had occurred. At 3.00 pm another loud noise was heard and a quick inspection from the inspection bridge showed large cracks had developed in the leg braces. The wind at the time had reached 128 km/h and decision was made to evacuate the tower. An aircraft carrier with helicopters was despatched to the scene to take the crew off the tower.

At 7.20 pm before the carrier had arrived the captain of the supply ship was observing the image of the tower on his radar-scope when suddenly the image disappeared. He called the tower on the radio but there was no response. The tower together with the 28 men aboard had been swallowed up by the ocean.

Error in Erection Procedure

EXAMPLE 43.4

A guyed mast designed to carry a television antenna system and to reach an overall height of 420 m collapsed at Nashville, Tennessee on 4 February 1957, when the structure had reached the 385 m level, killing four of the erection crew.

The completed structure was estimated at the time of erection in 1957 to have cost $US150 000 and would have been the third tallest in the world when fitted with the television antenna[4]. It was constructed of a low carbon alloy steel calculated to reduce the dead weight loading from the structure by about 100 tonnes. The steel also had superior corrosion resistant properties compared with the conventional material.

The structure was a twelve point guyed system with guys at 94 m, 198 m, 286 m and 368 m levels. Subsequent inspection after the collapse revealed that some of the guy anchorages had been ripped out of the ground.

The cause of the failure was never definitely established, but the method of erection and the sequence of the work were contributing factors. The circumstances at the time of the collapse were such that the only men with real knowledge of what happened on the structure were killed. Four riggers were on the mast at the time. These riggers were at about the 244 m level, installing some cross bracing elements and tightening up bolts of other cross bracing. At the same time another crew was on the ground reducing the tension set in the guy lines. This they were doing with a hydraulic jack device. The ground crew had reduced tension in several of the guy lines and they had just released the hydraulic jack on another guy line, letting this guy out about two centimetres, when very loud pops and snaps, as of bolts being sheared and steel members being torn apart, were heard.

In a matter of 8 to 10 seconds the whole structure had collapsed. Two bodies were found on the roof of the transmitter building, located about 18 m from the base of the mast, one was thrown clear into an adjacent property and the other body was found in the crumpled and twisted steel of the mast. The weather at the time of collapse was reasonably calm with winds estimated by the local meteorological office at 10 to 14 km/h at the 300 m level.

It appears that the number 1 guy rope gave way first and the tower buckled just above the second guy, about 198 m above ground level. One observer noted

Figure 43.11 Wreckage after collapse of 385 m mast (Courtesy WSM)

that the middle part of the tower buckled and from mid point to ground it looked like an accordion being closed.

Although the structure was 385 m high at the time, no elements of the main structure fell beyond the outer guy points. The twisted steelwork was confined to a radius of 100 m from the base and consequently several nearby houses were spared from damage. However, when decision was later made to proceed with the erection of a new 420 m structure, it was erected on a new 40 hectare site large enough to eliminate any danger to nearby residences in the event of repeat troubles.

Figure 43.11 shows the structure collapsed across the roadway and towards nearby houses.

It is considered by those closely associated with this tragic accident that three important lessons can be learned:

(a) No workman should be allowed on the structure while guy tensions are being set.
(b) The method of setting guy tensions should be such that shock waves cannot be created along the guy ropes. These shock waves are transmitted into the mast.
(c) All cross bracing and bolt tightening should be completed up to each guy level before further erection proceeds.

Cyclonic Winds

EXAMPLE 43.5

In the early hours of 25 December 1974, a tropical cyclone Tracy struck Darwin in Northern Australia causing the death of 49 people and widespread damage to homes, buildings and radio facilities. The anemometer at the airport recorded a gust of 217 km/h and failed shortly afterwards. The width of the area of destructive winds was thought to have been less than 40 km. The eye of the storm passed directly over Darwin and was moving slowly, about 8 km/h, so that the area was subjected to destructive winds for a period of about 5 h.

The cyclone had a devastating effect on communications both within and from Darwin. Damage to power lines, telephone facilities, radio equipment, antennas and support structures all combined to almost annihilate the communications system. The main antenna of the police communications network was damaged but local communications were maintained using mobiles as relay stations, the two medium frequency broadcasting stations went off air due to antenna and water damage, television transmissions ceased, the radio link connecting the local Civil Defence studio to an emergency broadcast transmitter some 32 km away failed when the mast collapsed and a nearby high power international broadcasting complex was extensively damaged. Army, Navy, Air Force, Civil Aviation and Marine radio communication services were also disrupted.

Of 66 structures in service in connection with national civil radio communications, broadcasting and television, 13 collapsed and were beyond repair and all of the remaining 53 had received some damage. The 13 structures which collapsed comprised two 50 m masts which supported log periodic antennas, eight 21 m towers, and three 25 cm girth lattice steel masts.

The 50 m masts which supported log periodic antennas were part of five similar antennas associated with a 250 kW high frequency international broadcasting complex. The original design called for the antenna to be operable in a wind environmental situation of 96 km/h and to withstand winds up to 192 km/h.

The antenna was formed by two log periodic planes in parallel. The dipole plane was supported by a catenary of hot dip galvanised steel rope divided in parts by strain ball insulators. The catenary was fixed at one end to a concrete block and in the front part of the antenna to another concrete block which acted as a counterweight. The mast had a square section made of hot dip galvanised steel angles. The guys were made of hot dip galvanised rope divided by strain type insulators. The dipoles were fabricated from copper wire and copper tube with each dipole being insulated at the end by high quality ceramic insulators and corona ring assembly. The top of the dipole was connected to the catenary by means of a special type of plastic rope and the lower half of the dipole was fixed to a foundation assembly. The mechanical tension of the dipole was determined by the catenary with a small turnbuckle situated at ground level being used for small correction. The feeder line was a two wire type made of copper tubing. The line was connected and suspended at mid point of the dipole by means of ceramic insulators. At the input, the feeder line was anchored to a metal support pole divided in parts by insulators.

The two masts which collapsed formed part of the one antenna system. The failure resulted from a common guy foundation block being pulled out of the ground and moved a distance of 15 m. The block is shown in *Figure 43.12*. In the initial design, the safety factor of the proposed foundation was relatively small with no consideration apparently being given to the effects of buoyancy. After installation of the footings, further loading in the form of large platforms and navigation lights were placed on the top of the masts with no increase in the

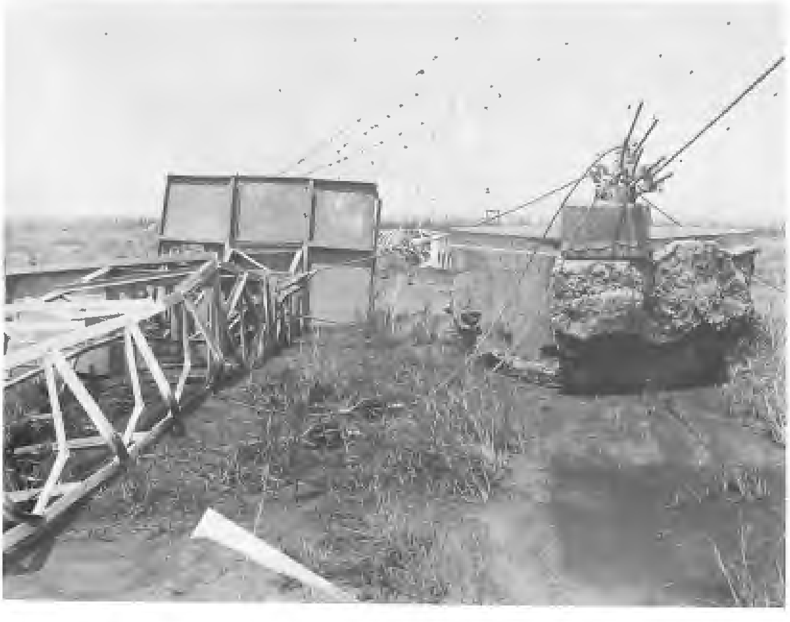

Figure 43.12 Guy foundation block pulled out of the ground

Figure 43.13 Collapsed log-periodic antenna

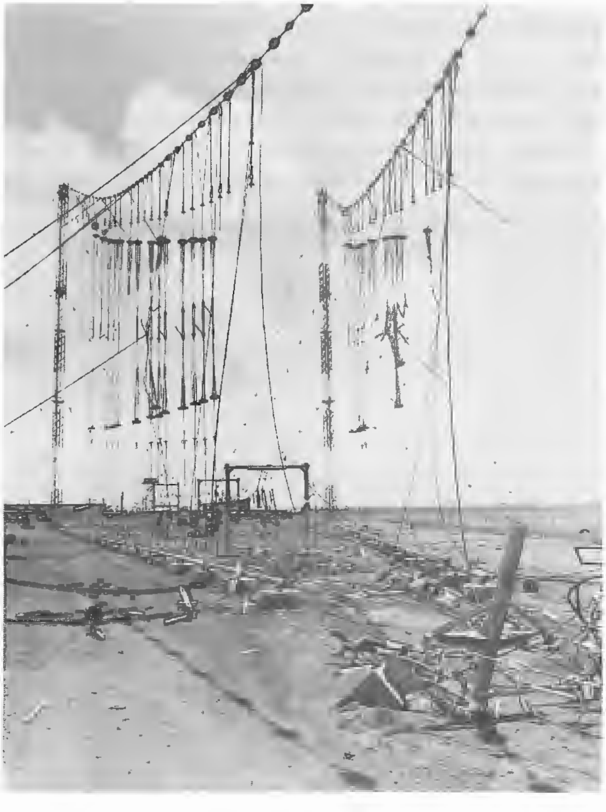

Figure 43.14 Damaged antenna elements

size of the concrete block. Further, when constructing the block it was of irregular shape and contained an estimated 1.2 m^3 of concrete less than the 9 m^3 indicated on the drawings by the designer. The thrust block of one of the masts was also lifted out of the ground when the structure collapsed. The back guys of the catenary of both masts had their foundation steelwork bent, spilling off some of the concrete. Eight of the large break-up insulators in the catenary systems were broken and all dipole elements and insulators were badly damaged. *Figure 43.13* indicates the extent of the damage.

The masts of the four other antennas remained intact except for minor damage. These included unscrewed turnbuck nuts, movement in some legs and bracing joints, slack guys, broken catenary insulators at crossover points, cracked plates attached to back stays and covers missing from catenary counterweight pits. The antenna systems were all extensively damaged. *Figure 43.14* indicates the extent of damage incurred by one antenna.

Figure 43.15 Damaged transmission line

The six wire transmission lines were also extensively damaged particularly those close to the antennas where falling dipole elements fell across the wires. *Figure 43.15* shows the extent of damage to one line between transmitter building and the switch hut.

The design of the eight 21 m towers that failed was such that they were not suitable for use in an area subjected to cyclonic winds. They were a general purpose tower and found wide application for airport radio systems, subscriber radio systems, and flat top type antennas at low power rural broadcast stations. *Figure 43.16* shows one of the structures which had been used with another to provide a standby antenna facility at one of the local medium frequency broadcasting stations. Flying iron from unroofed nearby houses contributed to the

Figure 43.16 Collapsed standby antenna

failure of the structure. The 36 m mast in the background was the main antenna for the station. Top loading wires were broken during the cyclone but these were soon repaired to enable transmissions to recommence.

The failure of the three 25 cm girth masts was attributed to bad construction practice. One mast collapsed due to a guy turnbuckle unscrewing because it was not securely wired or pinned. Another failed due to the use of an unsatisfactory footing comprising two star stakes connected by fencing wire to each other and to the guy wire and the third failed when the guy rope pulled through bulldog grips.

A 76 m tower used to accommodate television and microwave radiocommunications antennas had a lean of approximately 50 cm at the top due mainly to movement of bolts in clearance holes of all leg connections. Bolts removed from leg and bracing connections showed no real damage, only slight markings on the galvanising. The structure was subsequently straightened.

Four rhombic antennas with 30 m masts used for receiving purposes suffered only minor damage. A total of 16 bow tightener nuts were completely unscrewed because of improper pinning but all of the guys remained intact, even though they were very slack. Four wire transmission lines associated with these rhombics were extensively damaged.

Lightning Damage

Although radio masts and towers are invariably subjected to direct lightning strokes, not a great deal of damage is done to the structures. However, much damage is done to matching networks, transmission lines and cables, lighting circuits, communication and control circuits, sectionalising networks and lightning arresters. Of the few known instances of severe damage by lightning, the following examples are of interest.

EXAMPLE 43.6

In 1974, during a violent electrical storm at Port Lincoln in South Australia a 60 m high mast was struck by lightning and one of the top guy ropes broke away from the anchor block. The top section bent over at the second guy level and hung almost vertically until subsequently cut away.

The triangular structure with solid galvanised steel legs and welded cross members was guyed at four levels with the guy ropes being broken up with star type strain porcelain insulators. Its primary purpose was to support a vertical whip antenna connected by a plastic covered coaxial cable to a transceiver located near the base. The station was used as a base for radio communication with the local fishing fleet. The base of the structure had been connected by a galvanised wire cable to three star stakes when it had been erected but at the time of the incident the wire cable had corroded through at the lug point

Figure 43.17 Damage to structure following failure of guy

Figure 43.18 Damaged dipole termination

on the mast as a result of the action of salt and was no longer an effective earth The outer shield of the coaxial feeder cable was connected to the mast at the antenna but remained insulated to the transmitter point.

A fisherman on board his boat in the harbour about 150 m from the mast witnessed the incident. He said that lightning struck the whip antenna with a blinding jagged flash. The flash proceeded down the antenna support pole and then down one of the top guys jumping over the insulators. When it reached the ground he noticed that an area about 5 m in diameter around the anchor block glowed with an intense light for several seconds. Steam vapours appeared to rise from the spot. The guy rope melted at the point of contact with the anchor lug during the discharge and broke away. It moved towards the base of the mast causing the top section to be displaced and finally bend over to an angle of about 160 degrees. The extent of the damage can be seen in *Figure 43.17*. The wind velocity at the time was estimated to have been about 25 km/h.

EXAMPLE 43.7

In 1971 a direct lightning stroke to one of two 22 m triangular steel towers supporting a 45 m single wire T type antenna of a 10 kW broadcasting station at Naracoorte, South Australia, resulted in failure of the antenna.

The antenna was erected as a standby for the main radiating antenna which comprised two 125 m high lattice steel masts giving a directional radiation pattern. The standby antenna was located at a distance of 113 m from the nearest mast of the main system and was therefore outside its cone of protection zone.

The seven strand copper wire dipole antenna was terminated at each end by three 100 mm porcelain break-up insulators in series. Evidence indicated that the lightning surge passed from the top of the tower across the steel pulley wheel and counterweight rope and then across the three nearby break-up insulators before going to ground via the down conductor and matching unit. The heat generated by the discharge fused the steel counterweight rope, caused the first insulator to disintegrate and the other two to be shattered. That end of the antenna wire fell to the ground together with the counterweight rope. *Figure 43.18* shows the damage to two of the insulators.

Collision Damage

Damage to radio structures has shown a rise in recent years as a result of increased air traffic particularly with low flying military aircraft on exercises and small charter services. Contact between aircraft and structure in many instances has ended in disaster for the aircraft and crew but many of the structures have received only minor damage. One mast in Finland was struck on two occasions by low flying aircraft and on both occasions only relatively minor damage was done to the steel work. In 1973 a low flying aircraft collided with a mast at Caradon Hill in Cornwall and the only damage to the structure was to the steel guy rope and its attachment plates. In 1977 a guy rope of a 300 m mast at Caldbeck, Cumbria, was partly severed when a jet fighter hit the guy. The aircraft had passed between the mast column and a 5.4 cm diameter guy rope at about 183 m above ground and severed about half of the 169 strands of the rope. Although the rope cut off about 1.2 m of the wing tip, the pilot was able to land the aircraft.

Probably the most amazing collision incident occurred in 1918 when a seaplane crashed into a 100 m high mast at a Naval wireless station in England. The engine became firmly wedged into the interstices of the girders so that the plane stuck out at right angles to the mast. Men were working on the mast at the time. The pilot was injured but was safely lowered to the ground by the workman.

Patterns from these and other examples indicate that if the guy ropes of a mast remain intact then the mast will most likely remain *in situ*. However, very few self-supporting towers have escaped major damage following aircraft impact.

EXAMPLE 43.8

About midday on 3 September 1973 during a period when a microwave radiocommunications mast at Finland, Minnesota, was shrouded in fog a light aircraft crashed into the guy ropes of a 107 m mast.

The two occupants of the aircraft were killed and the mast bent over at the 11 m level with part of the upper section falling to ground so that the whole structure took on the shape of a large capital R. Broken guy ropes struck the guys of another nearby mast putting it off plumb but not out of operation. Extremely bad weather conditions prevailed during the service restoration activities but full restoration was completed in 4 days.

Explosion Damage

Damage to structures caused by deliberate explosion has been of concern to security people for many years. Damage to dishes, insulators and waveguides by gunshot is difficult to control in design but at least some measures are available to minimise access to the base of a structure by vandals and others intent on causing on explosion. However, 100% protection is not practicable particularly at remote unstaffed sites.

EXAMPLE 43.9

On 14 February 1974 during darkness, an explosive device, deliberately activated, caused considerable damage to a 700 m mast at Brest, Roc Tredudon in Brittany, France. The structure folded at the 60 m level and damaged the equipment building near the base. The mast supported antennas for television and v.h.f. sound broadcasting services and radiocommunication parabolic antennas. The station was an important master station for a network of rebroadcast transmitters and also a relay station carrying international traffic between Paris and the earth station at Pleumeur-Bodou.

Reaction caused by the explosion broke the upper guy ropes and although the top part collapsed the lower reinforced section which was self supporting received very little damage. This section accommodated the radiocommunication antennas and although the antennas were not seriously damaged, the waveguides were destroyed by falling debris. Temporary guys were attached to the upright section to make it safe. Collapse of the roof of the building damaged a 10 kW transmitter beyond repair.

The action deprived about a million people of the television and broadcast programmes and it was estimated at the time that it would take a full year to complete the erection of a new mast and install new antennas, feeders waveguides and equipment. Within three weeks of the incident about 60% of the viewers had been provided with at least one television programme by means of temporary and re-arranged services.

Snow Load Failure

EXAMPLE 43.10

One of the highest structures in Great Britain, a 386 m cylindrical television mast at Emley Moor, Yorkshire, collapsed on 19 March 1969 during a period of very low temperature and little wind. It was considered that ice almost certainly played a major part in the collapse. The failure was preceded by a period of freak weather with still air for several weeks.

The structure which was erected three years prior to the collapse was the first of a new type of cylindrical design that constituted a significant departure from the conventional lattice steel structural form. Although not the first of the new type—others had been built in central Europe and United States of America—it was the highest of its kind. The new type of structure resulted in a bonus of accessibility from inside in all weather conditions, greater freedom in choice and layout of cabling and waveguides and also it allowed the installation of a lift to the antenna access point.

Television antennas were mounted above a 272 m support cylinder. This support cylinder which was 2.74 m in diameter was fabricated from high yield steel comprising some 900 quarter segments of 11 mm to 6 mm thick steel in 3 m lengths, welded internally on the vertical and horizontal flanges. The antennas were supported on triangular steel lattice structures of 2 m face for the first section and 1.3 m face for the second section. For complete weatherproofing, the lattice steelwork and antennas were encased in a 3.65 m diameter fibre glass shell to the 334 m level and 2.74 m diameter similar shell to the 378 m level. At the very top, a 7.6 m section housing aircraft obstruction lights and lightning conductors protruded above the top guy level.

Where the structure changed from cylindrical shell to the lattice form special consideration was given to the problem of reduction in stiffness. This reduction could not be too pronounced otherwise effective control could not be achieved by the guy ropes on the upper spans. The configuration finally evolved resulted in a compromise between that required for optimum performance of the antenna systems and the proportions needed to maintain the required stability of the

Figure 43.19 Base segment and superstructure after collapse of structure (Courtesy Construction News)

structure. In order to satisfy electrical requirements of the antenna system, the deflection of the top of the structure was limited to $\frac{1}{2}$% of the full height under maximum wind conditions. Also, the average slope of the antenna aperture was limited to $\frac{1}{2}$ degree under half maximum design wind loading conditions.

The need to provide a large number of cables, feeders and waveguides to equipment mounted on the structure influenced the type of base. The 2.74 m diameter cylinder was mounted on a reinforced concrete superstructure. This superstructure was designed to cater for the worst possible combinations of bending and thrust. It incorporated large openings of sufficient dimensions to cater for cabling and waveguide installation as well as for general access purposes. *Figure 43.19* shows the superstructure after collapse of the mast. Over 300 tonnes of concrete and 30 tonnes of steel reinforcement went into the mast base raft and superstructure. The base segment which remained in position after collapse of the cylinder was fixed on to the superstructure by 18 large holding down bolts.

The structure was guyed as an 18 point system with 6 levels of guys at 120 degrees spacing. The levels of guy attachments on the lattice sections were dictated by the antenna apertures, whilst the lower guys were spaced according to certain empirical *l/b* ratios. Fully locked coil rope was used for the guys rather than strand or spiral types because of its superior weatherproof properties and high strength.

The largest guy rope was 62 mm diameter with a breaking load of about 340 tonnes. A guide to stresses in still air is given by the fact that the three guys at the 333 m level each had a landing tension of about 15 tonnes. Together, they weighed 30 tonnes.

Anchor blocks for the guys were constructed of mass concrete to resist the uplift component from the guys and designed with a factor of safety of two.

Figure 43.20 Anchor block guy attachment (Courtesy Construction News)

Figure 43.21 Damaged cables and waveguides (Courtesy Construction News)

Figure 43.22 Buildings damaged by falling steel and guy ropes (Courtesy Construction News)

Two guys were connected to all anchor blocks which were located at distances of 106 m, 209 m and 290 m from the base of the structure. *Figure 43.20* shows the two guy attachments connected to one of the blocks.

When the structure collapsed, debris was spread over a wide area extending beyond 180 m from the base. Only the base segment stub on the concrete superstructure was left standing. A 23 m section at the top guy point was sprung furthest out when tension in the guys was suddenly released. It was about 100 m clear of all other steel sections and is shown in the background in *Figure 43.19.*

Fibre glass sections scattered over the snow were lying among twisted cables, waveguide sections and shattered antennas. Some of the twisted and broken cables and waveguide pieces can be seen in *Figure 43.21.* The falling steelwork caused a large displacement of the soft ground.

The tall steel cylinder broke up into many sections, the largest of which was about 18 m in length. It was ripped apart by opposing stay tensions and ground impact forces. Some adjacent sections landed at opposite ends of the field. Various buildings on the site were damaged, some considerably. Two of the damaged buildings can be seen in *Figure 43.22.* Some of the mast pieces fell outside the site area and blocked a main road, and guy wires sliced through the roof of a nearby church. Staff who were carrying out maintenance work in the microwave radio equipment building, some 29 m from the base of the mast, at the time of the collapse were lucky not to be injured. One whipping guy rope lashed over the snow covered roof of the building causing it to crack and allowing water to seep in over the radio equipment.

The precise cause of the failure has not been made public, but the effect of heavy ice on the structure and guy ropes is considered by some observers to have been a major contributory factor. Only hours after the collapse, there were local fears that an identical structure situated at Belmont, Lincolnshire, would suffer the same fate. An inspection showed that icing of two of the three guys at one level had pulled the top 54 m of the mast 53 cm out of plumb. On the following night one guy shed its ice, reducing the list to 25 cm. Early the following afternoon, the third guy shed its load and the mast returned to normal. Engineers watching the process reported that as the ice load fell away, the mast sprang quickly back to position, apparently with no ill effects[5].

Another point of interest with the collapsed mast is that during the afternoon of 19 March the microwave link from the local network switching centre to the site became noisy. The antenna for the microwave link was mounted on the structure and waveguide pressure was lost. The indications were that the waveguide had been damaged, that moisture had penetrated and possibly that the antenna had been damaged. Late in the afternoon, technical staff members examined the mast, which was heavily iced and it was decided that ascent would be too dangerous. The staff were still on site when the structure collapsed with an explosive roar at 1703 hours.

It is of interest that the structure built to replace the one that collapsed is a self-supporting type constructed of reinforced concrete. It weighs about 16 000 tonnes, is 24 m in diameter at the base and tapers approximately exponentially to 6 m diameter at the 274.5 m level. A room built at this level is equipped as a microwave link station for outside broadcast use. Above this a 30.5 m high, 3.6 m diameter fibre glass cylinder is supported on a steel lattice structure for housing v.h.f. antennas. Above this section another similarly supported fibre glass cylinder 1.5 m in diameter and 24 m high contains u.h.f. antennas bringing the total height to 330 m.

Land Movement Failure

The most frequently encountered damage to structures resulting from land or soil movement has been caused by wind, rain and earthquake.

(a) Wind.

In a desert or semi-desert environment subjected to wind blow drifts, foundations of equipment buildings and structures are frequently eroded and unless quick action is taken severe damage or even total collapse can occur.

A good design will not allow for an uplift advantage as a result of soil cohesion or by undercutting in situations where the soil is likely to be removed by wind action. The problem is to prevent soil under the foundation block from being removed. In some areas it has been necessary to erect a strong high wall around the mast and building in order to prevent sand drifts from building up against the equipment hut, removing sand from the tower base or from building foundations.

Figure 43.23 Equipment building collapse following erosion of foundations

Figure 43.23 shows the extent of erosion at one radiocommunications equipment building. The equipment building inside the sun shelter collapsed. The buildings were subsequently repaired and the sand replaced. *Figure 43.24* shows how the area was restored and a bitumenised iron fence erected to prevent erosion.

(b) Rain.

Rain on a loose sand base will also be a problem, not so much by removal of the soil but by the reduced loading capability.

Figure 43.24 Protective fence to prevent erosion

EXAMPLE 43.11

In September 1970, a 168 m mast was erected at Loxton, South Australia, for television purposes. The structure rested on a sand dune consisting of near horizontal successions of limestones, silts, clays and sands covered with fine grained wind blown sands of recent age. The surface sands were of the collapsing type which tended to settle under their own weight when inundated with water. There was a history of building structural failure throughout the district which could be directly attributed to the phenomena.

In November 1970, station staff reported annular cracks in the soil around the mast base. Measurements indicated a drop in the original guy tension levels and movement of the thrust block. The Contractor subsequently inspected the structure and retensioned the guys.

Following measurements of further subsidence a soil specialist firm was engaged to investigate and recommend remedial action. The report indicated that if the soil around the mast base could be maintained in a dry condition, the soil would be capable of supporting the load imposed by the structure and thrust block.

Plans were prepared for paving, sealing and draining the area to a radius of about 9 m around the base so that the large volume of water which ran off the structure during rain was diverted well clear of the thrust block. The work was completed and the guys retensioned in February 1973 using measuring equipment shown in *Figure 43.25*. However, the thrust block subsided some 61 mm by July 1975 making a total subsidence of 225 mm since the structure was erected.

The radius of the sealed area was then extended to 12 m and the edge of the membrane extended down vertically for 2 m. The guys were then retensioned to the recommended values. Measurements taken two years after this additional

Figure 43.25 Equipment used to measure guy tension

work indicated that no further vertical displacement had taken place.

(c) Earthquake.

Ideally there should be no interruption to broadcasting and radiocummunication services in the event of an earthquake. Collapse of the structure could result following landslide, debris falling onto guy ropes and severe vibration causing displacement of the pivot on a sectionalised mast.

An earthquake is likely to cause greater stress in a rigid tower than the more flexible guyed mast of the same height. The vibration characteristics resulting from the earthquake may cause more stress than a gale force wind. An intense earthquake constitutes the most severe loading to which a stress structure might be loaded, yet the probability that any given structure in a network will ever be directly affected by a major earthquake is in many countries extremely low.

When the structure is mounted on top of a multi-storey building the combination of ground-building-tower form a structural unit which will significantly affect each other. In co-ordinating the design of the building and the tower it is essential that the natural period of the building in relation to the tower be taken into consideration together with the ground conditions. The tower should never be designed in isolation and experience has shown that tall towers should not be constructed on low buildings or on those which are built on piles.

The intensity of earthquake loading on a structure depends considerably on the properties of the structure. To minimise damage, the strength may be

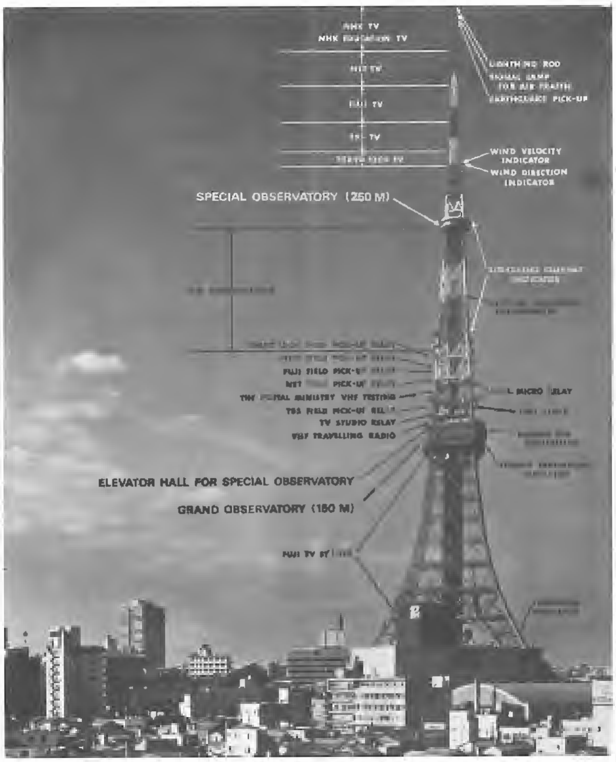

Figure 43.26 Tokyo tower (Courtesy Embassy of Japan)

increased or the stiffness may be reduced. This latter action will reduce the forces to be resisted. However, to arrive at the correct solution for a particular problem is not easy. The response to earthquake ground motion of a structure of height generally used in broadcast and radiocommunication engineering is a complex, dynamic phenomenon. Design criteria recommended in various Codes do not in themselves assure a structure adequate to resist the affects of earthquake ground motion. However, if properly applied they are reasonable and adequate to resist most major earthquakes. This is supported by experience gained following the performance of structures subjected to the earthquake in Alaska in 1964.

The 332 m Tokyo tower, shown in *Figure 43.26*, is an interesting example of a tower designed to take into account earthquake conditions. It is the tallest self-supporting lattice steel type structure in the world. It caters for five television transmissions, frequency modulation broadcasting, v.h.f., microwave and miscellaneous services. It also houses much scientific apparatus including earthquake and lightning indicators, altitude classified thermometer and wind speed indicators. The four thrust blocks at each mast leg weigh about 4000 tonnes and the four corners are linked to each other with 20 five cm diameter steel rods to maintain stability during earthquake conditions. Each thrust block is mounted on eight piles sunk deep into the earth. The tower has already withstood a typhoon of 190 km/h with the top deflecting only 82 m compared with an expected 102 cm.

Re-use of Damaged Material

EXAMPLE 43.12

In 1971 a radiocommunication system to provide for control and maintenance of a gas pipeline was installed between a gasfield and the control centre some 770 km distant. The system provided point-to-point and mobile coverage along the route of the pipeline.

During the erection of a 46 m tower for the support of two Yagi antennas associated with one of the mobile radio base stations, the structure was damaged by incorrect erection procedure. The damaged member was straightened on site using local facilities. A short time after erection, the structure collapsed. No one was at the site at the time but there were no reports of strong winds in the area. *Figure 43.27* shows the extent of the damage.

The three sided tower was made up in 3 m welded sections with 40 mm steel tubular legs, 33 mm tubular steel horizontal bracing and 10 mm solid rod cross members. The structure tapered from 3.27 m at the base to 15 cm at the top. Calculations indicated that the structure was adequate to support the Yagi antennas in winds up to 144 km/h.

Figure 43.27 Damaged base station tower

The designer had intended that the structure be erected by assembling the first 18 m on the ground and lifting it into position with a falling jury. The remaining sections were to be built one on top of the other using a jury mast.

However, the erection crew assembled the complete structure on the ground and attempted to lift it into position using a 25 tonne mobile crane. The lifting ropes were attached at about the 21 m level leaving the top 25 m free to whip. Two of the legs were hinged to the foundation steel work.

When the tower was almost upright with the free leg about one metre off the pad the tower suddenly dropped on to the concrete foundation block causing the structure to whip and vibrate violently and as a result one leg member was bent. The tower was lowered to the ground the bent leg member straightened with a sledge hammer and dolly and re-erected in a similar manner as before but with a little more care. A guy rope was taken out from near the position of the slings and attached to a truck which controlled the movement of the structure during the final positioning on the foundation. The tower was then painted for aircraft warning purposes.

Use of Incorrect Size of Material

EXAMPLE 43.13

On 26 March, 1978, a 92 m guyed mast supporting six UHF parabolic antennas at Mt Edith, New South Wales, collapsed during high winds causing extensive damage to the equipment building. The structure which was guyed at eighteen points collapsed as a result of six guy ropes pulling through the guy grips which were of the incorrect size for the particular guy rope being employed. The wind speed was recorded at 140 km/h at the time.

The guy grips fitted to the ropes were of the type which is preformed during manufacture. They are made so that the inner diameter of the grip is slightly less than the outer diameter of the guy rope. The grip therefore is clamped to the guy rope by inherent spring tension. Any axial force tending to separate the grip from the rope induces it to grip tighter.

However, should the diameter of the grip not be less than the diameter of the rope, the grip, as would be the case for an oversize model, would simply act as a pipe through which the rope could be pulled.

Subsequent tests showed that the grips were 1.2 mm oversize and on test in a tensiometer one of the grips which did not fail began initial slip at 55 kN and continued at 9 kN. The breaking strain of the guy rope was 96 kN. When one of the grips was fitted to a rope of recommended size for the particular grip it failed at 120 kN which was equal to the specified breaking strain of the rope.

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Chapter 44

Environmental Obligations in Mast and Tower Design

QUALITY OF THE ENVIRONMENT

Until recent years the expansion of private and public radiocommunication, broadcasting and television services was carried out with very little regard for their effect on the local environment, this effect being regarded as the price to be paid for progress. The environmental costs of development were borne by the whole community rather than specifically by the project.

However, in some countries many large scale construction works stimulated a growing realisation that the impact of development and expansion were too high and environmental protection emerged as an objective to be considered along with the economic, technical and particularly aesthetic considerations.

A feature of all aesthetic considerations is that the opinion of the individual plays a dominant role. What is ugly to one person might pass quite unnoticed or may even be pleasing to another. What effect a pleasant, uncluttered visual environment has on the quality of life of those living in that environment is hard to assess because many other factors, such as affluence, educational background etc., often affect attitudes. Changes in visual environment can cause annoyance and may even produce anxiety and irritability, but it is very difficult to assess quantitatively the impact on a person of the loss of a view from a window, the cutting down of a grove of trees or the erection of a nearby massive lattice steel structure. That such occurrences do affect some people is quite evident and visual and aesthetic factors are of importance in determining the quality of life. It is unfortunate that they have often been ignored owing to the difficulties in measuring their contribution to the quality of the environment. There is a clear responsibility on individuals and organisations to include aesthetic considerations in all aspects of the radio engineering design phase, particularly in the external works such as masts and towers and other structures associated with antenna systems. By careful forethought and planning most developments can be environmentally acceptable. An environment impact assessment process provides a framework for ensuring that all factors are included in reaching decisions about projects and that the fullest consideration has been taken of all aspects of the quality of the environment.

THE DESIGNER'S RESPONSIBILITY

Environmental improvements in radio engineering are most readily discernible to the general public in the design of structures to support broadcasting, television and radiocommunication antenna systems. A new awareness of environmental problems has developed in society and movements are active for the preservation of things as they are. Environmentalists are paying increasing attention to radio structures which they consider to be an abuse on the environment, although in many cases they recognise their necessity.

It is important that individuals, groups and organisations be given the opportunity to discuss proposals and to influence the decision. This means that they need access to information about the proposal and the opportunity and means of participating at a time when they can influence the outcome. The earlier in a project's life that public involvement is sought and listened to, the more likely it is that the contribution will be positive, of value to the proponent and that concensus will emerge. Polarised entrenchment of views is the frequent result of seeking public comment too late, after many options have been foreclosed.

In the past, economic and technical considerations dominated the design and location of structures for radio purposes. Tower height was governed by wavelength considerations in the case of broadcasting antenna structures, by height to meet Freznel zone parameters on path obstructions for microwave antenna structures and by height to give maximum line-of-sight coverage for television, frequency modulation or radio mobile services. For link repeaters through mountainous terrain, the highest accessible peaks were sought to reduce the

Figure 44.1 Base insulated broadcast antenna on city building

number of repeater stations in the system. At the terminal, particularly where it was located in a large city, the designer was frequently required to provide tall structures in order to overcome path problems introduced by multistorey buildings. The use of tall city buildings to mount broadcast radiators declined rapidly after about 1940 although there are still many in service today, kept in a standby mode in the event of failure of the remote transmitter or the interconnecting programme line. One such structure is shown in *Figure 44.1.* In addition to a broadcast role, they are ideal points at which to locate mobile radio terminals.

Increasing height of city buildings, electrical noise, corrosion influence and other factors have in recent times led to the use of coaxial cable feeds into the city communications centre from a broadband radio terminal sited at the perimeter of the city.

These peripheral points are frequently in the midst of, or in view of, residential areas, and large heavily loaded structures have a marked impact on the surrounding physical enviroment. The most frequent complaints are:

(a) Production of ghosting on local television reception.
(b) Destruction of the scenic quality of the environment because of the shape and physical dimension of the structure.
(c) Fear of direct lightning strokes in the immediate vicinity.
(d) Fear of the collapse of the structure or falling antenna dishes during high winds.
(e) Humming noise caused by high wind passing between lattice steel members.
(f) Falling debris, components and paint during construction and maintenance.
(g) Fear of aircraft collision.
(h) Psychological pressure resulting from the sheer size and mass of the structure.
(i) Casting of shadows on nearby houses.

In recent years engineers have seen the enactment of legislation requiring Environmental Notice of Intent and Environmental Impact Statements. They are rapidly adjusting themselves to a changed role by transferring themselves from a somewhat isolated situation to a much broader one, in which they are part of, and in the case of project consultants, often take a leading co-ordinating role in, multi-discipline studies, This ensures the full inclusion of all environmental aspects from the outset. The fact that the proponent of the project, rather than a government administrating body, undertakes the environmental evaluations not only enhances the developer's appreciation of, and competence in, environmental matters, but also enables proper integration of environmental factors within the planning, design and costing of the project, rather than as something which is merely tacked at the end as a palliative.

Mast and tower designers have always taken into consideration environmental factors and their effects on the erection and maintenance of the structure. What has been added in recent years is the reverse need to consider the effects of the structure on the environment. The engineer must now include in-depth environmental studies as a new dimension to the more traditional project planning than has been done in the past. A greater range of alternatives has to be taken into consideration and each examined in relation to the interaction with the environment in addition to cost/benefit aspects. However, methods employed in the assessment of benefits and costs to the environment are not clearly defined and are frequently a matter of value judgment.

The quantification of environmental values is no simple task and values may differ widely if emotional issues arise as a result of public interest in a project. Some progress has, however, been made in some areas and methods are now available by which construction environmental impacts can be quantified with a minimum of subjective interpretation. This involves the use of weighting factors.

There is a wide range of forms of construction for support of radio external plant facilities but economics, the site, and environmental considerations have an important influence on the type chosen for the facility. Types in common use include:

(a) Self supporting towers.
    Lattice steel towers of triangular cross section constructed
    of tubular or L-section members.
    Lattice steel masts of square cross section constructed of
    tubular or L-section members.
    Tubular steel towers
    Reinforced concrete towers
(b) Guyed masts.
    Lattice steel masts of triangular cross section constructed
    of tubular or L-section members.
    Lattice steel masts of square cross section constructed of
    tubular or L-section members.
    Tubular steel masts.

In addition to these basic types there are variations with mixed forms of construction. A self supporting reinforced concrete tower supporting a lattice or tubular steel mast – guyed or self supporting – is a widely used approach. Concrete towers and large diameter tubular steel structures have the advantage of protection for interior installations and also enabling ready access to the antennas during most wet weather conditions.

The inclusion of environmental factors in the conceptual development of a proposal derives in part from the adaptation of the principle that the polluter pays. In this way the developer, rather than the wider community, bears the environmental cost of a project. By evaluating these costs from the outset, the designer can take the necessary steps to minimise them in the proposal. Generally it is far less expensive to prevent or minimise adverse impacts occurring in the first instance than to alter them after they have been installed.

In developing his proposal, the designer has to take care in siting the facilities to ensure that the minimum environmental and ecological disturbances and adverse visual effects are produced. In the case of antennas and structures this is not easy and may require the examination of several alternatives. The following guidelines are appropriate:

(a) Likely environmental, ecological and aesthetic problems should be thoroughly examined.
(b) Co-ordination of the needs of other users of similar radio engineering facilities in the particular area should be carried out in order to minimise the spread of facilities over hills and mountain tops in the area.
(c) Antenna support structure should be kept as simple as possible.
(d) Wherever possible antennas should be mounted on a common structure and shared between facilities.

(e) Wherever possible buildings should be shared between facilities and kept as inconspicuous as possible.
(f) Clearing for facilities and power lines should be kept to a minimum.

AESTHETIC CONSIDERATIONS

Structures required for radio engineering purposes are invariably of great height and consequently because of their prominence are subjected to critical public appraisal. Their numbers are growing to such an extent that in many heavily populated areas it is extremely difficult to find a vantage point from which some structure cannot be seen. This situation has been brought about by the demand for communications and services utilising radio techniques and the requirements are such that the most acceptable sites for transmission or reception are high, and above the immediate surroundings.

It is not unusual for a public outcry to occur when a new structure is proposed, or appears in a built-up area. Vigorous protests may appear in the newspapers, public protest meetings may be held or deputations may call on the owners of the structure. Typical of protests is the letter signed by 300 people of Paris when the Eiffel Tower agreement was signed in 1877. The signatures included many influential and famous people of the time, but history showed their fears to be unfounded. From Rene Poirier, (1) part of the letter forwarded to the Director of Works of the Paris Exhibition and all Paris newspapers reads:

> 'Sir,
>
> We, the undersigned, writers, painters, sculptors, architects, lovers of the beauty of Paris, which so far has remained intact, write to express our indignant protest, in the name of taste, and the threat to the art and history of France, against the erection in the heart of our capital of the useless and monstrous Eiffel Tower which public malice, so often expressive of common sense and fairness, has already christened the 'Tower of Babel'.
>
> ....Does the city of Paris intend to be associated any longer with the ideas of a machine-builder, which can only lead to irreparable ugliness and disgrace ? For there is no doubt that the Eiffel Tower, which even America, commercial minded as it is, would refuse to have, is the disgrace of Paris. Everyone says so, everyone is deeply distressed, and we can only echo feebly the legitimate alarm that is universally felt. Lastly, when foreigners come to see our Exhibition, they will cry in astonishment, 'Did the French build this horrible thing to give us an impression of the taste of which they are so proud?' Their laughter will be justified, for Paris with its sublime Gothic buildings, the Paris of Jean Gourjon, Germain Pilan, Puget, Rude and Barye, will have become the Paris of Monsieur Eiffel.
>
> In order to realise the implications of what we say, it is only necessary to imagine for one moment this absurd building towering over Paris from a dizzy height like a giant black factory chimney, its barbarous mass dwarfing and humiliating Notre Dame, the Sainte Chapelle, the Tour Saint-Jacques, the Louvre, the Dome of the Invalides, the Arc de Triomphe, and all our buildings which will disappear beneath this astounding conception. And for twenty years this revolting column of bolted iron will hang like an ever-widening blot

> of ink over our entire city, which is still alive with the genius of so many centuries.
>
> ...And if our cry of alarm is not heard, if our reasons are not listened to, if Paris obstinately insists on bringing dishonour to Paris, at least we will all of us have uttered an honourable protest.
>
> Signed................................... '.

Most of the three hundred names are forgotten nowadays and the Eiffel Tower still stands today like an inscription which without malice, has retained only their memory. *Figure 44.2* shows a night time view of the Tower.

Figure 44.2 The Eiffel Tower (Courtesy Syndication International)

Because the cost of a structure increases rapidly with increasing height, tall structures can be costly items of plant. As the designer's objective is often to produce the most economical structure which will meet the technical requirements, he may be reluctant to voluntarily improve appearance, if this involves a reduction in its technical performance or substantially adds to cost.

All engineering structures are products of utility. The prime design consideration is that they will function correctly and be constructed adequately and soundly enough to go on functioning for the extent of their planned life. A mast or tower is expected above everything else to provide a rigid dependable support with service tolerances within defined limits. However well it may harmonise with the background, it would in many cases be of no technical value at all, if it failed to meet the prime requirements of satisfactory structural and electrical function. Nevertheless, because of the prominence of many structures against the skyline, and the need for an aesthetically pleasing appearance has to be recognised and should be considered as part of the basic design problem and not divorced from it. Forms which do not indicate their function and purpose clearly, usually do not fulfil them very well, and forms disguised as, or even looking like, other things are at a disadvantage perceptually.

Radio structures constitute an essential factor of the urban scene. Accordingly, a social duty is imposed on the designer of structures required in built-up areas, to design them with an active consideration for their aesthetic value to the urban landscape. He has a duty to design in such a way as to combine economy, naturally a requisite for public communications and broadcast facilities, and the artistic beauty desirable in what has become a day to day symbol of present day urban society.

In many cases, such as microwave relay, television and frequency modulation services, it is often not the antenna which is publicly criticised but rather the massive structure required to support it. The antenna proper is in many instances hardly visible from a distance. However, very large spun dishes or horns can have a disastrous affect on the appearance of a lattice steel structure. Stepped outline towers and stalk like type structures have been effective in providing an acceptable solution for dishes and horns. Special painting arrangements have also been used to advantage. The application of vertical columns of a darker colour paint than the other components has the effect of emphasising the verticality of the structure.

In order to overcome some of the objections to the appearance of lattice steel structures, and also for several other reasons, many structures have been erected which take on the appearance of a slender column or building. In addition to meeting the requirements for antenna systems they provide accommodation for equipment, staff and in some cases public revolving restaurants. Typical are the Post Office Tower London, *Figure 44.3,* the Telecommunications Tower Stockholm and the Communications Tower Ostankino.

Some antenna systems, such as tropospheric scatter antennas *Figure 44.4* do not lend themselves to erection on buildings or to concealment in bushland because of their size and shape, and also because of their critical path clearance requirements in the forward beam direction. Radar antennas also come in this category. At some locations it is necessary to cover the plant from rain, snow etc., and large plastic randomes have been used. With proper design considerations these in most instances present an acceptable appearance.

It is unfortunate that there have been many buildings erected under architect design, while radio structures mounted on the roof have been designed by engineers who have considered technical requirements only. However, since roof top structures have gained social acceptance it is now becoming general practice for the towers to be designed from both the aesthetic and structural engineering points of view.

In design, the aesthetic factor implies that the completed structure should be harmonious with its enviroment and generally pleasing to the eye. The requirements of aesthetics and economics are not always completely incompatible and minor changes – changes within the limits of economic and safe design – are

Figure 44.3 Post Office Tower, London (Courtesy British High Commission)

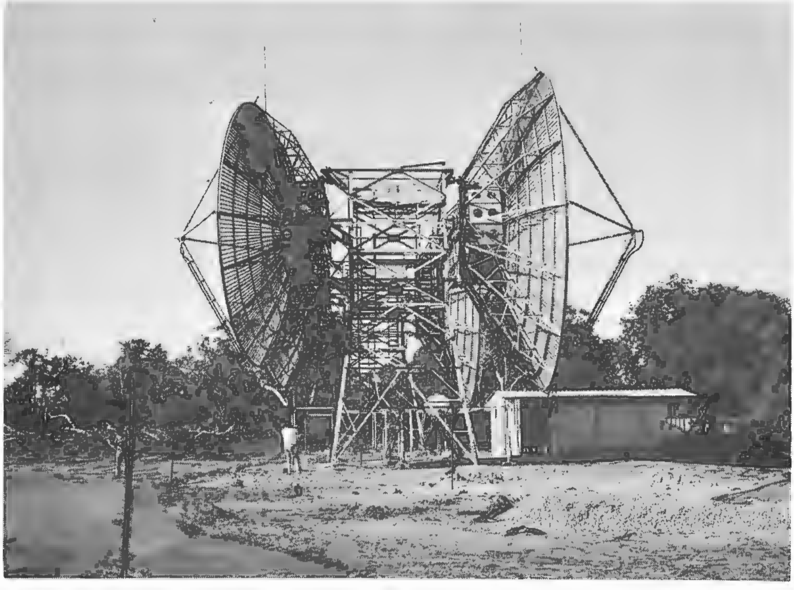

Figure 44.4 Tropospheric scatter repeater antenna system

Figuer 44.5 Roof top antenna and support structures

often all that are needed to improve aesthetic values. *Figure 44.5* shows one building used as a Police Communications Centre where the requirements for high frequency and very high frequency antennas were taken into consideration during the design of the building.

A leading architect, discussing this matter some years ago, commented that any structure that is aesthetically pleasing and satisfactory always builds well and is economical. Conversely, any structure which is economically planned should possess the basic elements of a pleasing design. In short, if both the architectural and engineering approaches to design were perfected processes, the form arrived at through the scientific engineering procedure would be about the same as that which the skilled and experienced structural artist would achieve.

To possess true beauty, a design must be perfectly adapted to the service it is to perform and must utilise the materials involved in the most effective manner. Horns and the dish type antennas, in particular, offer interesting and sculptural shapes and the acceptable design solution generally starts by setting out the essential features required to satisfy the function of the service and then utilising a simple outline. The process of design for the different structures may vary considerably but the end sought is the same. No structure can be aesthetically pleasing which does not possess in its general lines and form the outward and visible signs of its functional and structural soul. These aspects were evidently

Figure 44.6 Microwave antennas and structure on city building

taken into consideration during the design of the structure in *Figure 44.6*. It formed part of a microwave relay system interconnecting a network of remotely controlled power substations.

DESIGN TECHNIQUES

Environmental impact examinations seek to ensure the proper balance of environmental factors alongside the technical, economic and social factors involved. The process is one of optimising, i.e. seeking the best overall balance between competing considerations involved in any project. As an optimisation process, where environmental factors will be considered on a par with other issues, some environmenental costs are likely to be incurred, just as more onerous technical solutions may need to be found, or higher economic costs incurred to reduce other more serious environmental impacts.

A wide range of design techniques are available to meet environmental requirements but new techniques are being continually created because rules and regulations have tended to be more restrictive with the passage of time. The designer is under pressure to ensure that attractive economic solutions are found to resolve the problems presented. Heavy additional expenditure needed to resolve satisfactorily particular environmental parameters may require the adoption of an alternative engineering design or facility. For example, a submarine cable may be more attractive economically in providing high density telephone traffic between two large cities separated by a bay or gulf.

Environmental techniques which have been used on projects include the following:

(a) Use of Trees as Screens.
In cases where structures are erected on a prominent hill which has been cleared of trees years earlier for farming purposes, tall pine trees with a tapered outline similar to a tower can be effectively used to screen one or more towers. *Figure 44.7* shows this technique adapted to a 10 kW transmitting station with supporting towers being prominent against the skyline. In time, the pines will grow as tall as the towers and provide an effective camouflage.

Figure 44.7 Pine trees planted to screen two steel towers

(b) Use of Paint.
Most antenna support structures are fabricated from galvanised steel and do

not require painting for protection against corrosion except in some special situations. However, painting and also lighting is mandatory in some locations in order to comply with air transport regulations. In these circumstances, the colours are fixed by international agreement and because the colours and banding arrangements are such as to improve the visibility of the structure, there is very little that can be done to attempt to conceal or camouflage the structure. Where there is no restriction on the colour of the paint which can be applied, certain colour patterns can be very effective in overcoming aesthetic problems. Highlighting main vertical panels with dark colours can produce an effect reducing the mass and increasing the verticality. Special paints are available which give good camouflage effect but which introduce negligible loss in the radio system.

(c) Use of Combined Antennas.

Because of the shortage of suitable sites and also to cause minimum impact on the local environment there has been a trend towards consolidation of base stations for mobile systems. The same can also be said for television transmitting systems. In the case of base stations for mobiles, it is not uncommon for 10 to 20 bases to be installed on a common site with antennas sharing a single structure. However, there has been considerable public criticism of this approach where each transmitter uses an individual antenna, as it results in the tower or mast being festooned with a cluster of antennas.

Apart from the fact that many of the installations have bad aesthetic impacts they are most inefficient because of the lack of effective electrical isolation between systems. Each time a new base station and antenna are added, isolation between systems becomes increasingly more difficult.

This problem can be overcome by the design of a multiple antenna system which has the individual antennas electrically isolated but grouped on a single tapered tubular support column. The complete system appears as a slender aesthetically pleasing spire.

The use of common antenna systems with multicouplers is also widely used. Systems with multiple networks are in use at many sites. Although insertion losses are high, all, or a good portion of this loss, may be recovered with a high gain antenna. Quadrature hybrids can be successfully used to combine multiple transmitter outputs without interaction.

(d) Use of Low Height Antennas.

In many large cities antenna systems are necessary for various purposes such as links between television studio and transmitter, for trunk route terminations, power substation and pipe line remote control purposes etc. In some cases heights may be restricted because of local buildings codes but as long as any structure disturbs the skyline contour it is likely to be the subject of attention by environmentalists.

Most objection can be overcome by incorporating antenna decks within the building frame. For a large city terminal more than one deck may be required. In a good design the antenna decks are not only structurally, but also visually, part of the building. Where an existing building has to be adapted to accomodate an antenna on the roof top, the antenna should be kept as low as possible with sufficient height to just clear nearby walls and buildings and maintain path integrity. Additional height or antenna gain may be required at the distant end because of compromise at the city terminal.

An alternative is to mount the antenna on the wall of the building rather

Figure 44.8 Antenna mounted on wall of building

than on the roof as shown in *Figure 44.8.* Although this may satisfy the skyline effect it could result in other objections by environmentalists.

In some installations an existing room may be utilised with the dish occupying the window space. The problem with this is that the path direction is virtually fixed.

(e) Erection of Special Towers.

This concept has become popular in recent years and a great many different designs have been produced which have satisfied not all, but many, environmentalists. They are not usually identified as a communications structure, particularly if they contain office type accommodation or public restaurant facilities. A typical 700 m high tower costing about $6.0 million constructed to accommodate television frequency modulation, radio mobile services, radio paging, radiocommunication trunk line services and also for lookout and dining facilities for visitors with a fast lift service would generally be a viable project. Aesthetically, there is virtually little difference between a tower with a restaurant and one without. The extra cost of providing the restaurant is minimal when compared to the total cost involved and can be supported from an economic view point.

ENGINEERING PENALTIES

With the advance of environmental legislation, some engineers and administrations have expressed concern at the engineering penalties which have resulted. Typical examples of penalties encountered are as follows:

(a) Long delays occurred in obtaining approval to proceed and jeopardised commissioning timetables and added costs as a result of large amounts of capital being tied up with delivered material. In one tower project, erection work had to be stopped pending legal resolution.
(b) Building and other codes limited the height of structures on city buildings, in hills face zones and on mountain skylines resulting in a compromised design for a radiocommunication broadband system.
(c) Some mountain sites which were ideal from a radio engineering point of view were barred because they were in wildlife or public recreational areas. Alternative sites resulted in expensive access road works.
(d) Modifications to tower designs in order to satisfy aesthetic considerations resulted in additional costs. In one case additional lattice members resulted in the wind loading being greatly increased necessitating the elimination of a dish antenna from the system design.
(e) Restrictions in site availability because of environmental considerations required the insertion of an additional repeater, introduced path overshoot problems, introduced frequency co-ordination problems and resulted in insufficient Fresnel zone clearance in the path.
(f) The zoning of radiocommunication services to a single site resulted in a complicated frequency plan, interference and congestion on the structure with antennas.
(g) The zoning of broadcast services to a specific site caused high additional expenditure in the provision of special foundations for a 300 m mast due to the unsuitability of the soil for this type of facility.
(h) The need to retain a natural environmental effect on a hills face position required the excavation of a tunnel in order to accommodate the equipment of a radiocommunication terminal.
(i) Restrictions placed on the removal of timber and road building to a mountain top site for a television transmitter necessitated the provision of a cable car at great cost.

ENVIRONMENTAL IMPACT STATEMENT

Most governments require the submission of a narrative statement, usually referred to as an Environmental Impact Statement (EIS), before work commences on the construction of communication facilities which are likely to have a significant or controversial impact upon the environment. The Statement gives government and other environmental jurisdictional bodies as well as members of the public the opportunity to comment.

The EIS can be defined as a document which first defines the need for action and then describes the action or development proposed, the existing environment and the effects on this environment expected to result from the proposed action. Alternatives to the proposed action (including the alternative of doing nothing) and their likely environmental effects must be advanced and compared. Finally, measures proposed to protect the existing environment are described.

Confusion sometimes arises as to whether or not a proposed work is likely to have a significant or controversial impact upon the environment and it is usual therefore for a new project and proposal to be referred to the appropriate government department for a decision on the need for an EIS. Details of such proposals are usually forwarded in the form of a document known as a Notice of Intention. This document provides a brief preliminary summary, usually between two and ten typed pages, together with maps, plans and photographs of the details of the project. This includes information on the proposed site and surrounding region, the status of the project and a summary of any potential effect of the project on the environment, including any beneficial effects.

In order to ensure that adequate information is provided with the Notice of Intention typical guidelines include descriptions of the following:

(a) The general need for the proposal and the objectives it is intended to fulfil.
(b) The benefits of the proposal.
(c) Any alternative means of achieving the objectives and provide reasons for their rejection.
(d) Alternative locations for the proposal and provide reasons for their rejection.
(e) The existing environment, including land use (of location and surrounding area), vegetation, fauna, protected features, drainage patterns, zoning provisions, etc.
(f) Any likely effects of proposal on the environment, including effects on land form vegetation, fauna, drainage patterns, protected features, traffic and any emmissions (noise, heat, light, electromagnetic radiation, radioactivity, gases, liquids or solids) which may result. Include any adverse effects during construction, operation, emissions and activities associated with the proposal.
(g) Any monitoring, safeguards, standards or ameliorative measures for protection of the environment intended to be adopted or applied.
(h) Any effects that the proposal may have on the local community.
(i) Any actions that have been taken to involve the public in the planning and conceptual development of the proposal, to inform them of the proposal, and elicit comment from them.
(j) Any studies or investigations which are proceeding or intended to be made of the possible impact of the proposal on the environment.

Notices of Intention are not normally subject to public review but are closely examined by the government department responsible for the administration of environmental protection regulations.

The requirement to prepare an EIS obliges the proponent to study and take into account environmental factors from the earliest stages in the formulation of a new proposal. The preparation of an EIS also encourages a proponant to examine thoroughly, possible alternatives to the action proposed, to compare the relative environmental impacts of these alternatives, to assess any adverse environmental effects which cannot be avoided should the station facility be constructed and erected and the relationship between short term use of the environment and the enhancement of long term productivity. A proponent must also develop, where appropriate, environmental safeguards. Through their inclusion in an EIS, these safeguards including procedures and designs are subject to public scrutiny and criticism.

The preparation of an Environmental Impact Statement is properly an integral part of the project planning and design processes and consequently costs involved in the preparation of analyses and developing the Statement should be recognised as necessary and justifiable project costs.

Figure 44.9 Telecommunication tower, Black Mountain (Courtesy The Canberra Times)

The information contained in the EIS will depend upon the nature of the project but the following broad headings are typical when preparing a submission for a 200 m high concrete Communications Tower similar to *Figure 44.9* intended to cater for television, frequency modulation and radiocommunication services as well as a public restaurant:

Part A Background

(a) Brief Description of the Project.
(b) Present Status and Urgency of the Project.

(c) How the Project was Developed in Consultation with Other Bodies.
(d) Reason for the Location of the Tower on the Site Chosen.
(e) Description of the Actual Site.
(f) The Effect of the Project and Land Usage.
(g) Why Recreational Facilities for the People are Part of the Project.

Part B Environmental Impact

(a) Impact on Ecology.
(b) Visual Impact of the Tower.
(c) Criticisms Offered and Proponent Responses.

Part C Alternatives Considered

(a) Alternative Sites.
(b) Steel Tower as an Alternative to Concrete.
(c) Inclusion of Restaurant and Other Visitor Facilities.
(d) Closed Circuit Television as an Alternative.
(e) Communications Satellites as an Alternative.

Part D Attachments

(a) Coloured Photographs of Tower Model with Sectional Drawings.
(b) View from the City of the Mountain Top Site with Tower to Scale Superimposed.
(c) Silhouettes of Tower With and Without Restaurant.
(d) Diagrammatic Sketch Illustrating Visitor Facilities.
(e) Locality Plan of the City Showing the Site and Other Sites Examined.
(f) Aerial Photograph Showing Site Boundaries of the Various Activities on the Mountain.
(g) Site Plan Illustrating the Re-development of the Summit.
(h) List of Sites Around the City Examined for Feasibility.
(i) Sketch of the Overseas Towers Compared With the Proposed Tower.
(j) Financial Statement.

The government department or authority responsible for assessment and recommendations on the proposal bases its assessment upon the final EIS. It takes into account whether the project including its construction, operation and associated activities is likely to result in any possible:

(a) Impairment of the aesthetic, recreational, scientific or other qualities of the environment.
(b) Impairment of an area, feature or structure that has an aesthetic, architectural, cultural, scientific or historical significance or special value for present or future generations.
(c) Detrimental effects upon the present or potential use of land, including recreational, urban, industrial, agricultural or other land uses.
(d) Change or impairment of the qualities and characteristics of the human environment either locally or at individual or community level.
(e) Modification or change in the biophysical environment such as the emission of high power electromagnetic radiation.

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Chapter 45

Radio Frequency Spectrum Management

THE SPECTRUM AS A RESOURCE

The uses of the radio frequency spectrum are many, varied and dynamic. It is somewhat different from many other resources used by man, being characterised by the following:

(a) It is a resource that is used yet not consumed.
(b) It is a resource that is wasted when its full potential is not being exploited.
(c) It is an international resource available to all nations and all people.
(d) It has dimensions of space, time and frequency and all three are interrelated.
(e) It is subject to pollution and the utility of segments of the spectrum can be severely restricted by electrical noise.
(f) It is wasted when its parameters are not and correctly applied to the task.
(g) It is wasted when assigned to do tasks that can be done as easily in other ways.
(h) It is capable of assessment in monetary terms but unlike most resources it is also capable of being replanned for better use from time to time.

The most efficient sharing of the spectrum between users requires detailed rules, procedures and practices. The formulation and implementation of these rules is referred to as spectrum management. The International Telecommunication Union (ITU) which carries out this function on the global level allocates frequency bands for various categories of communications. Each nation which participates in ITU meetings is a party to fashioning the sharing rules and agrees to abide by them.

National plans for the use of the resource can be developed only within a framework of international agreement and this is the major reason why most nations participate in the World Administrative Radio Conferences held from time to time by the International Telecommunication Union.

Spectrum management is very much a problem in allocation and management and the situation is being complicated by the increasing number of different services requiring blocks of frequencies in the spectrum. Types of services currently in operation include the following:

Aeronautical radionavigation land station
Aeronautical radionavigation mobile station
Aeronautical fixed station
Broadcasting station, sound
Broadcasting station, television
Station open to official correspondence exclusively
Station open to public correspondence

Station open to limited public correspondence
Station open exclusively to correspondence of a private agency
Communication-satellite space station
Space telecommand space station
Space research space station
Space tracking space station
Meteorological-satellite space station
Radionavigation-satellite space station
Space telemetering space station
Experimental station
Aeronautical station
Base station
Coast station
Earth station (Earth-Space Service)
Land station
Port station
Receiving station only
Land station established solely for safety of life
Fixed station
Station on board a warship or naval craft
Radiolocation land station
Aircraft station
Space station
Land mobile station
Mobile station
Radiolocation mobile station
Ship station
Maritime radionavigation land station
Station open exclusively to operational traffic of the service concerned
Radio astronomy station
Non-directional radiobeacon
Directional radiobeacon
Maritime radionavigation mobile station
Revolving radiobeacon
Meteorological aids station
Communication-satellite earth station
Space telecommand earth station
Space research earth station
Space tracking earth station
Meteorological-satellite earth station
Radionavigation-satellite earth station
Space telemetering earth station
Television, sound channel
Television, vision channel

The spectrum's value for information dissemination and safety has long been recognised but its economic contributions have not been. Services compete for access to the limited number of frequencies available for allocation and there is a tendency for many designers to treat the spectrum like any other resource, to be combined in ways that minimise total costs.

PROGRESS IN INTERNATIONAL CONTROL

At first regarded purely as a radically advanced form of telegraphy, radio spread across the international scene, for the first time bringing ships at sea within the reach of telecommunications. It became clear with equal rapidity that international regulations were needed. One major problem was highlighted as early as 1902, when Prince Heinrich of Prussia, returning across the Atlantic from a visit to the United States, attempted to send a courtesy message to President Theodore Roosevelt, only to have it refused because the radio equipment on the ship was of a different type and nationality from that at the shore station. Partly as a result of this incident, the German Government called a preliminary radio conference in Berlin.

The conference met at Berlin on 4 August, 1903. The outcome of the conference was that all the representatives of the nine countries which participated, with the exception of Great Britain and Italy, agreed to certain proposals to be considered at a subsequent conference for the international regulation of wireless telegraphy. The British delegates had been instructed to maintain an attitude of reserve owing to the position in which wireless telegraphy was at that time placed in the United Kingdom, the fact being that in the then state of the law the Government had not that control over wireless telegraphy which would have enabled them to enforce the provisions of the Convention. The Wireless Telegraphy Act, which was passed in 1904 for two years only, and which was renewed in 1906 without modification, prohibited the installation or working of wireless telegraphy apparatus in the United Kingdom, on board British ships, without a licence from the Postmaster-General. Its principal objects were, by regulating wireless telegraphy, to make it more useful for purposes of defence and general communication. The memorandum which was laid before the House of Commons in explanation of the Bill stated that the necessity of legislation depended in the first place on the importance from the naval point of view of giving the Government control over wireless stations in time of war or emergency, and, secondly, on the desirability of placing the Government in the position to enter into an agreement on the subject with other countries if it should be found expedient to do so.

In October, 1906, a second conference was held in Berlin, and its primary objects may be classified under the following headings:

(a) The acceptance and transmission of telegrams.
(b) The adoption of rules of working.
(c) The provision of means of collecting charges and settling accounts between the different countries.
(d) Arrangements for the publication of all information necessary for intercommunication.
(e) Rules to prevent interference and confusion in working, with adequate provision for enforcement.
(f) Provision that, with certain exceptions, inter-communication must not be refused on account of the differences in the systems of wireless telegraphy employed.

The conference drew up the first international Radio Regulations, incorporating the principle that ship and coastal radio stations must accept messages from each other and adopting the SOS distress signal. The first frequency allocations for use in the maritime service (viz 500 kHz and 1000 kHz) were made.

The documents signed in Berlin on 3 November 1906 consisted of the Convention, the Additional Undertaking, the Final Protocol, and the Service Regulations.

These documents were revised at the London Conference held in 1912. The sinking of the British liner 'Titanic' two months before this conference alerted participating countries and stringent 'Safety-of-life-at-Sea' Radio Regulations were introduced. By then there were some 479 coast stations, 327 of which were for public use and 2752 ship stations of which 1964 were open for public correspondence.

About 40% of the delegates present at the conference were administrative, executive, or technical officials acting for the postal, telegraph, and cable departments of the various countries represented. About another third of the assembly (37%) were composed of army and navy officers, the relative ratio of naval and military officers being about 4 to 3. About 6% of the delegates were trained and experienced diplomats, and the remainder included eminent scientists, noted meterologists, and prominent personages interested in the technical, commercial, and humanitarian development of wireless telegraphy.

In all, about 350 amendments, additions, and proposals were considered in some form by the conference. About 100 of these proposals were accepted in full or in part, the majority of the amendments adopted, however, being of minor nature.

The First World War greatly stimulated the development of radio and then, in the early 1920s a new kind of radio service began—broadcasting. All this gave rise to a new problem—how to share out the radio frequencies so as to avoid the otherwise inevitable interference between stations. Since the use of radio constantly grows, it is a problem which has to go on being solved all the time, and now today, five decades and many conferences later, the international responsibility for radio frequencies remains one of the ITU's heaviest and most vital jobs. The first move was made at the Washington Radiotelegraph Conference of 1927 which proceeded by allocating bands of frequencies. Frequencies covering the range 10 kHz to 23 MHz were allocated catering for operation in the fixed, mobile, including aircraft, broadcasting and amateur radio services.

One of the most important decisions of the Washington Conference was to create the International Radio Consultative Committee (CCIR) on 18 November 1927. Another important event was the drawing up of the first Frequency Allocation Table.

Television and radiodetection (radar) both made their appearance in 1930 and it was evident that a new era in radiocommunications was dawning. At a conference at Madrid in 1932 a table of transmission frequencies and instability tolerances was introduced. Television bandwidths were determined having due regard to the state of the technical development at the time.

In 1938 at Cairo the Table of Frequency Allocations was extended to 200 MHz. The Conference also set down higher technical standards for transmitters through improved frequency tolerances and bandwidth tables. Another important decision was the first allocation of radio channels for intercontinental air routes in the band 6500 kHz to 23.38 MHz, which provided for existing and future services.

During the war, broadcasting brought the fact home to everyone that radio waves were no respecters of frontiers. It was not difficult to see therefore that much wider international agreements would have to be drawn up for radio.

At Atlantic City in 1947 the conference had to cope with the requirements of 600 delegates from 76 countries and improved radio communication technology. The frequency allocation table was extended to 10.5 GHz. An International Frequency Registration Board (IFRB) was created to deal with the notification and registration of frequencies in the Master Frequency List. Another important outcome was the formulation of a new volume of Radio Regulations to deal with the great expansion of radio. These Regulations were subsequently revised during the Administrative Radio Conference in Geneva in 1959.

The advent of the Space Age gave the ITU a new challenge since man's exploration of the outer space is critically dependent upon reliable radio communications. The first conference on space communications was called to meet in Geneva in 1963. Some 400 delegates representing 70 countries were present to determine frequency allocations for space radio communication purposes.

The Aeronautical Mobile (R) Service frequency assignment plan was dealt with in Geneva in 1966 followed in 1967 by matters relating to the Maritime Mobile Service. The International Radio Regulations were revised and published in 1968.

THE RADIO REGULATIONS

The Radio Regulations are quite different from the ITU Telegraph and Telephone Regulations since they are intended for a multiplicity of public and private users, not only the PTT Administrations and broadcasting organisations but other services such as aviation, shipping, radio navigation and radio amateurs. Moreover, radio waves are propagated in accordance with physical laws which take no heed of man-made national boundaries. It is therefore not enough to frame rules to govern the international exchanges of traffic. Allowance has to be made for the fact that radio waves cannot help crossing frontiers and that stations may interfere with one another. It is quite possible, for example, for an emission in one country to interfere with an emission in another country, although neither was intended to be received outside the country of transmission. For all these reasons the Radio Regulations have to contain very detailed provisions.

The purpose of the Radio Regulations is to enable communication to be established between stations and to prevent interference between stations.

One of the fundamental principles of the Radio Regulations stems precisely from the possibility of such interference: no radio station may be operated in a manner inconsistent with the Regulations unless no harmful interference will result.

The various sections of the Radio Regulations deal with ways of avoiding harmful interference and provide for a proper apportionment of the radio spectrum in bands of frequencies which are allocated to specific services, like broadcasting, the aeronautical mobile service, radionavigation, the space service, radio amateurs, etc.

This apportionment is supplemented by other provisions of a general nature or limited to a particular service. The aim is to make sure that stations which are capable of causing international harmful interference or which handle international traffic shall operate in such a way that the probability of interference is kept to a minimum.

One of the corner-stones of the international regulations governing radiocommunication is the Master International Frequency Register, in which the characteristics of some 300 000 frequency assignments are recorded. This Register is kept up to date by the IFRB, the International Frequency Registration Board, one of the four permanent organs of the ITU. Any new or modified assignment has to be notified to the IFRB by the national Administration which has the station concerned under its jurisdiction.

There are all sorts of other provisions relating to harmful interference but, as indicated above, such provisions are not the only raison d'être of the Radio Regulations, which are fundamentally concerned with making it possible for stations to communicate with one another. This is a vital requirement, for example in the maritime mobile service and in the aeronautical mobile service. Wherever they come form, ships and aircraft must be able to communicate with the stations located in the ports or airports of their destination.

This can only be done if stations located in a large number of different countries comply with common operating procedures and can handle traffic despite language differences.

For this purpose the Radio Regulations contain a series of conventional signals and essential codes. The best known conventional signal is probably the SOS signal adopted in 1906 although there are many other code abbreviations which are used more often, e.g. the groups of letters and figures making up the international series of call signs which are used to identify stations and their nationalities.

In addition to these operational questions, the Radio Regulations contain various other provisions, for example those relating to the qualifications required for station operators, the nature and contents of essential documents in the international service (e.g. International Frequency List, List of Ship Stations) published by the ITU.

THE INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

The International Radio Consultative Committee (CCIR) was founded on 18 November 1927 at the International Conference for Radio Telegraphy held in Washington when it was decided that an international technical consultative committee for radiocommunications be established to "study technical and operating questions relating specifically to radiocommunications and to issue recommendations on them". By international convention, the CCIR formally came into existence on 1 January 1929.

Membership of the Committee is by right open to all Members of the ITU. The Committee operates through Plenary Assemblies which are held every three or four years and draws up lists of technical problems concerning radiocommunications or 'Questions', the study of which would lead to improvements in international radiocommunications. Study Group recommendations are submitted to the succeeding Plenary Assembly and if adopted, they are published for the CCIR by the ITU. Since CCIR Recommendations are the sum total of studies by international experts, they have important influence on all aspects of radiocommunications throughout the world.

The work of the various Study Groups cover the following subjects:

(a) Spectrum Utilisation-Monitoring.
Studies, in collaboration with the other Study Groups, questions relating to the efficient use of the radio frequency spectrum and, in particular, problems of frequency sharing, bearing in mind the attainable characteristics of radio equipment (transmitters, receivers, antennas, etc.) and systems,
Studies principles for classifying emissions,
Develops means of specifying and measuring the characteristics of emissions and other forms of radiation likely to give rise to harmful interference.
Studies techniques for measuring at a distance the parameters of emissions and spectrum occupancy, to devise means for identifying emissions and for locating sources of harmful interference and to improve, in collaboration with the IFRB, procedures for presenting the corresponding reports.

(b) Space research and radioastronomy services.
Studies questions relating to the communications for spacecraft for scientific purposes and for earth exploration.
Studies questions relating to interference problems concerning radio-astronomy and radar astronomy.

(c) Fixed service at frequencies below about 30 MHz.
Studies questions relating to complete systems for the fixed service and terminal equipment associated therewith (excluding radio-relay systems).
Systems using the so-called ionospheric-scatter mode of propagation, even when working at frequencies above 30 MHz, are included.

(d) Fixed service using satellites.
Studies questions relating to systems of radiocommunication for the fixed service using satellites (including the associated tracking telemetry and telecommand functions).

(e) Propagation in non-ionised media.
Studies the propagation of radio waves (including radio noise) at the surface of the earth, through the non-ionised regions of the earth's atmosphere, in space where the effect of ionisation is negligible, with the object of improving communication.

(f) Ionospheric propagation.
Studies the propagation of radio waves (including noise) through the ionosphere, with the object of improving radio communication.

(g) Standard frequency and time-signal services.
Co-ordinates world-wide services of standard frequency and time-signal emissions.
Studies the technical aspects of emission and reception, including the use of satellite techniques in these services and means to improve the accuracy of measurement.

(h) Mobile services.
Studies the technical and operating aspects of the aeronautical mobile, maritime mobile, land mobile and radiodetermination services, including the use of satellites.

(i) Fixed service using radio-relay systems.

Studies questions relating to line-of-sight and trans-horizon radio-relay systems operating via terrestrial stations at frequencies above about 30 MHz.

(j) Broadcasting service (sound).
Studies the technical aspects of the broadcasting service (sound), including the use of satellites.
Studies the special problems of broadcasting in the Tropical Zone, taking into account the standards required for good quality service; interference in the shared bands; power required for an acceptable service; design of suitable transmitting antennas; receiving equipment; optimum conditions for utilisation of the frequency bands and other associated questions.
Studies the standards for audio-frequency recording to facilitate the international exchange of programmes.

(k) Broadcasting service (television).
Studies those technical aspects of the broadcasting service (television), including the use of satellites, which are of international importance.
Studies the standards for motion picture films intended for television and all forms of television recording relevant to the international exchange of programmes.

(l) CMTT-CCIR/CCITT Joint Study Group for television and sound transmission.
Studies in co-operation with the Study Groups of the CCIR and CCITT the specifications to be satisfied by telecommunication systems to permit the transmission of sound and television broadcasting programmes over long distances.

(m) CMV-CCIR/CCITT Joint Study Group for Vocabulary.
Studies, in collaboration with the Study Groups of the CCIR and CCITT, technical terminology and related subjects (graphical and letter symbols and other means of expression, systematic classification, units of measurements, etc) to meet the needs of these Study Groups, making the best possible use of the joint co-operation groups established between the CCIs and the corresponding Technical Committees of the International Electrotechnical Commission (e.g. Technical Committee No 1 for Vocabulary and Technical Committee No 3 for Graphical symbols.

The organisation chart for these Study Groups is shown in *Figure 45.1*. The Committee since its establishment 50 years ago has dealt with many important issues. The first meeting held at The Hague in 1929 proposed the study of high frequency radiation in the band 6-30 MHz, the definitions of power and frequency ranges, frequency measurements, monitoring, frequency tolerances, occupied bandwidth, frequency separation, spurious emission, fading, directivity, atmospheric noise and amateur's licences. Administrative Radio Conference held singe the War and specialised conferences have done much to ensure the orderly development of radiocommunications throughout the world. The entry of space systems and radio astronomy has added a new dimension and studies have been necessary in radio astronomy, radio relay systems, space communications, direct broadcasting from satellites, radio-navigation by satellites, meteorological and earth resource satellites, radar astronomy, the use of computers to improve the reliability of forecasts of frequencies likely to be usable between various points, developments in mobile communications and problems of coexistance between terrestrial radio relay systems and communication satellite systems using the same frequency bands.

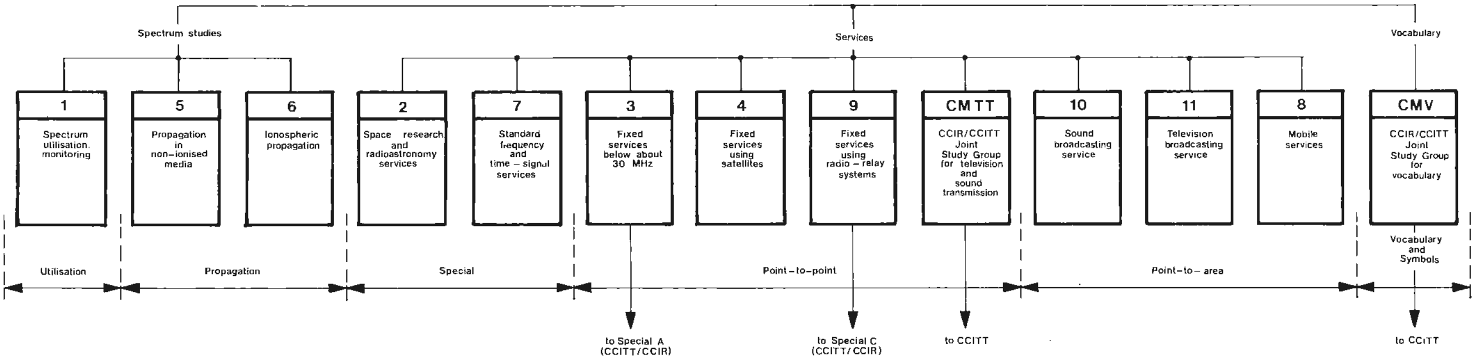


Figure 45.1 Organisation chart of the CCIR study groups

In 1977 The World Administrative Radio Conference on Broadcasting Satellites was convened with 600 delegates from 113 countries attending and dealt with the broadcasting satellite service and the services with which it shares the 12 GHz band. The arguments included a comprehensive plan assigning to administrations in ITU Regions 1 and 3, individual channels and polarisations at specific orbital locations for coverage of prescribed service areas on the ground. The plan made nearly 1000 frequency assignments distributed among about 250 service areas. The number of beams or service areas per country ranged from one to thirty five with the number of channels per beam ranging from one to eight. Region 2 which includes North and South America adopted only interim provisions for the development of systems during the period until a regional planning conference could establish a detailed plan for the region.

An important outcome of the conference was that 'first-come, first-served' may no longer be an acceptable principle on which to base international spectrum management and future conferences may adopt more rigid structured methods of spectrum management than those presently embodied in the Radio Regulations.

For a period of 10 weeks in 1979 the World Administrative Radio Conference was convented in Geneva to review and modify the Regulations to accommodate the telecommunications requirements of the world until the year 2000 and beyond. The last conference with such a far reaching charter was held in 1959 and although specialised conferences were held in 1963 (space and radio astronomy), 1966 (aeronautical mobile (R)), 1967 (maritime mobile), 1971 (space and radio astronomy), 1974 (maritime mobile), 1977 (12 GHz broadcast satellite) and in 1978 (aeronautical mobile (R)), these dealt with individual radio service aspects relating to rules, regulations and allocations. The impact of the conference results and 20 years of technological progress measurably increased the scope of study and revision necessary at the conference. Also, the increasing needs of developing nations in relation to domestic and international satellite services, land and maritime mobile services, television and high frequency international broadcasting services were taken into account during spectrum management discussions.

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD

One of the most difficult problems which has confronted the International Telecommunication Union has been the allocation, assignment, registration and orderly use of the radio frequency spectrum. The usable radio spectrum has changed over the years from the first transmission across the Atlantic in 1901 and in recent years the difficulty of the task of spectrum management has increased immensely.

Before the Second World War, any country could take into use, within certain limits, any frequency it required for any particular service, and all that was necessary was for the country concerned to notify its use of the frequency for the information of other countries.

After the war however, the situation in regard to the use of the radio spectrum became more complicated due in the first instance to the enormous increase in the use of the radio spectrum by all the countries of the world as a consequence of the development of their communications. The situation was quite chaotic and civil aircraft could not fly with safety because exclusive ground-air communication frequencies could not be provided and broadcasts were ineffective because of interference from other similar services. Faced with this situation, the ITU Atlantic City Radio Conference held in 1947 established the International Frequency Registration Board (IFRB) and charged it

(a) to maintain a register of all radio frequencies used for all purposes throughout the world.
(b) to ensure that no new frequency should be taken into use by any country if the use of this frequency would cause interference to radio services which were already in operation.

The Board consists of a number of members, all of whom must be technically qualified in the radio field, and who are elected as individuals by an Administration Radio Conference in a manner to provide wide geographical representation. The Board acts as a corporate body in which the individual members serve, not as representatives of their respective countries or of a region but as 'Custodians of an International Public Trust'. It elects its Chairman who serves for a period of one year. The members of the Board are assisted by a specialised Secretariat.

The essential duties of the IFRB are laid down in Article 13 of the Convention and are, briefly,

(a) to effect an orderly recording of frequency assignments made by the different countries in accordance with the procedures presecribed in the Radio Regulations.
(b) to furnish advice to Members and Associate Members of the Union with a view to the operation of the maximum practical number of radio channels in those portions of the spectrum where harmful interference may occur.

The IFRB's main task is to decide whether radio frequencies which countries assign to their radio stations are in accordance with the Convention and the Radio Regulations and whether the projected use of the frequencies concerned will, or will not, cause harmful interference to other radio stations which are already in service. Thus the Board, basing itself on purely technical considerations, determines the right of a given administration to use a given frequency for a specific purpose, as well as the duties assumed thereby by that administration vis-a-vis other administrations.

The Board maintains the 'Master International Frequency Register' in which are entered, with all the requisite observations of a legal nature, data relative to frequency usage by all the stations of the various types of services throughout the world. The Master Register takes the form of printed cards which reproduce visually the data recorded on a magnetic tape. The information recorded on this tape is produced and published periodically for the benefit of the Members of the Union in the 'International Frequency List'.

In addition, the Board collects and analyses the data received from monitoring stations spread throughout the world, with particulars of observations on the transmissions made by radio stations and which, in a summarised form, is distributed to all administrations. The Board also compiles and publishes four seasonal schedules of high frequency broadcasting operations and assists administrations in finding suitable frequencies for their high frequency broadcasting services.

In relation to the special assistance to be given to Administrations the Board has the responsibility of studying and advising the Administrations in cases where suitable frequencies, free of interference, are needed by countries to assure the regular operation of their services. Also the Board deals with those cases of harmful interference which occur in practice and recommends suitable solutions to the problem.

Another important function of the Board is to carry out the technical preparation for conferences, assembling the necessary technical and operational data which may be required by the conferences for frequency planning or other purposes related to the use of the radio spectrum.

The IFRB also holds Seminars to which telecommunications officials from Administrations, and in particular from the newly developing countries, are invited. In the course of these seminars a series of lectures is given by the Members of the Board, by the staff of its specialised Secretariat and by lecturers from Administrations. These lectures are followed by discussions. Participants at the Seminars receive guidance in the management and the use of the radio frequency spectrum involving technical and operational subjects.

SPACE RADIOCOMMUNICATIONS

Since the launching of Sputnik I, the first artificial satellite of the earth, on 4 October 1957, countless spacecraft have been placed on orbit round the earth or sent into space. Manned spacecraft have also been launched, systems making use of satellites, for telecommunication and meteorology, for example, have been brought into service and other practical applications are planned.

All these launchings, experiments and practical applications have one common feature: their use of radio waves as providing the sole link between the spacecraft and earth. Indeed, it is difficult to think of any other field in which radiocommunication is of such paramount importance: without radio links there is no possible means of knowing what is going on on board, no way of giving orders to the crew or craft or receiving the results of the measurements made. Except in the case of passive satellites, a satellite reduced to silence by a breakdown is a mere pebble in the cosmos, nothing more. And conversely, the impossibility of making it stop transmitting to order is a particular nuisance, since the satellite may be illegitimately taking up one or more frequencies and causing interference to other transmissions.

The first conference to allocate frequency bands for space radiocommunication purposes, better known as the Space Radiocommunication Conference, opened in Geneva on 7 October 1963.

This occurred at a time when the first communication satellite successes and the first launchings of manned space vehicles were making serious international co-operation more and more necessary.

On 8 November, the 400 delegates from 70 countries left after having successfully completed the tasks on the agenda. A series of frequency bands had been allocated either exclusively or on a shared basis to various space services.

Some sections of the Radio Regulations had been reviewed particularly as regards the assignment, use, notification and registration of frequencies, the identification of stations, and technical terms and definitions.

Important resolutions and recommendations had also been adopted with an eye to future developments in the use of outer space. For example, considering that the number of flights by space vehicles or manned satellites was likely to increase, and "that in such circumstances the search for and rescue of the occupants and recovery of the vehicles present problems very similar to those encountered by aircraft and ships in distress and emergency, that the frequency of 20 007 kHz has been selected by the Conference for search and rescue to augment those already designated in the Radio Regulations for distress, emergency, and survival craft..."

The Conference adopted a Resolution to the effect that the conventional distress signal of ships and aircraft (SOS in radio-telegraphy, MAYDAY in radiotelephony) should also apply for the time being to space vehicles.

The development of satellite systems, particularly for telecommunications, meteorology and navigation, was also dealt with in a Resolution which specified that any ITU Member telecommunication administration (or group of administrations) which intended to establish an international satellite system should provide the International Frequency Registration Board with information giving a general description of the satellite system, to enable harmful interference to be avoided and to facilitate the management of the frequency spectrum.

On 7 June 1971 the Second World Administrative Conference for Space Telecommunications assembled in Geneva with 740 delegates representing 101 countries to revise the Radio Regulations.

Great advances had been made in techniques since the 1963 meeting and it was clear that international regulations on space communications had to be adapted to the technical developments. Satellites were being used for telecommunications, sound and television broadcasting, meteorology, aeronautical and maritime navigation and exploration of earth resources, interplanetary probes had been sent to study Venus and Mars and Man had landed on the Moon.

The following included Recommendations adopted at the meeting:

(a) Recommendation relating to the criteria to be applied for sharing between the broadcasting-satellite service and the terrestrial broadcasting service in the band 620–790 MHz.
(b) Recommendation relating to the use of bands allocated to the inter-satellite service.
(c) Recommendation relating to the future use of certain frequency bands between 40 and 275 GHz.
(d) Recommendation relating to the future use of the 41–45 GHz band by the fixed and mobile services.
(e) Recommendation relating to future frequency allocation requirements for the maritime mobile satellite service.
(f) Recommendation relating to the protection of radio astronomy observations on the shielded area of the Moon.
(g) Recommendation relating to the future provision of a band near 10 MHz for the radio astronomy service.
(h) Recommendation relating to the examination by administrative radio conferences of the situation with regard to occupation of the frequency spectrum in space radiocommunications.
(i) Recommendation relating to technical standards for the assessment of harmful interference in the frequency bands above 28 MHz.
(j) Recommendation addressed to the CCIR and to the administrations relating to frequency bands shared between space services and between space and terrestrial services.
(k) Recommendation relating to the 'co-ordination of earth stations' in which

it invited the International Radio Consultative Committee (CCIR) to continue its study of the co-ordination area of earth stations in certain bands shared between terrestrial radiocommunication services and space radiocommunication services at frequencies below 1 GHz and above 40 GHz.

(l) Recommendation relating to 'carrier energy dispersal in systems in the fixed satellite service'. This technique could lead to a considerable reduction of interference to stations of a terrestrial radiocommunications service operating in the same frequency bands as the fixed satellite service systems, or to a substantial reduction in the level of interference between systems in the fixed satellite service operating in the same frequency bands.

(m) Recommendation relating to the 'use of space radiocommunication systems in the event of natural disasters, epidemics, famines and similar emergencies'. The Conference recommended

  (i) that administrations, individually or in collaboration, provide for the needs of eventual relief operations in planning their space radiocommunications systems and identify for this purpose preferred radio frequency channels and facilities which could quickly be made available for relief operations.
  (ii) that administrations concerned waive the coordination procedures provided for in the Radio Regulations in the case of transportable earth stations used for relief operations.

ELECTROMAGNETIC COMPATIBILITY

Electromagnetic compatibility (EMC) refers to the ability of separate, yet physically adjacent, radiocommunications networks and systems to operate without causing mutual interference. In practice there are multitudinous electromagnetic actions which can mutually interfere and so prevent the full and effective use of the available spectrum. There is concern in some quarters that the problem of interference is becoming worse and in the near future may deteriorate irretrievably if present controls in the use of the electromagnetic spectrum and devices which cause undesirable interference are not tightened. Steps may have to be taken to not only reduce spurious radiation from apparatus and equipment, but also to design equipment for effective noise immunity.

Interference whether in the form of natural noise or from man-made sources is a form of environmental pollution. Although natural noise cannot be eliminated its effect on the operation of a service can often be minimised by the employment of suitable techniques. However, much can be done to deal with the man-made problem. Natural noise sources include Johnson or white noise, noise produced by active circuits and atmospheric, cosmic and galactic noise.

Man-made noise originates from many sources with the most important being

(a) electrical discharges from contacts, arcs, switches, motors etc.
(b) signals produced within equipment such as spurious emissions, harmonic radiations, and intermodulation and cross-modulation products.
(c) continuous wave signals caused by a wide range of communication systems.
(d) power line hum introduced via mains fed power supplies.
(e) pulse modulated signals emitted by radar type systems.
(f) square wave type signals produced by data transmission systems.

The concept of electromagnetic compatibility is now generally well understood and many Standards are based on the mutual compatibility of electromagnetic apparatus, equipment and systems. The basis of the concept is the relative immunity of operational equipment to interference of an electromagnetic nature which may be conducted or radiated and generated either externally or within the equipment itself. Mutual interference may be caused by transmitter spurious emissions, receiver spurious responses, and non linearities. A more recent interference problem which has introduced a limitation upon the ability to increase network densities is associated with the spectral purity of oscillators incorporated in transmitters and receivers.

The principal technical bases on which the practice of electromagnetic compatibility has been built are in the areas of production, measurement, suppression and analysis. The practical application of these requires a good understanding of radio frequency interference and the techniques available to combat it. The engineer during the equipment or network design stage has to predict and dispose of electronic noise and interference and at the operating stage he has to be sure that the environment in which the facility has to be operated is not polluted to such an extent that noise or interference signals will cause the equipment to malfunction or be unsuitable for the purpose for which it was designed.

SPECTRUM PLANNING

The International Telecommunication Union has divided the world into three regions for the purpose of international spectrum allocation. Region 1 covers Europe, Africa and the USSR, Region 2 includes North and South America and Region 3 is the remainder of the world. The allocations are set out in the International Table of Frequency Allocations and allocations in some instances differ from one region to another. Because the demand for spectrum far exceeds the availability of the spectrum resource, more than one radio service may be allocated within a given portion of the spectrum in the same geographical region.

Nations are required to use the spectrum so as not to cause interference with the services in other regions but in the case of neighbouring countries within a zone close co-operation in frequency allocation matters is essential as radio signals are not confined by national geographic boundaries.

Plans can only be developed within a framework of mutual agreement and bilateral agreements are often essential between adjacent countries to ensure a minimum of conflicts between frequency assignments of one country and its neighbour. Negotiations are necessary from time to time to amend the agreements because of increasing demands placed on the spectrum.

The function of the development of a national spectrum policy is in practically all countries vested in a government department or instrumentality. It determines which group or individuals may use the various allocations it makes in the spectrum and ensures that the spectrum plan being made will meet the long term social and economic needs of the country and at the same time will represent a balanced demand on this limited resource by its various current and potential users.

Considerations also included the weighting placed on national policies by such matters as

(a) Expansion of telephone, telegraph, broadcasting and television services through a domestic satellite system.
(b) Expansion of private point-to-point microwave radio relay services for control of pipeline equipment, electricity remote sub-station control, outside broadcast relays for television etc.
(c) National disaster organisations.
(d) Public mobile radio telephone networks.
(e) Expansion of national and international sound broadcasting, frequency modulation and television services.
(f) Expansion of data services.

However, as technology enables more and more complex applications of systems which operate in the radio frequency spectrum, the magnitude of the interference problem and the probability of interference increases sharply. The natural expansion of national and private radio facilities and consequent crowding of the spectrum underline the necessity of eliminating and preferably preventing interference between links of the same network as well as between different networks. It is the role of spectrum engineering to provide the technical guidelines for authorisation of operating licences.

The spectrum engineering function is to provide technical analysis capabilities for the conduct of spectrum resource analysis, electromagnetic compatibility analysis, equipment performance analysis, measurement support, facility behaviour under interference conditions, measurement of spectrum usage, field measurement of equipment parameters and monitoring and observation services. Included in these services are the formulation of standards for transmitters and receivers to meet minimum harmful radiation, response characteristics, minimum frequency separation of adjacent channels and other critical technical parameters. Most organisations require that equipment be approved as a 'type' to meet minimum specifications.

Technical advances, particularly in the area of improved antenna systems, have substantially facilitated the development and effective use of the spectrum. This has enabled closer and closer geographic spacing of users. Well known examples include the use of narrow directional beams for terrestrial and space satellite radio communication systems, and directional antennas in medium frequency and high frequency broadcasting. Antenna types now currently available for these and other purposes include parabolic, horn, flat passive reflector, shrouded, Cassegrain, helical, discone, travelling wave, tuned long wire unipole, unipole with cardioid, Yagi, slot, lens, parallel array of dipoles, loop, shell, log-periodic, corner reflection, rhombic and Vee-beam.

A knowledge of interference analysis, propagation characteristics of signals in the various frequency bands, the various modulation techniques as well as likely technological changes which may cause demand pressure on frequency allocations are essential for effective spectrum planning. The interference analysis problem is particularly difficult with increased loading of the spectrum by a range of sophisticated equipment and because of the scope and complexity of evaluation, a computer assisted technique is the only practical approach for interference analysis. A considerable amount of reliable input data is necessary and the gathering of the data may take a long time. However, the analysis is only as good as the information and the data base.

Typical input parameters include

- Site designation
- Co-ordinates of the site
- Co-ordinates of adjacent stations
- Elevation of the site
- Antenna type and gain
- Antenna azimuth
- Antenna elevation
- Antenna polarisation
- Feeder loss
- Transmitter frequency
- Transmitter power output
- Harmonic output levels of transmitter
- Receiver frequency
- Median received signal
- Radio frequency amplifier gain
- Radio frequency amplifier noise figure
- Radio frequency filter characteristics
- Receiver input filter characteristics
- Intermediate frequency of receiver
- Receiver local oscillator frequency
- System channel capacity

In many large cities the most severe frequency assignment problem occurs in the highly utilised land mobile v.h.f. position of the spectrum. Many areas have already reached a point of saturation. It has been estimated that as the density of the stations in the same frequency band increases then the number of calculations necessary to ensure electromagnetic compatibility and interference free operation of additions to the network increases in proportion to the square of the density.

Spectrum congestion has in many cases been the result of previous conservative frequency management practices based on administrative convenience and inadequate planning. Changes to conserve spectrum and alleviate shortages are now costly because of huge investments in equipment and installations. The situation is heading to crisis point in many areas and more emphasis must be directed to sound engineering and analysis so that more effective spectrum management practices can be employed. *Table 45.1* shows the bands available for radio communication purposes.

One of the most congested bands is the 3 to 30 MHz band widely used for long distance point-to-point services and for international broadcasting. The number of transmitters operating in this band has increased considerably in recent years and there is a serious problem with co-channel and adjacent channel interference. Congestion is extreme with many channels seriously overloading during certain peak broadcast periods.

The use of high frequencies is wide and diverse with the most important applications being

- International and tropical broadcasting
- Long distance point-to-point radiocommunication links
- Diplomatic services
- News agency services
- Civil aeronautical ground-to-air services
- Military aeronautical ground-to-air services
- Maritime shore-to-ship services
- Naval shipborne services
- Feeder links between satellite earth stations
- Remote radio telephone subscriber services
- Police communications
- Transportable stations

TABLE 45.1 BANDS USED IN RADIOCOMMUNICATIONS

Band Number	*Name*	*Frequency range*	*Wavelength range*	*Characteristic*	*Application*
4	Very low frequency (v.l.f.)	3–30 kHz	100 km–10 km	International communications	Submarine communications Industrial
5	Low frequency (l.f.)	30–300 kHz	10 km–1000 m	International communications	
6	Medium frequency (m.f.)	300–3000 kHz	1000 m–100 m	Regional	Regional broadcasting, Coastal beacons, Aircraft beacons
7	High frequency (h.f.)	3–30 MHz	100 m–10 m	Global communications	HF broadcasting, Amateurs, maritime, aircraft
8	Very high frequency (v.h.f.)	30–300 MHz	10 m–1 m	Line-of-sight	Television, mobiles, radiocommunication links
9	Ultra high frequency (u.h.f.)	300–3000 MHz	1 m–0.1 m	Line-of-sight	Tropospheric scatter, mobiles, television
10	Super high frequency (s.h.f.)	3–30 GHz	0.1 m–1 cm	Microwave line-of-sight	Broadband radiocommunication links, radar, satellites
11	Extra high frequency (e.h.f.)	30–300 GHz	1 cm–1 mm	Line-of-sight	Radar, satellites

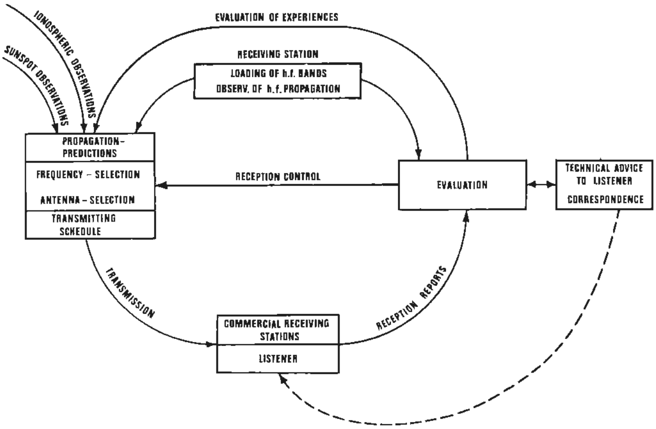


Figure 45.2 High frequency broadcasting and reception control

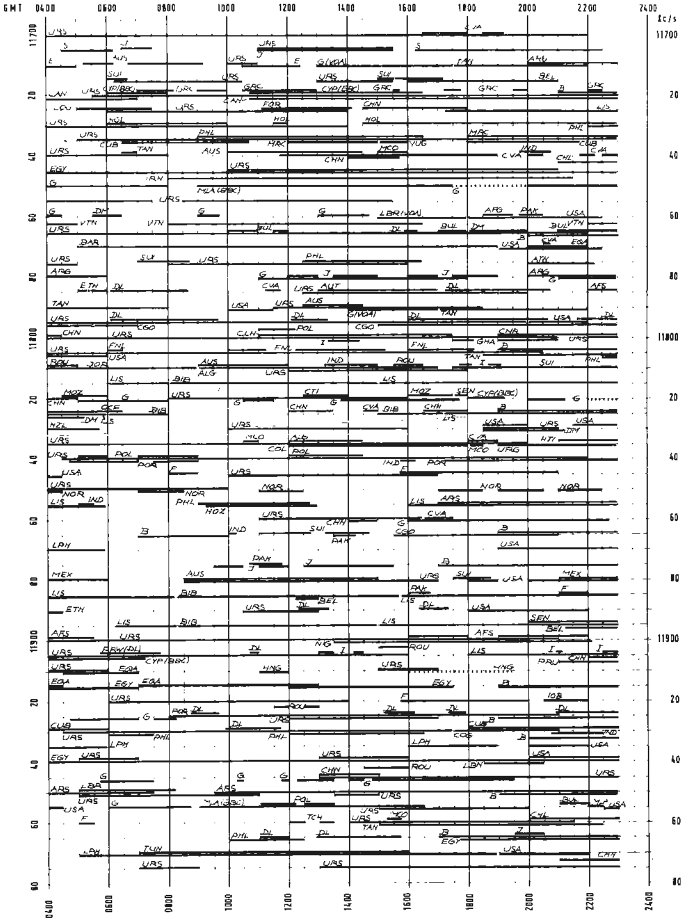


Figure 45.3 Occupancy chart 11 MHz band

One of the major problems in operation of transmitting services in the high frequency spectrum is that the characteristics of the ionosphere have an important bearing on the frequency which may be used in order to provide acceptable signal level at the received end. The characteristics of the ionosphere vary with time of day, season of the year, and phase of the eleven year sunspot cycle and this often requires the employment of more than one frequency in order to maintain communication for a lengthy period. Also, as the sunspot activity changes from maximum to minimum, the useful range of the high frequency spectrum is reduced considerably.

The demand for spectrum space is such that the selection of a suitable frequency is very difficult, calling for a skilful analysis of all relevant factors including band occupancy monitoring of the frequency bands concerned and obtaining feedback in the form of reports from listeners. *Figure 45.2* indicates some of the factors involved in high frequency broadcasting and reception control.

Present planning in the use of the high frequency spectrum for broadcasting purposes is at least only equivalent to short term planning.

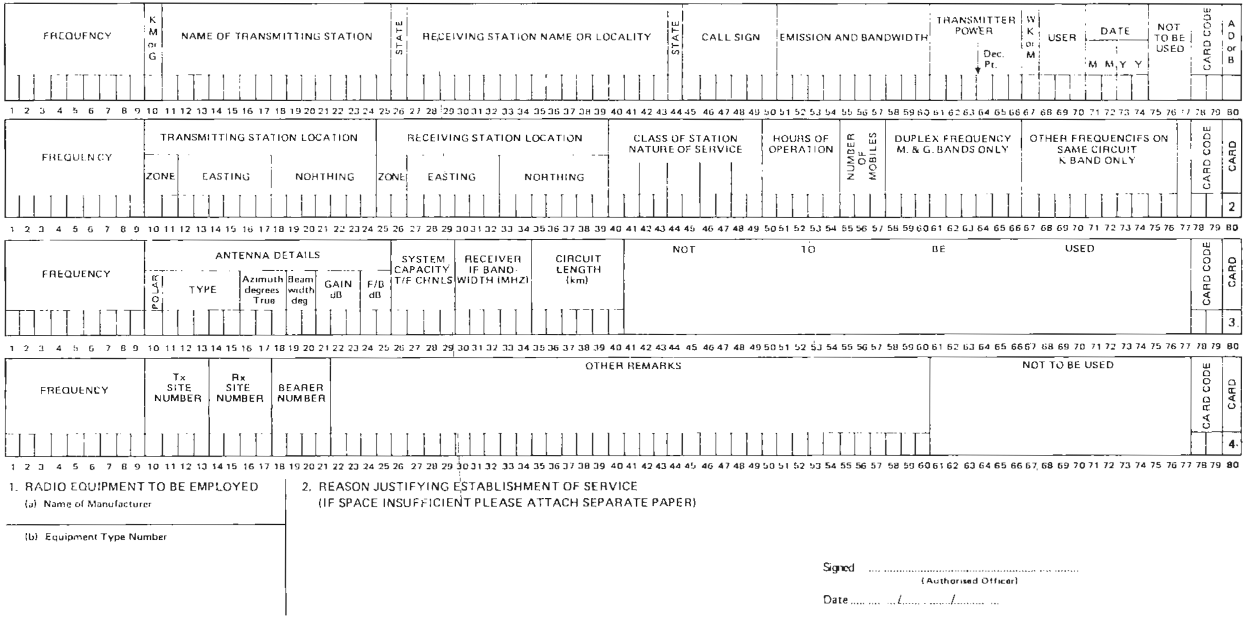
In some cases, radio frequency managers are faced with the problem four times a year of working out a transmission scheduling plan which can be put into operation without creating undue interference to or receiving interference from other legitimate broadcasting services. Problems encountered in the selection of suitable frequencies can be gauged from *Figure 45.3*. It is a typical chart plot of frequency against time in the 11 MHz band prepared in recent times. The usage is represented by a line of length corresponding to the duration of transmission and position corresponding to the particular channel occupied. With such congestion, those services which employ the most powerful transmitter/antenna gain combination will emerge as the most effective with a result that transmitter powers are increasing and improved techniques in transmission such as trapezoidal modulation are being widely employed in the international broadcasting field.

Most administrations now submit their broadcasting schedules in advance to the IFRB which co-ordinates them and advises the degree of acceptability of the proposed broadcasting plan in terms of field strength in the reception areas and possible interference from other stations. If the IFRB finds that after a technical examination, probability of interference exists, it returns the proposed schedule back to the administration which submitted it so that a new frequency may be scheduled or a change made to the characteristics of the station so that the probability of interfernece is avoided or at least minimised.

In the case of broadcasting activities in the low and medium frequency bands, coverage in general is determined by both noise and the level of interference. Efficient use of the spectrum can only be made when the service area is limited by interference rather than noise. In the presence of interference, reception can be considered acceptable only when the signal of the wanted transmitter exceeds that of the unwanted signal by at least the r.f. protection ratio.

The effect of high powers at medium frequency is that after dark many other stations are subjected to harmful interference. This is due to the coverage of the interferring stations being extended great distances through sky wave signals which come into existence after sunset. The practical effect of this interference is to cause the useful service areas of stations to be reduced at night time..

The application for a frequency allocation for any type of service usually has to be accompanied by a Frequency Assignment form. From information shown on the form the licensing authority can add to or amend its Master Frequency



FREQUENCY	K M or G	NAME OF TRANSMITTING STATION	STATE	RECEIVING STATION NAME OR LOCALITY	STATE	CALL SIGN	EMISSION AND BANDWIDTH	TRANSMITTER POWER Dec. Pt.	W K or M	USER	DATE M M Y Y	NOT TO BE USED	CARD CODE	A D or B

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

FREQUENCY	TRANSMITTING STATION LOCATION			RECEIVING STATION LOCATION			CLASS OF STATION NATURE OF SERVICE	HOURS OF OPERATION	NUMBER OF MOBILES	DUPLEX FREQUENCY M. & G. BANDS ONLY	OTHER FREQUENCIES ON SAME CIRCUIT K BAND ONLY	CARD CODE	CARD 2
	ZONE	EASTING	NOHTHING	ZONE	EASTING	NORTHING							

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

FREQUENCY	ANTENNA DETAILS					SYSTEM CAPACITY T/F CHNLS	RECEIVER IF BAND-WIDTH (MHZ)	CIRCUIT LENGTH (km)	NOT TO BE USED	CARD CODE	CARD 3
	POLAR	TYPE	Azimuth degrees True	Beam width deg	GAIN dB	F/B dB					

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

FREQUENCY	Tx SITE NUMBER	Rx SITE NUMBER	BEARER NUMBER	OTHER REMARKS	NOT TO BE USED	CARD CODE	CARD 4

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1. RADIO EQUIPMENT TO BE EMPLOYED
   (a) Name of Manufacturer
   (b) Equipment Type Number

2. REASON JUSTIFYING ESTABLISHMENT OF SERVICE
   (IF SPACE INSUFFICIENT PLEASE ATTACH SEPARATE PAPER)

Signed ....
(Authorised Officer)

Date ..../........../..........

Figure 45.4 Frequency assignment form

Assignment Register. A typical Frequency Assignment form is shown in *Figure 45.4*

SPECTRUM SURVEILLANCE

The Radio Regulations require that radiocommunications shall be carried out without causing interference to those of other countries. To this end, administrative bodies are entrusted with ensuring that radio licensees are complying with the regulations applicable to their operations. This requires that the frequency allocated to the licensee must be monitored and measurements carried out to determine whether the technical requirements are being fulfilled. Another task is to detect unlicensed transmitters and to locate jammers.

In order to carry out this function, radio monitoring facilities are necessary. The facilities include a suitably equipped station employing a fixed installation and mobile facilities for dealing with radio interference measurements including investigation of radio inteference caused by various electrical devices and installations.

In addition to monitoring, other surveillance activities are also usually performed. These include observation and reconnaisance. Radio observation covers the recording of field strength in propagation measurements, the determination of the locations for new transmitters and the determination of radiation patterns of antenna systems. In radio reconnaissance the object is to record and identify unknown radio signals and to analyse the results. This requires facilities for frequency measurement and for determining the direction, preferably location, from which they originate.

By Article 12 of the Radio Regulations monitoring consists primarily in measuring the frequency bandwidth, modulation, field strength and spurious emissions of transmitters operating within the territory of a particular member nation. The technique of measurements are to be in accordance with the most recent recommendations of the CCIR. In addition to detection, the Article requires elimination of harmful interference.

By Article 13 member nations are obliged to perform monitoring and measurements on behalf of the International Frequency Registration Board or for other administrations. The technical standards for stations participating in international radio monitoring activities have been set down by the CCIR but in order to meet some needs for monitoring data, stations of lower technical standards than those recommended by the CCIR may participate in the international monitoring system at the discretion of the administration. Summaries of useful monitoring data are prepared by the Board and published from time to time.

THE ROLE OF THE MONITORING SERVICE

The number and positions of stations in a radio monitoring network are influenced by the size of the country, the density of the population, the spread of the communication and broadcasting services, the degree of industrialisation and topography. In many countries installations comprise main or primary stations, secondary stations and mobile stations. Main or primary stations are usually given the tasks of national and international radio monitoring functions with capability of monitoring emissions in all frequency bands originating from transmitters within a range of some 500 km depending on topography and population density. The range restriction would not apply to high frequency observations. The secondary stations as a general rule monitor emissions in the v.h.f. and u.h.f. ranges and also m.f. and. h.f. services in a subsidiary role to the main stations. The mobile stations are used mainly for measurement work in the v.h.f. and u.h.f. ranges. These mbile stations can quickly identify sources of interference and assist in locating pirate transmitters.

In broad outline, the services provided by the monitoring station network can be categorised as follows:

(a) Monitoring and investigation of interference to existing radio services including measures to, determine the cause of the interference, identify the interfering emission, and determine the technical characteristics of the interfering emission.

(b) Frequency monitoring and quality of emissions consisting of measuring the frequencies and bandwidths of emissions, checking the quality of the modulation, checking for freedom from spurious emissions, and measuring field strengths of emissions.

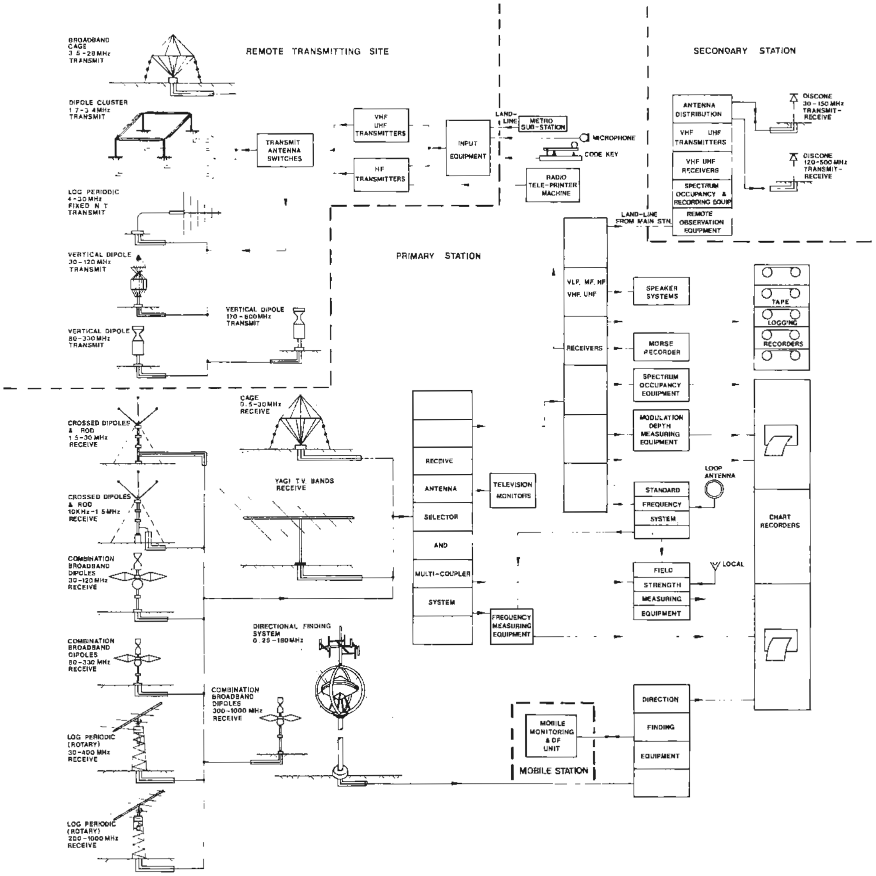


Figure 45.5 Radio detection system layout

(c) Monitoring of infringements in the use of authorised emissions and to check on their observation of the relevant national and international technical and operational regulations.
(d) To search after and determine the location of unlawful radio transmitters which are potential dangers to the functioning of approved services.
(e) Radio frequency spectrum occupancy observations to confirm selection of channel availability for new services.
(f) Participation in international monitoring activities requested by the International Frequency Registration Board or services as may be requested by other authorities.
(g) Provide a systematic watch on frequencies allocated for distress calls to ensure Radio Regulations are properly observed.

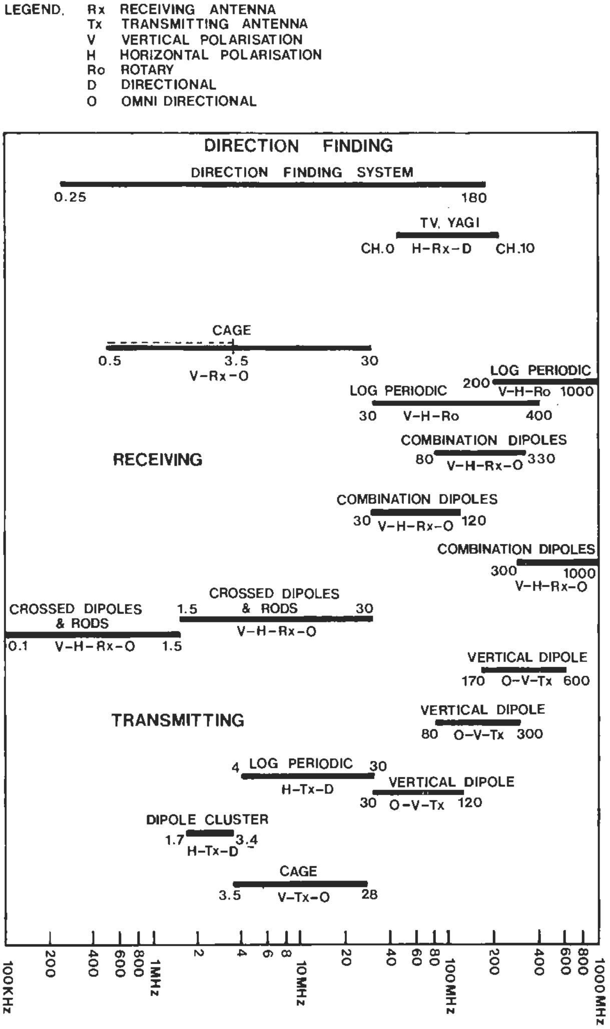


Figure 45.6 Antenna characteristics

Facilities provided at a radio monitoring station depend upon the task envisaged for the particular station but basically all major fixed installations consist of antenna systems, antenna selectors, pre-amplifiers, multicouplers, and equipment required for observation, monitoring, reconnaissance and recording. The operating principle is determined primarily by the antenna systems, receivers, analysers, recorders, and other equipment which have to meet specific requirements according to the functions to be fulfilled. *Figure 45.5* shows a radio detection system layout designed for one network comprising primary, secondary and mobile stations.

The facilities with this station also include remotely controlled transmitters to enable monitoring staff to talk directly to operators detected of using incorrect operating procedures or where their equipment is causing interference. *Figure 45.6* shows the receiving and transmitting antenna characteristics designed to meet the operating requirements.

The Primary Station building comprises Operations Room, Frequency Standard Room, Field Strength Measuring Room and two Monitoring Rooms.

The Operations Room contains all ancillary type facilities including chart recorders, long playing multitrack logging tape recorders, teleprinter, Morse recorder, photo recording equipment, antenna selector and multicoupler equipment, television monitors and transmitter control together with a third or standby monitoring position similar to facilities provided in the Monitoring Rooms. The antenna selector facility is of design which gives maximum flexibility in utilisation of the antenna systems between the three monitoring systems.

The Field Strength Measuring Room contains all necessary equipment for field strength measuring work and also direction finding functions. Facility for remote control of chart recorders is available.

The two Monitoring Rooms are fitted with identical facilities and include a l.f./m.f./h.f. monitoring system and a v.h.f./u.h.f. monitoring system. The equipment comprises consoles, receivers, synthesisers, frequency analyses and bandwidth occupancy measuring equipment, multitrack stereo tape recorders, signal distributors, remote antenna controls, panoramic adapters, frequency indicators and frequency band recorders.

The Secondary Station which is tied to the main or Primary Station carries out surveillance in the v.h.f. and u.h.f. bands only and is installed in a city building.

The Mobile Station comprises a complete v.h.f./u.h.f. monitoring system installed in a van with direction finding facilities.

FURTHER READING

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Section 6

Specifications and Contract Administration

Introduction

Specification writing and the administration of contracts are two important activities associated with engineering management. Skill in these fields depends to a considerable degree on experience and engineering judgement, for which there is no substitute, but guidelines and illustrations taken from actual situations can do much to assist the young engineer.

The examples chosen are representative of the best current practice and therefore are useful as a guide in the preparation of similar documents for specific radio engineering projects. However, care should be taken to ensure that, for a particular application, consideration is given to the meaning and intent of the wording. Engineering records are full of disputes and litigation which have resulted from the injudicious copying of all or part of a specification or contract document simply because it had been satisfactory for an earlier project.

Following on the preparation of the specification and the calling of tenders, there is the need for inspection and acceptance of the material, facility or work. The inspecting officer must be given guidance to avoid disputes and misunderstandings with the contractor. If there is no guidance in the specification, the inspecting officer is left to use his own experience and judgement in deciding whether the standard offered is satisfactory. This may place him in an awkward and untenable position with the contractor's quality control staff. Where an item fails to meet the specification it is important that the schedule clearly sets down the procedure to be followed and the responsibilities of the contractor and the principal.

Experience has shown that all engineering contracts should be in the form of signed documents. They may vary from a simple straight forward offer and acceptance to a lengthy document detailing all the technicalities and conditions of the work. Many organisations now have well-established contract forms and procedures to meet most conditions likely to arise in their activities. However, from time to time, document clauses used in contract administration by various individuals, groups and organisations are tested in court and it is wise to have standardised clauses which are regularly inserted in contracts and reviewed from time to time by an experienced legal officer in consultation with the engineer.

Chapter 46

Specifications

The purchase of radio engineering plant, equipment and services is generally made after competitive tendering and it is important, therefore, to define in detail as far as possible, what work, equipment or facility is required. Otherwise the offers received may not be for the same thing and there will thus be no effective competition. To achieve this, specifications should be prepared setting forth the requirements in such detail that all organisations or individuals tendering will offer the same thing and the price will be a true measure of the value of the offer.

The specification should:

(a) Define clearly and precisely the type and quality of material, equipment or plant required.
(b) Specify the grade of service or standard of performance of the facility.
(c) Detail the standard of workmanship required.
(d) Indicate the time allowed for delivery or provision of the facility.
(e) Detail the payment conditions.
(f) Prescribe the guarantee expected.
(g) Provide a basis for tendering.

ENGINEERING SPECIFICATIONS

Specifications are necessary in the absence of an exact duplicate unit serving as a sample. The specification consists of a series of specific provisions, each one of which defines and fixes some element of a requirement. The definition should as far as possible be in measurable terms.

Where possible the requirements of the specification should be in accordance with National or International Standards. It is necessary for the specifying engineer to be thoroughly conversant with applicable Standards. Also, more economical offers will usually be received if the specification complies with relevant National or International Standards.

A specification must define exactly the complete requirements of the work. It must detail the results to be obtained within the defined limits. It must state all essential requirements as to the final form of the product and the service which the device is expected to perform. It must define the type and quality of materials and workmanship to be used and provided, and it must give complete quantitative information. The specification should impart its details with facility, i.e. it should be clear, concise and well organised, following a logical and systematic arrangement, and avoiding omissions, contradiction and ambiguity, and be supplemented by drawings, where applicable, to fully describe the work. Each is explanatory of the other, each often incomplete without the other, and unless each is carefully and properly prepared, many disputes and misunderstandings are apt to arise.

The specification should restrict the supplier as little as possible in his method or procedure, as long as the results are in accordance with the requirements for the finished device or the work. In this sense, the specification enables the tenderer to estimate the cost of the proposed work and after the contract is placed, it serves as the rules for inspection and acceptance of such work.

An important consideration often overlooked is that a specification is an instrument of mutual benefit to the purchaser and to the supplier. Avoiding confusion as to the extent and nature of the work, it ensures that the purchaser receives what he states he wants and defines the minimum which the supplier must deliver. The specification protects the supplier from responsibility beyond compliance therewith. For example, the silver plater of an inductor, to be used in the tank circuit of a transmitter, has no part in the design and fabrication of the coil and cannot be responsible for the overall performance of the completed coil. His obligation is discharged if his silver plating conforms to the specification and is of the quality he represents it to be. The specification protects him against possible injustice arising from any misuse of his product by others. A well prepared specification will define the rights and duties of the two parties to the contract to each other, and embody proper provision for any changes in the plans and for the settlement of disputes which may arise.

It is necessary for the engineer to appreciate that specifications for many major works and items of plant are generally widely distributed throughout the country, and in some instances overseas. It is therefore of considerable importance that, both in content and in mode of presentation, the specifications should be of the highest standard. This will not only command respect and confidence from tenderers but will also depict the professional engineer and his organisation in a favourable light.

In summary, the objectives of specification preparation are as follows:

(a) To avoid uncertainty in tendering and to ensure that all tenders are prepared on the same basis.
(b) To obtain economies in tendering.
(c) To simplify administration of the contract.
(d) To minimise dissension between principal and contractor, particularly with regard to variations.

THE SCHEDULE

The schedule and the specification are complementary to each other and the combination comprises the tender document. The schedule may be issued as an appendix to the specification or issued separately. Separate issue, however, generally applies only when large works are involved.

The schedule lists the items of materials to be supplied or the work to be carried out, and in it is set out:

(a) The item number.
(b) Description of the material or work.
(c) Quantities of each item.

(d) Tender price of each item.
(e) Country of manufacture of materials.
(f) Time of delivery guaranteed by the tenderer.

PRINCIPLES OF SPECIFICATION WRITING

A full understanding and knowledge of the facilities or services required, definite ideas as to the materials and practices which should be employed and ability to express these ideas with clarity and with precision in a readily understandable manner are essential qualifications in specification writing. A specification must be accurate, factual, specific, concise and brief.

The main points to be considered during the preparation of the specification may be listed as follows:

(a) Clarity and precision.

A major requirement of a good specification for radio engineering purposes is clarity and precision in composition. The preparation of a good specification is an art, but it is art in which clarity and precision of expression are fundamental. A pre-requisite is that the person drafting the document has a clear understanding of the material, work or service, because a great deal of poor English in specifications results from confused and muddled thinking, rather than any lack of familiarity with the accepted rules of grammar.

Paragraphs should be constructed coherently and proper consideration should be given to sentence structure, so that the specification reads smoothly. Words should be chosen to present the requirements clearly and concisely, and the accepted rules of grammar, punctuation and spelling should be observed. Every portion and detail of the work should be described in clear and simple language which will be understood by the tenderer and those later involved in the work. Also, clear and precise language, in sufficient detail to meet all reasonable contingencies of the work and suitable for literal interpretation, will not only prevent unncessary disputes but will add to the efficiency and effectiveness of supervision and inspection.

Uniform terminology should be used. Once an item has been specified the same term should be used throughout the specification. It is both confusing and irritating to find words like antenna and aerial, or plate and anode, or tube and valve being used throughout the text.

The specification not only describes the equipment or work, but also serves as the instruction to engineers and inspecting offiers in the administration of the contract. It is therefore necessary that the specification should be capable of a literal interpretation, not only for a clear understanding between the contractor and the principal, but so that the engineer or inspecting officer in charge of the work will know what requirements he is bound to enforce.

In most of his work, the words used by the engineer are sufficiently clear, because no great degree of accuracy in interpretation is required. However, for specification purposes, the meaning and intent of these same words must be crystal clear and precise. They must be defined and qualified to bring out the limited meaning. For example, two weeks time could mean 10 working days or 14 calendar days. Similarly two days can mean working days or a period of 48 hours.

The words 'shall' and 'will' should be used throughout the specification to express mandatory requirements, the former being used when an instruction to the contractor or a requirement is concerned, and the latter when the specification states the condition with which it will comply. The word 'should' is often found in some mandatory requirements but this should be avoided. It is preferable that it be used only in non-mandatory matters and recommendations, as may be appropriate for the situation.

The specification documents are in general an integral part of a contract and, in consequence, in the event of a dispute, their validity is liable to test in legal proceedings. If schedules fail to state requirements explicitly, unsuccessful tenderers may contend that competition on a basis of equality has been frustrated. The need to state requirements in clear and unequivocal terms cannot therefore be too strongly stressed.

(b) Limitations and restrictions.

In compiling the specifications, the engineer must continually keep in mind the economic aspects of the work. He should describe the materials and work in such terms as will ensure that standards of quality adequate for the particular requirement are obtained at the minimum cost. Only the average requirements which characterise a good material or standard of workmanship desired should be embodied in the specification, unless there are special circumstances, such as high reliability space equipment. He should avoid any stipulations which would give rise to unnecessary expenditure in respect of material, processing, testing, packaging and workmanship. The minimum requirement for materials which serve as a criterion of rejection determines very largely the cost of the work. A specification should contain the fewest possible restrictions consistent with obtaining the material or work required. To base a specification on the very highest tests known of a given material, and to require this extraordinary quality for all the material furnished, may be uneconomic for the majority of works.

Limitations which are excessively severe should not be incorporated without very good reason. Often they are unnecessary, they add considerably to the cost of the job, they prevent intelligent offers by unnecessarily restricting the number of tenderers. Frequently, tight specified requirements are difficult to meet on the average, particularly for a newly developed product and may result in demands by the contractor for concessions which may have to be agreed to, if the work is to be kept on schedule. It often leads also to friction and in some cases even underhand practices in order to have the device passed by the inspecting officer. Average requirements are, as a general rule, readily enforceable.

It is also unwise to specify too closely to a particular manufacturer's equipment, unless the device is the only one which the engineer is prepared to consider. Under these circumstances there is little point in calling tenders. Material should always be specified in sufficient detail, and in such a manner, as to leave the tenderers free to offer any suitable material. Also, the description should have reference to the ultimate end to be accomplished, rather than to the means and methods the contractor has to employ to achieve that end.

(c) Indeterminate specifications.

Clauses which include 'as directed by the engineer', 'as considered necessary', and the like, should not be used in the specification as the tenderer or contractor has no means of determining precisely the extent of the work or standard of workmanship required. Specifications must be entirely practicable and feasible so that those required to carry them out, and those required to interpret them for inspectorial, acceptance and commissioning purposes, will find no occasion to use discretion in the interpretations of the stipulations.

Sometimes these phrases or clauses may be accepted without question for a small job, but for a large work there may be uncertainty as to the extent of the work or service and the practice of including such indeterminate wording is inexcusable. There could, for example, be a vast difference in the extent of the work if an item in the specification calls for the touching-up of paint work of 20 transmission line poles 'as directed by the engineer', compared with the touching-up of paint work of a 200 m mast 'as directed by the engineer'. If the work is worth doing, the tenderer has a right to know the exact requirements before he tenders, and should not be held subject to the uncertain requirements of the engineer. Different engineers may have widely different views on what should be done, or the standard of workmanship, if it is left to their discretion.

(d) Obscurity and ambiguity.

A specification is obscure when the reader finds difficulty in gathering the real meaning of the various clauses. Speaking generally, it may be said that technical people who are thoroughly at home in their particular discipline are sometimes liable to become obscure, because they frequently take too much for granted. They themselves see so clearly the connection between cause and effect that they think it unnecessary to state clearly many things which are plain to them but may be quite unknown to the reader. A common form of obscurity in writing specifications is known as ambiguity. In this form, a sentence may convey either of two meanings.

It often happens in many engineering situations that an engineer, other than the one who wrote the specifications, has to settle questions about the intentions of those specifications. It is important, therefore, that every requirement and instruction be set out clearly and precisely so that there is no doubt as to the intention. There should be no uncertainty as to what is required and as to what the engineer will actually require.

Specifying in a negative sense can cause the meaning to become obscure or at least not immediately apparent. For example, one specification called for the line current control switch of a 50 kW transmitter antenna matching unit to be placed off centre by not more than 30 cm from the meter. In a subsequent re-issue, the specification was amended to read 'the switch shall be placed within 30 cm of the meter'.

(e) Indefinite specifications.

Many indefinite clauses in specifications can be traced to carelessness, ignorance as to the exact requirements or mental laziness on the part of the specification writer. In practice, it is found that very few indefinite clauses are incorporated for dishonest purposes.

Indefinite expressions often found in specifications, such as reasonable, good regulation, best quality and the like should be avoided. Also, such qualitative terms as good, suitable, soft, hard, small, big and strong, should not be used alone, but should be related to some standard reference. Such indefinite working may result in the tenderer loading his price to cater for a standard that the engineer had not intended.

The writing of a definite specification is however not as easy as it first seems, as it may prove indefinite through the various conditions under which it may be exercised. For example, in specifying a variable-output high tension supply, for a broadcast transmitter, to allow the output voltage of the supply to be varied over a range from zero to 10 kV with a regulation of plus or minus 200 V at 10 kV, how does the engineer word the specification to indicate the regulation for all other supply voltages? A broad statement such as ± 2% would seldom be applicable, because the relationship may not be linear. Additional information must therefore be supplied. A graph may supply all the information necessary for the tenderer to fully appreciate the real requirement. Another method of presentation would be a tabulated list of regulation values for various output voltages.

Just as the engineer drawing up the specification may incorporate indefinite requirements which could be misconstrued, he must be just as careful in interpreting specifications of equipment supplied by the tenderer with his bid. Many specifications issued by manufactuers with their products often lean towards the theoretical ideals rather than the practical conditions. For instance in the example on the high tension power supply, the regulation indicated by the tenderer could be that achievable under ideal conditions and not those achievable in the field with wide temperature variations, changes in mains supply voltage or frequency and various levels of transmitter modulation loading.

Some specifications are drawn up on the basis of requiring the contractor to assume all the risks and responsibilities of a work. This is a short sighted policy, because in dealing with experienced and reasonable contractors, everything has a price. A contractor tendering to an indefinite specification may add more than enough to cover probable expenses. The principal therefore pays more, and usually much more, than he would under properly drawn up specifications which are definite and clear cut.

(f) Conciseness.

Whilst it is important that every element of the specification be clearly, completely and precisely described, it is also important and essential that such description be as brief as is consistent with a complete description. A concise specification is frequently much easier to read and interpret than a verbose one. The meaning is often clearer and the intent more easily followed.

Conciseness may be attained by omitting all irrelevant material and all words not needed for a clear, complete and correct exposition of the specification. However it should not be sought by the omission of information required for a full and proper understanding of the specification. Care must be exercised that conciseness is not taken to extremes. Its value should be weighed against completeness and the technical correctness of information.

One of the main causes for lack of conciseness in a specification is failure to analyse and organise the material carefully before writing the specification and neglect of the precaution of editing the document critically before putting it in final form. The engineer who is not clear as to what is required may tend to resort to excessive verbiage to compensate for clear thinking. Careful reading of the first draft almost always reveals many places in which the phrasing can be condensed and simplified, without sacrifice of clarity and precision. Only those characteristics or features which are essential should be specified in order to secure the results desired and any paragraph, sentence, word or drawing which can be omitted from the specification without material effect on the complete understanding of the subject should be deleted.

TYPES OF CLAUSES

There are three main types of specification clauses used in radio engineering. They are (a) Materials and workmanship clauses (b) Performance clauses and (c) Closed clauses. However, most specifications contain a mixture of these clause types and their associated features in varying degrees, as the use of these clauses in their unmodified form is often not desirable in most practical situations where project type works are involved.

In material and workmanship clauses, materials and workmanship details are specified with a result that achievement of the necessary performance is closely tied to the engineer's standard of design and performance. If, as an example, the engineer specifies that 'the transmitter tank circuit inductor shall be fabricated from 12 mm diameter copper tubing', then it is not good enough for the contractor to propose the installation of his standard solid rectangular section inductor despite his thinking that it would be suitable.

The engineer may have good reason for specifying a tubular type conductor. It is the contractor's responsibility to provide the specified unit but once he has done that the onus for the overall performance of the coil is with the designer. Basically these clauses are restrictive types since they restrict the tenderer to the engineer's own design and specification. A major advantage of these clauses is that the principal knows that the product furnished will not vary significantly from the preliminary design and that the tender price is likely to be close to his estimate of the cost of the work.

In performance clauses, the object is to describe the end result the work must achieve. They specify what the furnished product must do and at the same time indicate certain factors which could affect the design and construction. This is a widely used method particularly with small organisations who cannot support a design engineering group. For example, single broadcast transmitters are frequently obtained along these lines. The tender simply calls for a broadcast transmitter of a certain power output and frequency to meet the technical requirements of the licensing authority. This allows the contractor to use materials of his own choice, assembled as he wishes provided the specified performance meets the licensing requirements. In this situation the tenderer becomes the design and construction authority.

Closed clauses give control over the product supplied similar to materials and workmanship type clauses but in a more emphatic form. In many cases items of material are specified by reference to brand names etc. with a result that the contractor only guarantees his workmanship. The final overall performance depends upon the sufficiency of the engineer's design and specification. This procedure makes standardisation easy because the engineer has complete control over the selection of the equipment and tendering is straight forward requiring only minimum of data and explanation. Radio test equipment and instruments are frequently purchased under this arrangement.

ASSEMBLING MATERIAL FOR THE SPECIFICATION

The preparation of a specification depends upon the possession of definite knowledge of performance, composition and properties of equipment, plant and materials and of the limitations and capabilities of manufacturing, installation and construction methods. During the early stages of development of many new products this knowledge is not available. The producer is feeling his way by investigation and trial towards a satisfactory article. The purchaser is naturally cautious about using a product which has not been field proven and of which he may doubt the usefulness. It is only as the product comes into wider use that knowledge of its characteristics and of the effects of changes of composition, design and manufacturing or construction methods become available. Thus a detailed specification is the result of the gradual accumulation of knowledge by both producers and purchasers, until the latter have found out exactly what they want and the former have found out all about the means of meeting that want.

Before the engineer starts assembling the material, there are two conflicting demands which have to be reconciled. The first is that the engineer preparing the specification must be much better informed about the project work which has to be accomplished than those for whom the specification is being proposed.

Secondly, he must concentrate on the matters strictly necessary for the specification and not waste time gathering material which, however interesting, will not be of immediate and direct use for the job in hand.

It is obviously important to get the balance right. If he fails to find out enough about the project, he may draw misleading conclusions and prepare an inadequate or misleading specification. If he goes to the other extreme, he may take too long in merely assembling the material and data, and leave himself and others too little time for reviewing it properly.

There is no hard and fast rule about the best way of resolving this dilemma. There is, however, one useful guide: to relate the efforts closely to the purpose of the document. Everything necessary for that purpose must be fully studied but he need not stray beyond it. It is essential that the engineer should fully and accurately know the exact purpose and requirements of the work to be specified. *Table 46.1* shows a specification check list of the type often used by many engineers when assembling data preparatory to writing the specification. The particular example is associated with a specification for a microwave radio relay system and each item in the system is described in terms of its key parameters.

The material for the specification may be drawn from various sources, such as:

(a) Documents, technical reports and other specifications.
The physical process of extracting material from documents is not difficult, provided that the idea is abandoned that a document must be read from end to end in order to master it. This is rarely necessary. In the course of design work associated with a complex project, particularly one involving systems, many voluminous documents in the form of technical design reports, mathematical calculations, model test, field trials etc. are prepared and it would be virtually impossible for the engineer preparing the specifications to study in details, and digest all the detailed information available on the subject. The first essential therefore is to find out which and what parts of the documents require the most attention.

Table 46.1 SPECIFICATION CHECK LIST FOR MAJOR ITEMS

Sub-system	*Components*
Transmitting equipment	1 Exciter (r.f. oscillator) 2 Power amplifier
Receiving equipment	1 Low noise pre-amp 2 Mixer 3 i.f. amplifier 4 Combiner 5 f.m. demodulator
Antenna system	1 Transmission line/waveguide 2 Antenna reflector 3 Antenna feed horn 4 Dehydrator 5 Pressurisation equipment
Multiplex equipment	1 Baseband amplifiers 2 Group through-filters 3 Group-modems 4 Group patch-board 5 Group distributing frames 6 Supergroup modems 7 Multiplex frequency gen.
Termination equipment	1 Circuit condition monitoring facilities 2 VU meters and other level indicators 3 Distortion measuring equipment 4 Patching facilities 5 Distribution frames 6 Filters and channel termination sets 7 Signalling equipment 8 Control monitoring equipment i.e. fault alarm and auto switch equipment
Power generating equipment	1 Generators 2 Switchgear 3 Distribution equipment 4 Starting equipment
Environmental control	1 Air conditioning and heating 2 Humidifiers and de-humidifiers 3 Ventilation 4 Air filtering

OF RADIO RELAY EQUIPMENT

Key parameters	*Specified by equipment designer*
1 r.f. output impedance 2 Carrier frequency stability 3 Spurious emission suppression 4 Pre-emphasis characteristic	1 Output frequency 2 Power output 3 Radio frequency bandwidth 4 Deviation capability
1 r.f. input impedance 2 Frequency stability 3 Image and out-of-band frequency rejection 4 Intermediate frequency characteristic (a) i.f. centre frequency (b) output impedance	
Antenna 1 Type 2 Characteristic impedance 3 VSWR 4 Transmission line or waveguide	1 Dual diversity 2 Diameter of reflector 3 Type of transmission line 4 Polarisation 5 Shrouding 6 Spacing for diversity 7 Support structure characteristics
1 Input and output impedance levels and frequencies 2 Noise and interference 3 Envelope delay distortion 4 Total noise 5 Harmonic distortion 6 Stability of multiplex frequency generator 7 Net loss variation 8 Gain change for output level increase 9 Maximum overall change in audio frequency	1 Number and arrangement of channels, groups and supergroups
1 Input and output impedance, levels and frequencies 2 Noise	As required
1 Frequency regulation 2 Voltage regulation 3 Total load	Total primary power required
1 Temperature 2 Humidity 3 Pressure 4 Lightning protection	As required

Reading technical documents should be a ruthless process, strictly related to one object and wasting no time on appreciating the document for its own sake. Quick and accurate realisation of what need not be read is a quality which the engineer should cultivate. It involves the power to know at a glance whether a document contains anything of use or can be ignored. It involves deliberate turning aside from irrelevancies, however agreeable, if they do not serve the purpose in hand. Once the relevant information has been located it must be thoroughly studied and mastered. The object is not to save effort, but to apply the whole effort to the best advantage.

It is useless to embark on the collection of material unless the purpose for which it is needed is accurately defined. The engineer must know, within reason, what he is looking for. He must have a clear enough conception of his object to enable his judgement to distinguish between what is likely or unlikely to be useful to him.

Originality in the writing technical specifications is not recommended, particularly for the inexperienced engineer. Often the engineer may not be experienced in every phase of the work for which he is preparing a specification, and well established precedents are safe guides to follow. It is useful, therefore, to assemble as many previous recent specifications as possible which have been used on works of a similar nature. Well prepared specifications which have proved their soundness in actual work situations provide probably the best source of information and the adoption of well considered clauses that are really applicable to the particular case at hand has been found to be extremely useful.

However, great care must be taken to ensure that the material is applicable for the situation and that it is in accord with current policies. A careful analysis and study of the subject is necessary before using the material of another specification, and requires much more than the judicious copying of the clause. Unintelligent copying should be avoided as it not only results in the possibility of setting down incorrect parameters, but may result in the insertion of conditions or tolerances which have no application to the case in hand. Also, mistakes in the original document may be carried forward into the new specification resulting in a new cycle of embarrassment for new people. Some cases are known where clauses were copied, because the engineer did not fully understand their significance, but felt their inclusion was required for the perfection of his specification.

Very seldom will a specification of a previous work be found to be fully applicable to a new work, and consequently a major danger in copying to any great extent is the possibility of overlooking an important requirement peculiar to the case in hand. Also, all specifications in actual daily use need revision from time to time, as new information is obtained, due to progress in knowledge and changes in techniques, methods of manufacture and use of materials. In the preparation of specifications for radio engineering works, often the materials are so numerous, the processes so involved and the various parts and divisions so manifold, that some material, process or work is apt to be overlooked, and omitted, unless special precautions are taken to comprehensively analyse the full requirements of the work. Overlooking important specification requirements can be much more serious than copying meaningless and irrelevant material from another work.

Many specifications are integrated with drawings and the specification cannot be properly interpreted without reference to these drawings. In these cases, copying of contents of the specification must be carefully watched as a totally different meaning may be placed on the wording of a clause when it is read separately from the drawing. The specification may be interpreted as being complete in itself, when such is not the case.

(b) Knowledge possessed by others.
Very rarely can the engineer obtain all the information he needs to compile the specification. He needs the knowledge and experience of other engineers and workers to supplement what the collected documents contain. The information he seeks may be fact or opinion. The former generally presents little difficulty but when one is handling matters of opinion it is not at all easy to be detached in one's attitudes. It needs discipline to keep emotion in check when we hear an opinion expressed with which we agree or disagree. The material incorporated in a specification is very important and must be accurate, specific and correct and the engineer should be aware of the risks associated with opinions. They can however be largely eliminated by deliberately analysing them and applying his own correctives, so that balance is restored.

A special problem arises when the engineer has to deal with experts as sources of information. Experts, particularly those associated with the research activities, are not always skilful in explaining the technicalities in a simple enough language to allow the specification writer to wholly understand all the facts he requires. Where the expert provides advice, the engineer must display a relentless insistence on testing the advice against the facts at his disposal.

(c) The engineer's own knowledge.
Logically it would seem that the engineer's own knowledge should be considered as the first and not the third sources of information. The wise engineer will not use his own knowledge in preparing the specification as an actual source of information until last.

The first use of his own knowledge should be to guide him towards those matters which call for further study of reports or for consultation with other persons. In the course of that study and consultation his knowledge will not only be increased, it will be corrected and modified. At the end of the preparatory work, he would be sure to find that there are several points on which his initial knowledge, had he relied on it in the first place, may have led to error.

There is also the problem of personal bias which the engineer must appreciate. That all people whatever their line of work are to a greater or lesser degree biased in their judgement of themselves, and of all the problems and conditions with which they come in contact, is established by common experience. This bias is due to their local and individual experience, special knowledge, personal interests and other factors. That this bias is possessed by others and injuriously affects their judgement is easily recognised, but it is more difficult for the individual to recognise such bias in himself. It is, however, most important for the engineer to recognise the possibility of his own bias slanting the specifications towards his own interpretation of the requirement. He should provide for its elimination so far as possible by the same factors of safety which he applies to uncertainties in the technical areas.

PLANNING THE SPECIFICATION

A well prepared radio engineering specification will cover the following aspects:

(a) Task.
A clear definition of the scope and nature of the work expected of the contractor.

(b) Detail of the work.
A definition of the nature and extent of the work, material or equipment characteristics, types of construction and character of the finished product, required for each item.

(c) Site of the work.
In a construction work, a clear identification of the geographical location of the site and method of access.

(d) Facilities, materials, drawings and work to be provided by the principal.
A statement of items to be supplied by the principal.

(e) Work by principal.
A statement of any work to be carried out by the principal or others, together with time tables and any desired limitations or restrictions to be placed on the contractor's activities, in the interests of co-ordination of the overall project work.

(f) Inspections, tests and commissioning.
Details of methods of inspection, tests and commissioning to which the work is to be subjected, together with tolerances, performance, finishes and quality of workmanship.

(g) Basis of measurement and payment.
A clear description of methods to be used in arriving at the actual quantities of units supplied or completed under the contract and payment arrangements.

(h) Tender details.
Summary of the information required to be submitted by the tenderer and the date of closure of tenders.

A considerable amount of instruction to tenderers is necessary, besides setting down the technical requirements of the work. These instructions are often placed before the technical specifications and generally indicate how the tenderer is to go about submitting his tender. They also bring to his notice essential particulars, such as freight charges, completion dates, extras and many other details which may substantially affect the final estimate of the cost of the work.

The tender should be submitted on a definite form which generally forms part of the schedule document. Some organisations require a deposit for the document with the money returnable after the tender is accepted or rejected and provided that it has not been withdrawn in the meantime. No extension of time for submission of tenders is generally permitted other than in exceptional circumstances. However, when extra time is granted to a tenderer all other interested parties should be also given the extra time.

The wise engineer will lay special stress on completion or delivery dates, as obviously the cost of the work can be considerably influenced by the time available, particularly where the work has to be carried out in a harsh environment such as a tropical location where the monsoon season may cause serious disruptions to field works.

For important works, penalty clauses are written into the contract as incentive for the contractor to meet the time limit requirements. This may be in the form of deduction of a lump sum from payments due, or as a percentage deduction for every week or month that the work exceeds a stated period of time. The contractor generally has right of appeal for unforeseen circumstances, such as force majeure.

The sections of the contract dealing with the so called general conditions are usually drawn up by the commercial experts of the organisation. Although the engineer may be responsible for suggesting the subject matter, the commerical experts are responsible for the actual wording. Variations in the general conditions are infrequent and only minor changes are usually necessary over a long period of time.

While the general non-technical specifications and the general conditions of contract may appear unnecessarily voluminous, their purpose and effect is to clearly define the business relations of the parties and to prevent injustice being done to either party. They are also calculated to prevent litigation and delay in final settlement, and if they are able to effect these ends they are well worth while inserting, even when the work is relatively small.

The general non-technical specification and the general conditions of contract are very similar. The development of these provisions has been somewhat inconsistent over the years and, as a general rule, there is no set procedure for the allocation of material between these two forms. Frequently, it is determined by considerations of expediency and emphasis. The provisions of the specification and of the contract are equally binding on the contractor, but as the contract document is a stronger document from the legal aspects the general conditions of contract are generally drawn up or at least closely examined by the legal and commercial experts.

Large organisations which have many specifications often have a final clause designated a 'General' clause and includes any matter of a general nature not included elsewhere. In particular it contains, in the case of amended specifications, a sub-clause giving details of the differences between the current issue and the issue that it replaces.

The specification should include drawings, where appropriate, an index and summary of contents. The index is particularly valuable for quick reference during on-site activities. The summary assists in determining if all relevant matter is included in a particular copy of a specification. For a very large project involving buildings, civil engineering works, internal equipment transmitters etc., external plant antennas etc., and support facilities the technical section of the specifications should be grouped into types of construction or equipment. This facilitates distribution to likely subcontractors by a prospective tenderer.

As a general rule the specification is divided into a number of main sections and in each section the work is set out in some predetermined sequence. The arrangement is of no great consequence, but consistency throughout makes for easy reference. This is important, because the document which in some major works can involve hundreds of pages will be used by the field staff as their main guide, sometimes for a year or more.

MAIN SECTIONS OF THE SPECIFICATION

There are, in general, five main sections to the usual radio engineering specifications. These are:

Section 1 Introduction

The introduction section encompasses the following:

(a) Title–Subject matter of the specification.
(b) List of contents, issue number and date of issue.
(c) Preliminary deposit.
(d) Discount.
(e) Intention.
(f) Extent of the work.
(g) Definitions.

Section 2 Information, equipment and facilities to be provided

This section covers the following five aspects:

(a) Information to be supplied by the tenderer.
(b) Information to be supplied by the contractor.
(c) Information to be supplied by the principal.
(d) Equipment facilities to be supplied by contractor.
(e) Equipment and facilities to be supplied by the principal.

EXAMPLE 46.1

An example of Section 2 of a typical specification prepared for the supply of several medium frequency broadcast transmitters is as follows:

2.1 Information to be Supplied by the Tenderer.
Sufficient information should be furnished with the tender to enable the full merit of the offer to be assessed.

The tenderer shall furnish, in duplicate, with his tender:

(a) Comments on each and every clause (including sub-paragraphs) in the order in which they are in the specification, indicating whether or not the equipment offered complies with the individual clause.
(b) Statement of guarantees.
(c) A complete description of all equipment offered including:
    (i) A comprehensive block schematic diagram showing the overall technical details of the equipment.
    (ii) Details of the total primary power consumption of the equipment when delivering the full rated carrier power into the artificial antenna (1) unmodulated, (2) when modulated 40% with a sinusoidal tone of 1000 Hz, (3) when modulated 100% with a sinusoidal tone of 1000 Hz.
    (iii) Overall sizes and weights of the units comprising the transmitters.
    (iv) Photographs of the equipment where available.
    (v) Complete information regarding the electron tubes and semi-conductor devices which will be used in the equipment.
    (vi) Precautions taken against entry of dust, prolonged high humidity and minute insects which exist in tropical vegetation.
    (vii) Extent of ventilation required for any externally mounted components.
(d) Preliminary information regarding foundations and building accommodation requirements.

2.2 Information to be Supplied by the Contractor.

The contractor shall supply the following information relating to the equipment ordered as part of the contract and without additional charge:

(a) Handbooks shall be supplied in accordance with the specification as follows:
   One copy for each transmitter supplied, for the principal's office, addressed and packed separately. Two copies for each transmitter supplied, for the station, addressed and packed separately.
(b) Linen transparencies. The contractor will be required to supply sets of linen transparencies of all drawings included in the handbook.
(c) Certified test results: The contractor shall supply details of the tests and measurements recorded during acceptance testing of the equipment and certified as correct by the inspecting officer as follows:
   One copy for the principal's office.
   Two copies for the station to which delivery of the equipment is to be made.
(d) Details of foundations: cabling entries, cooling duct entry and exit, and any mounting or installation features involving building design to be supplied within two months of acceptance of the tender by the principal as follows:
   One copy for the principal's office.
   Two copies to the station.

2.3 Information to be Supplied by the Principal.

The contractor will be advised of the operating frequencies for each transmitter at the time of, or as soon as practicable after, the order has been placed.

2.4 Equipment and Facilities to be Supplied by the Contractor.

The contractor shall supply and deliver the transmitters complete in all respects so that connection of primary power supply, programme input equipment, transmission line and antenna system will render them fully operative. The transmitters shall therefore include:

(a) Power equipment for converting the primary power supply to forms suitable for energising the transmitters.
(b) Electron tubes, semi-conductors and artificial antenna and cooling systems.
(c) Control, protection, supervisory, local antenna switching equipment and artificial antenna.
(d) Cabling busbars and hardware but with the exception of the main earth busbar.
(e) Base plates, sills, holding down bolts and other assembly devices for the transmitter.

2.5 Equipment and Facilities to be Supplied by the Principal.

(a) Building accommodation, including ducts in floors and walls cut outs.
(b) Concrete foundations.
(c) Primary power supply.
(d) Main earth busbar throughout the station building.
(e) Radiating system including transmission line, and antenna.
(f) All power and audio frequency cabling interconnecting the transmitter with the incoming power supply panel, and the programme input equipment.

(g) Control desk to provide integrated control of several transmitters, where necessary.
(h) Lighting and heating, and other building services.

Section 3 General non-technical specifications
The general non-technical specifications to be included as part of the overall specification will depend on the character and extent of the work and they often vary with each specification, although seldom to any great extent. They define all the general requirements of a non-technical nature which are applicable for the particular specification. The line of demarcation between the general non-technical specification and the general conditions of contract are sometimes hard to determine and there is no fixed rule for the allocation of subject matter between the two documents.

EXAMPLE 46.2

The following example indicates the form and composition of Section 3 for a typical radio engineering project involving the provision of internal and external equipment and plant.

3.1 Tendering.

Tenders must be submitted on the tender form which is available on application. The attention of tenderers is drawn to the conditions of tendering appearing on the back of the tender form.

Any tender which is not delivered in a closed envelope at the place and at or before the time fixed for the closing of tenders or properly completed or signed by the tenderer and witnessed may be rejected.

3.2 Alternatives.
Tenderers are invited to offer alternative materials or designs which are in accordance with the main requirements of this specification provided that full details of differences between the alternative offered and the material or design specified are stated. When an alternative material or design is offered, it will be assumed that this is in accordance with all the requirements, except where specifically stated in the tender to be otherwise.

3.3 Lump Sum Tender Prices.
The tender shall be a lump sum, including any money provisions mentioned, sub-contractors profit and the like.

3.4 Currency.
If prices are subject to adjustment in the event of a variation in exchange rate, the tenderer must state clearly:

(a) The currency intended.
(b) The amount of the tender price subject to exchange.
(c) The basis on which adjustment is to be made.

3.5 Prices.
The prices tendered shall be considered firm unless the tenderer stipulates that the prices are subject to adjustment in respect of variations of costs.

Where there is such a stipulation, the tenderer shall:

(a) In the case of material manufactured by the tenderer:

Indicate in the tender the basic date/dates for labour rates and material costs and keep detailed records of original estimates of cost showing how tender price was derived. The successful tenderer shall record details of actual costs incurred as against estimates of costs included in his tender.

In the event of any variations of the prices either up or down, all records must be made available for the purpose of cost investigation by the principal.

(b) In the case of material not manufactured by the tenderer:
Indicate the basis sought to reflect variations in costs.

3.6 Rates of Freight.

Tenderers shall state the rates of freight on which their tender prices are based. Subject to these rates being stated, in the event of the tender being accepted, adjustments will then subsequently be made, either for or against the principal, according to the rates actually paid and subject to the production of satisfactory documentary evidence.

3.7 Time for Completion

The time for completion of the whole of the work is . . . weeks (which time is inclusive of all holiday periods) from date of acceptance of the tender.

For the guidance of tenderers, the delivery, installation, testing and handing over (excluding maintenance period) should comply with the following proposed target dates:

(a) Manufacture and ship to site	. . / . . / 19 . .
(b) Start installation	. . / . . / 19 . .
(c) Start testing	. . / . . / 19 . .
(d) Commission and handover	. . / . . / 19 . .
(e) Special integration tests	. . / . . / 19 . .

3.8 Payment.

(a) For Internal Equipment.
Upon certification by the principal's inspecting officer, the successful tenderer shall be entitled to progress payments as follows:

(i) Payment of 90% of the contract price of all items, upon delivery of all materials in accordance with the contract.

(ii) A final payment of 10% of the contract price when the equipment and plant have been accepted after installation in accordance with specifications, provided that all adjustments of contract price resulting from additions to, deductions from, or variations of, the specified requirements authorised by the principal in writing, shall be effected in making this payment, provided also that all information required, as at that time, by the conditions of contract shall have been furnished to the satisfaction of the principal.

(iii) No part of the final payment will be made when otherwise due unless, in the opinion of the principal, the guaranteed performance of the plant is being achieved and the plant is in good order and condition at that date, except for deterioration which may have occurred due to fair wear and tear or negligence by persons other than the contractor's servants. Final payment will be made only on the condition that the successful tenderer enters into a bond of like amount to make good any defect of workmanship or material which may become manifest during the guaranteed period.

(b) For External Plant.

The contractor shall be entitled to payment for the fabrication and delivery of the plant as follows:

(i) An initial payment of 75% of the value of the item upon completion of the delivery of the plant to the site.

(ii) A further payment of 20% of the value of this item after acceptance of the completed plant, provided that all adjustments of contract price resulting from additions to, deductions from, or variations of the specified requirements authorised by the principal in writing shall be effected in making this payment, and provided also that all information required as at that time by the conditions of contract shall have been furnished to the satisfaction of the principal.

(iii) The final payment of 5% of the contract price for this item on expiration of three months after acceptance in accordance with the specification provided that all information required as at that time and by the conditions of contract shall have been furnished to the satisfaction of the principal.

No part of the final payment for plant will be made when otherwise due unless, in the opinion of the principal, the guaranteed performance of the plant is being achieved and the plant is in good order and condition at that date, except for deterioration which may have occurred due to fair wear and tear or negligence by persons other than the contractor's servants.

No payment will be made until the contractor enters into a bond equivalent to 5% of the contract value to make good any defects of workmanship or material which may become manifest during the guarantee period.

In the event of the erection of the plant being delayed by circumstances outside the control of the contractor, consideration will be given to payment of the additional and final payments of 20% and 5%.

Claims for payments of 20% and the final payment shall include particulars of previous payments.

The contractor shall be entitled to full payment for concrete foundations, 30 days after placing of the concrete, provided that the requirements of the specifications have been met.

The contractor shall be entitled to full payment for the erection of plant after acceptance of the completed plant in accordance with the specifications.

The contractor shall be entitled to full payment for the painting of plant after acceptance of the completed works.

The contractor shall be entitled to full payment for the tools, drawings, transparencies and spares after acceptance in accordance with the specifications.

Claims for payment shall be accompanied by a statement setting forth particulars of the items for which payment is sought.

The payment of any contract sum or portion thereof shall not prejudice claims by the principal in respect of any defects, other than those due to normal wear and tear or due to negligence of the principal that may become manifest during the guarantee period.

3.9 Customs Duty and Primage

Where material offered includes imported components or basic raw materials, the price shall include any Customs Duty and/or primage payable on such components or raw materials, and the tender shall show separately the rate and amount of Duty and/or primage applicable. Any variation in the rate or amount of Customs Duty and/or primage actually paid shall be to the principal's account.

It shall be obligatory on the successful tenderer to advise the principal of any variation (up or down) in the amount of Duty and/or primage actually paid.

3.10 English Language.

All information supplied by the tenderer and contractor and all markings or designations on equipment, meter scales and on circuit diagrams shall be written in the English language.

3.11 Packing.

The equipment supplied shall be securely packed to avoid damage during storage and transport to its destination. The contractor shall give particular attention to the protection of equipment for transport by sea including wharf storage and handling.

All components liable to sustain damage or to cause damage if mounted in the equipment during transport shall be removed from the equipment and packed separately.

The contents of each package, together with the number of the contract, under which the material is supplied, shall be clearly indicated on at least two external surfaces of the package.

3.12 Rates of Freight.

Tenderers shall state the rates of freight on which their tender prices are based. Subject to these rates being stated, in the event of the tender being accepted, adjustments will then subsequently be made, either for or against the principal, according to the rates actually paid and subject to production of satisfactory documentary evidence.

3.13 Guarantees.

(a) For Internal Equipment or Plant.

The tenderer shall submit, with his tender, an undertaking to accept the following guarantees which will be required of the contractor:

- (i) A guarantee that the equipment and plant supplied will be in accordance with the specifications, varied only insofar as specifically stated in his tender and agreed to in the contract.
- (ii) A guarantee to make good at his own expense any defects, other than those due to negligence of the principal, which may arise within a minimum period of 12 months from the date of acceptance of the equipment and plant. The tenderer is invited to indicate the period in excess of this for which he is prepared to guarantee the equipment and plant.
- (iii) A detailed statement of the guaranteed performance of the equipment and plant, and the period over which the guarantee applies.
- (iv) A guarantee of the useful life hours of electron tubes.

The tenderer shall state whether or not he will be prepared to guarantee as a contractor the availability of all components, plant and equipment needed for replacement purposes for periods of 5 and 10 years from date of acceptance of the equipment.

(b) For External Plant.

Guarantees are required to be furnished by the contractor as follows:

- (i) Contractual guarantees as required by the general conditions of contract and specifications forming part of the tender form.
- (ii) A general guarantee in respect of the quality of materials to be utilised in the manufacture of the plant and the grade of workmanship to be achieved.
- (iii) A guarantee that the material supplied will be in accordance with the specifications varied only insofar as specifically stated in the tender.
- (iv) A guarantee that the plant will be in accordance with the design details as approved by the principal.
- (v) A guarantee to make good any defects, other than those due to normal wear and tear or due to negligence of the principal, which may arise within the minimum period of 24 months from the date of acceptance of the plant. Such defects shall include any fault that may develop in foundations due to subsidence, faulty design, poor workmanship, or the use of inferior cement, aggregates, or other materials.
- (vi) Notwithstanding the fact that all design details will be examined by the principal, the contractor will be required to guarantee the overall safety of the plant, when subjected to the wind velocity as indicated in the specification.

3.14 Insurance.

Until the work concerned is accepted by the principal, the contractor shall be solely responsible for all loss, damage or injury which may be sustained by any person, firm or corporation as a result of, or by reason of, execution of works, and shall indemnify the principal and all his officers and agents against all actions, proceedings, claims and demands whatsoever which may be brought or made against them or any of them as a result or arising out of the execution of the works and against all costs which may be incurred in connection with such actions, proceedings, claims and demands and the contractor shall insure in the joint names of the principal and the contractor accordingly. The conduct of all claims is to be carried out entirely by the contractor and the insurers. Prompt notice shall be given of all claims. In the event of any work being undertaken by the principal, the principal shall accept full responsibility for that work.

3.15 Observance of Acts and Regulations

The contractor shall observe and comply with the provisions of all Acts, Ordinances, Regulations, By-Laws, Orders and Rules and all requirements, including the payment of all necessary fees of any Authority, as shall for the time being be in force in the district where the works are to be executed and relate to the execution of work of the kind contracted to be executed or to a person executing such works.

3.16 Assignment and Sub-letting of Works.

The contractor shall not assign the contract or sub-let any part of the work without approval of the principal.

3.17 Notice of Commencement of Works.

The contractor shall give thirty days clear notice in writing to the principal before commencing on-site work.

3.18 Extras and Variations

If at any time whilst the contract works are in hand it shall be deemed expedient by the principal to order plant, equipment, materials or work of a different description from that specified or to increase the dimensions or extent of the contract work or to alter their situation or vary the form or dimensions of the works or of any part thereof or to make any variation or to substitute one class of work for another the principal shall have full power to do so and to order and direct any such variations and additions, and the work involved in any such variations and additions shall be executed by the contractor if of the class of work provided in the bill of quantities at the prices set out in the bill of quantities or schedule of prices if any, and no such variations or additions shall annul the contract or extend the time for the completion thereof, unless such extension shall have been given as provided for in the general conditions of contract.

Before any extra work or work of an altered value or class is undertaken it shall be imperative for the contractor to procure an order in writing from the principal for carrying out such extra or variation of work. The contractor shall not be obliged to carry out such work unless and until such order in writing is given by the principal.

3.19 Disputes.

Any dispute arising under the contract shall be referred to the principal for his decision.

If the contractor is dissatisfied with the principal's decision he shall within 10 days after receiving notice of such decision nofity the principal that he disputes the decision and the dispute shall thereupon be referred to an independent arbitrator to be appointed by the principal and the contractor.

The decision of the arbitrator appointed under this condition shall be final and binding on both parties.

3.20 Removal of Rubbish and Final Cleaning Up.

The contractor shall remove all rubbish and debris resulting from his operations from the site from time to time as is necessary and as directed by the inspecting officer.

On completion, the contractor shall ensure that the premises and/or site are cleaned, surplus materials, debris, spoil and sheds are removed to the satisfaction of the principal, so that the whole is left fit for immediate occupation or use.

3.21 Accommodation and Messing.

The contractor shall make his own arrangements for accommodation and messing facilities for his own engineers and workmen. Permission will not be granted for the contractors staff or any of his sub-contractors to be quartered anywhere on the site. The contractor and his sub-contractors shall arrange for the provision of transport to and from the place of accommodation and to the works site.

3.22 Damage to Property.

The contractor shall make good to the satisfaction of the principal and at his own expense, all damage to buildings, property, plant and finishes caused by the contractor, his sub-contractors and their employees, during the currency of the contract up to the time of acceptance of the work.

Section 4 Acceptance of the material or work

The main points generally covered in this section of the specification may be briefly set down as follows:

(a) Definition of inspecting officer.
(b) Authority of inspecting officer.
(c) General conditions of acceptance, inspection and tests.
(d) Inspections and tests at contractor's factory or works.
(e) Supply of tools, equipment and facilities for acceptance testing work.
(f) Acceptance tests and inspections on site:
    (i) General.
    (ii) Preliminary trials, tests and inspections.
    (iii) Main trials, tests and inspections.
    (iv) Special site trials, tests or inspections.
(g) Test certificates for samples and equipment.
(h) Acceptance test records.
(i) Notice of intention to commence or cover work.
(j) Acceptance certificate.

The details set down in this section may vary considerably, depending on the work, even though there may be little difference in principle.

EXAMPLE 46.3

An example of Section 4 of a specification prepared for the supply of a quantity of 50 kW medium frequency broadcast transmitters is as follows:

4.1 Definition of Inspection Officer.
An officer of the engineering department assigned by the principal to undertake inspection of material and work and to report upon its compliance with the conditions of the relevant contract. He may be a professional engineer or other officer nominated by the principal.

4.2 Authority of Inspecting Officer.
The terms of the contract shall not be varied without the approval, in writing, of the principal. The contractor shall note particularly that the inspecting officer is not authorised to vary the terms of the contract or the specification or to anticipate the approval of the principal of such variations.

The inspecting officer will not knowingly perform any act that will release the contractor in any way from bearing full responsibility in regard to his obligations under the contract. If in the opinion of the contractor the inspecting officer is performing such act, the contractor shall immediately notify the inspecting officer.

4.3 General Conditions of Acceptance Tests.
Acceptance tests on the equipment will be carried out after the equipment has been installed to determine its compliance or otherwise with the requirements of the contract. An inspecting officer will be nominated by the principal for the acceptance tests. If he so desires, the contractor may elect to be represented during the acceptance tests. Acceptance tests shall include such electrical and mechanical tests and inspections as the inspecting officer may consider necessary

to confirm that the equipment or material complies with the requirements of the contract.

The principal's inspecting officer may, at his discretion, reject the whole or any part of the transmitters and spares that, in his opinion, do not comply with the terms of the contract. The contractor shall note particularly that the inspecting officer is not authorised to vary the terms of the contract.

4.4 Tests at the Contractor's Factory or Works.

Notwithstanding the above, tests shall be performed by the contractor at his factory or works to demonstrate that the transmitters and spares will comply fully with the requirements of the contract when installed in their permanent locations. Factory tests shall be carried out under the direction of a responsible professional engineer employed by the contractor. The contractor shall advise the principal, four weeks in advance, of the date on which he proposes to commence factory tests on each set of equipment.

The principal may elect to be represented at the tests by an inspecting officer.

The contractor shall provide, at his expense, all labour, testing and measuring instruments, power, incidental material and other facilities necessary for the conduct and recording of the tests at the factory.

The contractor may be required to carry out, at his factory, the heat run test specified in the specification.

A record of all tests and measurements made during factory testing shall be kept by the contractor.

The Test Certificate shall outline the conditions of test and the results obtained, and all such certificates shall be signed by the responsible engineer-in-charge.

Delivery of the equipment shall not be effected until certification compliance has been given by the inspecting officer.

4.5 Station Acceptance Tests.

The following tests shall be carried out on each and every transmitter as a complete unit after installation at the station buildings, when set up to operate under its normal operating conditions:

(a) Inspection and/or test of any or all component parts.

(b) Any tests which the inspecting officer considers necessary to prove that the guarantees given by the tenderer in accordance with the specifications have been met and that the equipment complies fully with the conditions of the contract.

(c) A heat run for a continuous period of 24 hours at any frequency to be specified by the inspecting officer within the operating frequency range of the equipment. For this test, the transmitter shall be adjusted to deliver fully rated unmodulated carrier power to an artificial antenna and shall then be modulated to a depth of 40% with a sinusoidal tone of 100 Hz, except that during each 60 minutes of the test the modulating depth shall be increased to 100% for the last 10 minutes. The tone shall be kept applied during the whole of the 24 hours. Should this test period be interrupted for any reason other than for short periods required for the above tests, a further period of 24 hours must be commenced, i.e. it must be demonstrated that the transmitter is capable of operating continuously and maintaining the required performance for a continuous period of 24 hours. During and after the heat run, the ratings and limits specified shall not be exceeded.

(d) Spare parts will be passed for acceptance after delivery when inspections and/or tests have shown that they are correct for their intended application and are technically satisfactory.

(e) Tools and equipment for measurement purposes will be passed for acceptance after delivery when inspections or tests have shown that they satisfactorily perform their required function.

(f) Handbooks and transparencies will be passed for acceptance after delivery when the inspecting officer is satisfied as to their content and quality. Notwithstanding that the handbooks and transparencies may have been accepted before the installation of the associated transmitter has been completed, the contractor will be required to supply any subsequent amendments.

EXAMPLE 46.4

A further example of Section 4 of the specification is given below, but in this case it relates to supply and erection of a guyed broadcast radiator.

The definition of inspecting officer is similar to that shown in *Example 46.3* and has not been included:

4.1 General

Acceptance tests shall comprise such tests and inspections as the principal's inspecting officer may consider necessary to confirm that the plant or material complies with the requirements of the contract, and may include those submitted by the tenderer for proving the structure or its components.

The contractor shall be represented by a responsible structural engineer during acceptance tests and the taking of samples of materials. The contractor shall, before work commences, forward the name(s) of engineer(s) nominated for this purpose.

The contractor shall be responsible for providing the principal's inspecting officer with the necessary facilities at the manufacturer's works and at the site, as applicable, to enable him to inspect all work and material. The inspecting officer shall have the right to remove any material forming part of the contract works from the manufacturer's works or from the site in order to apply any tests he considers necessary to confirm compliance with the specifications.

The inspecting officer may, at his discretion, reject the whole or any part of any item that, in his opinion, does not comply with the terms of the contract.

The terms of the contract, including the specifications shall not be varied without the approval, in writing, of the principal. The contractor shall note particularly that the inspecting officer is not authorised to vary the terms of the contract or specifications or to anticipate the approval of the principal for such variations.

The inspecting officer will not knowingly perform any act that will release the contractor in any way from bearing full responsibility in regard to his obligations under the contract. If, in the opinion of the contractor, the inspecting officer is performing any such act, the contractor shall immediately notify the inspecting officer.

After each inspection and after the conduct of tests on the installation, the inspecting officer shall inform the contractor or his delegated representative of any additional work which is required to meet the contractual conditions. This advice shall be supplied verbally, in the first instance, within 24 hours after completion of the inspection or tests and shall be confirmed in writing within a further 24 hours.

Where any work requires acceptance before other work may proceed, e.g. in the case of interim acceptance of concrete work, the contractor will be advised in writing whether or not the work is acceptable, within 24 hours after the completion of tests and/or inspections.

After completion of tests and inspections on the complete installation, the contractor will be advised in writing within 14 days, whether or not the installation has been accepted.

4.2 Factory Inspection.

Preliminary inspection of the steelwork and galvanising will be carried out at the contractor's works. The inspecting officer may witness any welding process or any special process of fabrication employed. The contractor shall notify the principal at least one week before fabrication of the steelwork commences, in order that suitable arrangements may be made for inspection. The contractor shall notify the principal at least one week before the electrical and mechanical proof testing of insulator assemblies commences, in order that suitable arrangements may be made to witness the tests.

4.3 Certified Concrete Samples.

No less than 30 days prior to the commencement of placing concrete on site, the contractor shall furnish to the inspecting officer 'Certified' samples of the materials to be used for mixing of the concrete, together with full particulars of their source of supply.

Not less than 30 days prior to the commencement of placing concrete on site, the contractor shall furnish to the inspecting officer a quantity of six (6) off, 'Certified' standard test cylinder specimens. No concrete shall be placed unless and until tests on such 'Certified' specimens, when made in accordance with the specifications show that the concrete meets the design strength requirements.

In the above context, the term 'Certified' shall mean, in the case of raw materials, certified as being random samples from the intended source of supply. In the case of concrete test cylinder specimens, it shall mean specimens from concrete prepared in a like manner to, or the equivalent thereof, that intended to be adopted, and from raw materials from the intended source of supply.

4.4 Inspection on Site.

Tests, acceptance tests and inspections will be performed on site as follows:

(a) The excavations for the mast foundation and guy anchors will be inspected immediately before pouring of the concrete commences.

(b) Samples of the concrete being placed in the thrust block and guy anchors will be taken and tested in accordance with the specification.

(c) Steelwork will be inspected on delivery to site.

(d) Galvanising will be inspected on site prior to erection of steelwork and any damaged galvanising shall be repaired, prior to erection, by a method approved by the principal.
The principal would normally insist that members so affected be regalvanised by the contractor; the prior approval, in writing, of the principal shall be obtained before any substitute method is utilised.

(e) The completed installation will be inspected, prior to painting, for quality of galvanising, size of members, tightness of bolts and general workmanship. Where galvanising has been damaged during erection, the damage shall be repaired to the principal's satisfaction before painting.

(f) The direct current insulation resistance of the completed mast will be measured by the inspecting officer in accordance with the specification.

(g) Paintwork will be inspected for type and colour of material, number of coats quality of application, completeness of cover and finish.

(h) The contractor shall set the initial tensions in all guys, at the earliest practical date after their installation, and in the presence of the inspecting officer, to ensure that when the mast is free standing under no-wind conditions it is held vertical, and all guys are under tensions corresponding to the design values for this condition.

(i) Special fittings, tools and appliances, spares, drawings and transparencies will be inspected after delivery.

When rock is encountered during excavation, in order that he may be able to certify the contractor's claim for additional cost in respect to the excavation, the inspecting officer shall be advised immediately and this officer will advise the contractor whether or not explosives may be used to remove the rock.

The principal's inspecting officer will maintain a record of the quantity of rock excavated as agreed to on site with the contractor's authorised representative. This record shall be the basis of a claim for additional excavation costs.

The contractor shall advise the principal seven days before he anticipates pouring the concrete for the thrust block and guy anchors and 14 days before the anticipated completion of erection of the structure in order that acceptance inspections and tests may be arranged.

4.5 Acceptance.

The foundations, the completed structure, spares, tools, drawings and transparencies will be regarded as having been accepted when tests and inspections have demonstrated to the satisfaction of the principal that the requirements of the contract have been met.

Section 5 General technical specification

The aspects of the specification covered under Sections (1) to (4) will generally be common to most types of radio engineering work to be carried out under contract conditions. However, the general technical specifications will be peculiar to each job or item of equipment or plant and would be drawn up accordingly.

Typical examples of the form and composition for selected radio engineering projects are detailed in the following Chapter.

REVISION OF SPECIFICATIONS

A specification is often not a static thing. It is linked on the one hand with the purchaser's requirements and on the other with what may be available or practicable. As the engineer frames the specification, there is not much difficulty in keeping it abreast of his requirements, but it is not so easy to keep it in harmony with up-to-date performance, practices, techniques, installation and production methods. To this end a systematic overhaul of all specifications at regular intervals is necessary. The intervals need not be the same for all items but would be greater for old established and long standardised practices and products, and less for products where further development is in progress. During the intervals between overhauls, the wise engineer will ensure that records are kept of any points of difficulty which required investigation from operational and acceptance viewpoints and this investigation would be made at the time of overhaul of the specification. The collection of information on practices and manufacturing processes, which might affect the specification, is closely linked with the work of acceptance testing and inspectorial activities and regular feedback is necessary from inspecting officers and field engineers to the engineer who prepared the specification.

FURTHER READING

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Chapter 47

Typical Radio Engineering Specifications

The following examples of technical sections of specifications have been selected as a general cross section of a short list of some specifications encountered in radio engineering project work. It is not practicable to include all matters which should be or have been covered in the technical section of various specifications, particularly for major works, but those matters listed are considered to be basic guidelines of general application in the particular field concerned.

BONDING AND EARTHING FOR HIGH POWER BROADCAST STATION BUILDING COMPLEX AND SUPPORT FACILITIES

EXAMPLE 47.1

1.1 Definitions

The following definitions apply to this specification:

(a) 'Bond' means a low impedance connection between two points. A truly low impedance path is possible only so long as the dimensions of the bonded members are small as compared to a wavelength of the voltage being considered. At high frequencies, the members can be considered as transmission lines whose impedance can be inductive or capacitive of varying magnitude, depending upon geometric shape and frequencies.

(b) 'Bonding' means the process in which the various components or modules of an assembly are electrically connected by means of a low impedance conductor. The purpose is to make the structure homogeneous with respect to the flow of radio frequency currents thus avoiding the development of electric potentials between metallic parts.

(c) 'Earth' means a point of 'zero' or 'reference' potential, equipotential with all other earth points of the system such as frame, cubicle, chassis, etc. All earthing in this specification should be by the multipoint principle. Metal members of greater length than about one eighth wavelength with only one end earthed can be relatively efficient antennas. Radiation and coupling is increased considerably as the member length approaches one quarter wavelength. Hence as the frequency is increased, multi-point earthing is required at shorter intervals for metal members.

(d) 'Earthing' means the process of connecting materials, equipment, etc., to points of 'zero' or 'reference' potential.

(e) 'Shielding' means a metallic enclosure of good shielding efficiency surrounding a source of interference, viz. transmitter area, or a circuit sensitive to interference, viz. control room in transmitter area, or receiver room in receiver building, or test room in transmitter area or receiving building. The fundamental idea of shielding is to provide a perfect reflecting surface comletely surrounding the apparatus, and all accessories which radiate or have to be protected from the interference. A perfect shield would completely enclose the space with a metal surface which approaches zero impedance.

(f) 'Connected' means attachment of conductive materials in such manner as will create electrical continuity.

(g) 'Standards' means Standard Specifications and Codes prepared and issued by approved Standards Associations or Institutions such as British Standards Institution, The American Society for Testing Materials, United States of America Standards Institute, Standards Association of Australia etc.

1.2 Inspection and Tests

(a) Bonding and earthing shall be left uncovered until the approval of the inspecting officer, thereof, has been obtained.

(b) Impedance tests of connections to earth shall be made at any radio frequencies 500 kHz to 27 MHz, to be determined by the inspecting officer.

(c) Test points shall be located as follows:

  (i) On floor and roof areas, beginning not more than 8 m from perimeter walls, at intervals not over 16 m in each direction and

  (ii) On walls, at mid points between floors and roofs, at intervals not over 16 m.

  Where measured impedance at the selected radio frequency exceeds limits set down on the drawing it shall be corrected by additional bonding and earthing as directed by the inspecting officer.

1.3 Materials

(a) Strap connectors shall be soft copper, 1.5 mm thick and 50 mm wide, unless otherwise stated, to approved Standards.

(b) Wire shall be copper, soft or annealed, not less than 3 mm diameter to approved Standards.

(c) Earth rods shall be 'Copperweld', or approved equal.

  (i) Construction:

  Core, high strength steel.
  Copper, electrolytic grade molten welded to steel core.
  Thickness, at least 0.37 mm, for 15 mm rods,
  at least 0.45 mm, for 18 mm rods.

  (ii) Conductivity, 25% of that of pure copper rods of same diameters.

  (iii) Dimensions:

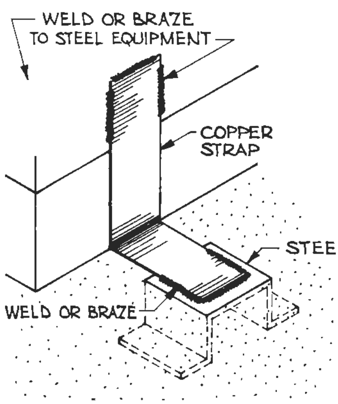
  Length, as stated on drawings.
  Diameters, as stated on drawings.

1.4 Connections

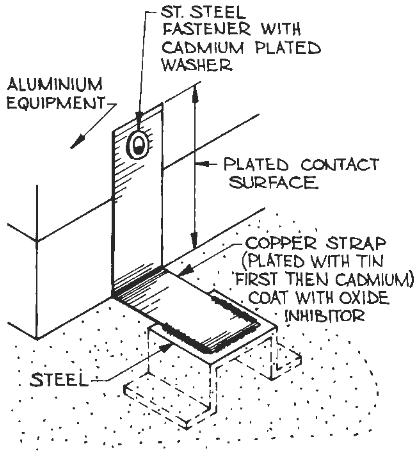
(a) Typical connections are detailed on drawings:

  (i) They may be made directly between one material and another, or by use of intermediate conductors.

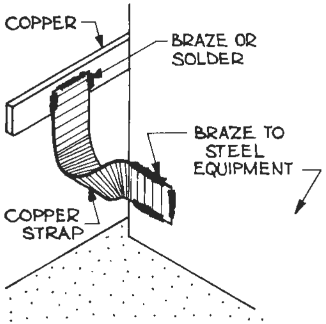
  (ii) At points of contact materials shall be clean, bare metal.



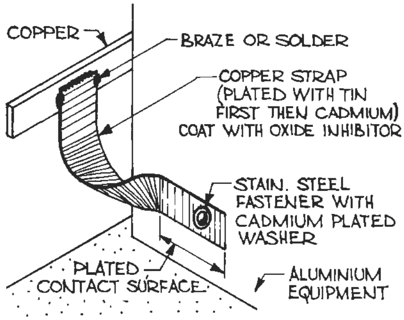
TYPICAL STRAP CONNECTION
BETWEEN STEEL TO STEEL



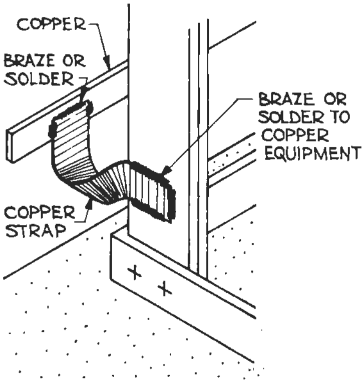
TYPICAL STRAP CONNECTION
BETWEEN STEEL TO ALUMINIUM



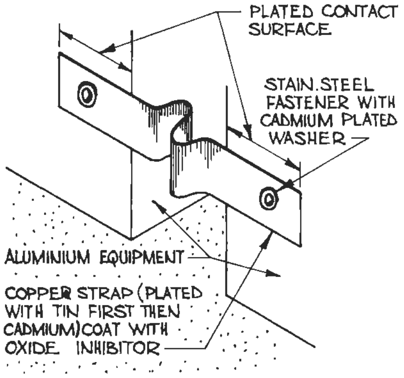
TYPICAL STRAP CONNECTION
BETWEEN COPPER TO STEEL



TYPICAL STRAP CONNECTION
BETWEEN COPPER TO ALUMINIUM



TYPICAL STRAP CONNECTION
BETWEEN COPPER TO COPPER



TYPICAL STRAP CONNECTION
ALUMINIUM TO ALUMINIUM

Figure 47.1 Typical strap connections in bonding and earthing

  (iii) Connections between dissimilar metals shall be such as will minimize galvanic action or electrolysis: Connector materials shall be electroplated to make contact points in closer order of galvanic series; Copper jumpers shall be hot tin coated on one end; Connections shall be coated with inert material, to prevent penetration by corrosive media or electrolyte to contact surfaces.

  Figure 47.1 illustrates typical connection arrangements between different materials.

(b) Welding shall be:
  (i) By an electric arc fusion process, by qualified tradesmen, and in conformity with applicable requirements of appropriate Standards.
  (ii) Surfaces being welded shall be clean, bare metal.
  (iii) Welds shall be solid and homogeneous, of full areas as indicated or required, continuous along lines of contact.

(c) Thermit welding shall be with reactive elements of powdered copper oxide and aluminium. 'Thermoweld' or 'Cadweld' or approved equal may be used.

(d) Brazing shall conform to appropriate Standards and the following:
  (i) Filler material, copper-phosphorous or silver alloy, as recommended, for base material.
  (ii) Flux, borax or boric acid, as recommended.
  Completed connections shall be thoroughly cleaned of all traces of flux or other residue after completion of the brazing work.

(e) Soldering shall conform to accepted standard practices using Solder, Tinlead, 60/40 and Flux, to relevant Standards.

(f) Connectors shall be as follows:
  (i) Ring clips, for joining sheets of expanded metal, 'K Lath' or approved equal.
  (ii) Electrical clips, 'Crimpit' types or approved equal.
  Types and sizes for each specific use shall be as recommended by the manufacturer.
  (iii) Mechanical clamps, 'Copperweld, Type A' or approved equal.
  (iv) Stainless steel drive screw fasteners and washers, 'Parker Kalon' or approved equal. Washers shall provide full contacts against joined surfaces. Types and sizes for use—shall be as recommended by the manufacturer.
  (v) Aluminium fasteners, 'Alcoa' or approved equal, of types and sizes for each use as recommended by the manufacturer.
  (vi) Rivets shall be of proper type and sizes for each use, and such as will provide permanent electrical contacts between materials.

(g) Methods of connecting materials.
  (i) Steel
  Structural to structural or reinforcing to reinforcing, welded steel straps or brazed copper straps.
  Sheet to sheet or structural, spot welding or brazed copper straps.
  Galvanised to galvanised or mesh to mesh, soldered rings or brazed electrical clip fasteners.
  Galvanised to structural or mesh to reinforcing, brazing or brazed copper straps.

(ii) Copper

To copper, brazed ring clips or soldered mechanical clamps.

To steel, brazed.

Mesh to steel, brazed or brazed copper straps.

To aluminium, copper strap plated one end with tin and stainless steel mechanical clamps.

(iii) Aluminium

To aluminium, welded in shop with mechanical clamps or hardened aluminium or stainless steel rivets or alternatively aluminium straps with mechanical clamps.

To steel or galvanised steel, stainless steel separators and mechanical clamps or tin plated copper straps and mechanical clamps.

(iv) Earth rods

To copper straps or cable	Brazed Thermit welds Mechanical clamps.

All connections to earth rods shall be such as will avoid damaging copper coating, or exposing the steel.

1.5 Expanded Copper Mesh

(a) Bonding

Copper expanded mesh shield material shall have connections as follows:

(i) At laps of sheets, with connectors, 100 mm spacing
(ii) To trench curb angles, connections, 150 mm spacing
(iii) To adjacent wall shielding, connections, 70 cm spacing
(iv) To any bonded materials which are within 50 mm of conductive materials, connected, 1.37 m spacing.

(b) Earthing

Bonded metal shall be connected directly to or through adjacent systems that lead to the building earth grid system.

1.6 Concrete Reinforcement

(a) Bonding

Steel reinforcement, in slabs, walls, trenches, columns etc:

(i) Intersections of bars
(ii) Laps of wire fabric, and
(iii) Connections between bars and wire fabric shall be connected at 1.37 m spacing.

Figure 47.2 shows typical bonding and earthing arrangements for reinforcement materials.

(b) Earthing

Bonded metal shall be connected:

(i) Directly to, or
(ii) Through adjacent systems that lead to the building earth grid system.

1.7 Structural Steel Work

(a) Bonding

The entire structural framing and all members and pieces 1.37 m or longer shall be electrically connected.

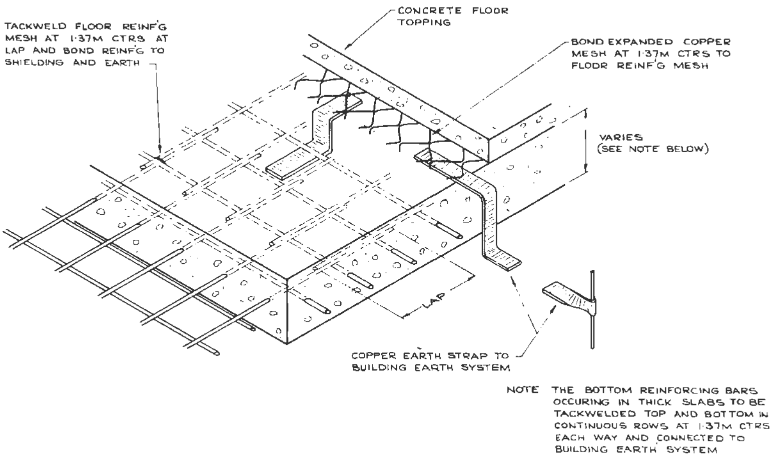


Figure 47.2 Typical concrete reinforcement earthing details

(b) Earthing
Bonded metal shall be connected:
- (i) Directly to, or
- (ii) Through adjacent systems that lead to the building earth grid system.

1.8 Masonry Work

(a) Bonding
- (i) Shield material in walls shall be connected as follows:
  Connectors at joint of sheets 1.37 m spacing
  Connections to adjacent floor shielding, 70 cm spacing
  Connected to any bonded materials which are within 50 mm of conductive materials, 1.37 mm spacing.
- (ii) Wall reinforcement in horizontal joints:
  Connectors at joinings of sheets
  All courses shall be connected together 3 m spacing and connected to adjacent bonded construction 3 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid systems.

1.9 Built-up Roofing and Sheet Metal

(a) Bonding
Sheet metal shall have connection as follows:
- (i) At laps of sheets, solder or braze, 1.37 m spacing
- (ii) To adjacent metal guttering and the like, connections, 70 cm spacing.
- (iii) To any bonded materials which are within 50 mm of conductive material, connected, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected
- (i) Directly to, or
- (ii) Through adjacent system that leads to the building earth grid system. *Figure 47.3* shows typical roof bonding to this specification.

Figure 47.3 Roof bonding at 250 kW station

1.10 Insulated Metal Walls

(a) Bonding
Insulated metal walls and acoustical wall panels shall be connected between joints, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.11 Aluminium Work

(a) Bonding
Metal items 1.37 m or longer shall be connected to any bonded materials which are within 50 mm of any conductivity materials, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.12 Glass and Glazing

(a) Bonding
Metal frames shall be bonded as shown on drawings.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to building earth grid system.

1.13 Metal Doors

(a) (i) Metal door frames shall be bonded as shown on drawings.
  (ii) Certain doors in shielded areas, acting as shielding, shall be bonded 1.37 m spacing.
  (iii) Overhead doors shall have flexible jumpers between hinged sections.
  (iv) Roll up type metal doors shall have slip rings fitted to roller bars.

(b) Earthing
Bonded metal shall be connected directly, to or through adjacent systems that lead to the building earth grid system.

1.14 Cranes and Gantries

(a) Bonding
The entire structural framing and all pieces 1.37 m or longer shall be bonded as shown on drawings.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.15 Ceiling Metal Work

(a) Bonding
  (i) Suspension system, connections for joints between all members, horizontal and vertical, 70 cm spacing.
  (ii) Lath connectors at laps of sheets, 70 cm spacing.
  (iii) Accessories, connectors to lath or suspension system, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.16 Terrazzo Work

(a) Bonding
Metal divider strips shall be connected at intersections.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.17 Resilient Flooring

(a) Bonding
Metal items, 1.37 m or longer, shall be connected to any bonded materials which are within 50 mm of any conductive materials, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.18 Metal Partitions

(a) Bonding
Toilet compartments, connections for bottoms of pilasters, and partition

panel units shall be connected along vertical joints, 1.37 m spacing.

(b) Earthing
Bonded metal shall be connected directly to, or through adjacent systems that lead to the building earth grid system.

1.19 Bin Storage Equipment

(a) Bonding
Normal secure metal assembly connections will act as bonding.

(b) Earthing
Each assembly shall be connected to any bonding strap connector or other bonded materials which are within 50 mm of conductive materials 3 m spacing and connected to building earth system.
Figure 47.4 shows part of a typical tube bin store, constructed of metal shelving and bonded in accordance with this specification.

1.20 Workshop Equipment and Benches

(a) Bonding
Normal metal assembly connections will act as bonding.

(b) Earthing
Each assembly shall be connected to any bonding strap connector or other bonded materials which are within 50 mm of conductive materials, 3 m spacing and connected to building earth system.

Figure 47.4 Metal shelving arrangement in tube bin store

1.21 Plumbing

(a) Bonding
  (i) Metal piping with screwed or soldered connections will act as bonding. To ensure integrity of the metallic connection throughout the entire conduit system, it is essential that every section of screwed conduit be screwed up tight into its coupling or the threaded hub of its fitting.
  (ii) Metal hangers and supports shall be connected to piping with brazed jumpers.
  (iii) At flexible connections, jumpers are required.
  (iv) Metal piping shall be connected to any bonded materials which are within 50 mm of any conductive materials, 1.37 m spacing within transmitter room areas, and 3 m spacing outside transmitter areas.

(b) Earthing, each item of equipment
Metal items of equipment, and metal hangers and supports, shall be connected through adjacent systems that lead to building earth grid system, 3 m spacing.

1.22 Water Distribution and Sewage Disposal

(a) Bonding
  (i) Metal piping with screwed, bolted or soldered connections, will act as bonding.
  To ensure the integrity of the metallic connection throughout the entire conduit system it is essential that every section of screwed conduit be screwed up tight into its coupling or the threaded hub of its fitting. Metal water and fire lines which are buried in the ground shall be bonded at their terminal ends upon entering a building or pumping station.
  (ii) Metal hangers and supports shall be connected to piping with brazed jumpers.
  (iii) At flexible connections, jumpers are required.
  (iv) Metal distribution piping shall be connected to any bonded materials which are within 50 mm of any conductive materials, 1.37 m spacing within transmitter areas and 3 m spacing outside transmitter areas.

(b) Earthing
  (i) Metal items including pipes and metal hanger supports shall be connected through adjacent systems that lead to building earth grid system 3 m spacing.
  (ii) Outside buildings, metal items including pipes shall be connected to earth rods in accordance with drawings.

1.23 Lunch Room and Food Storage Equipment

(a) Bonding
Normal assembly connections will act as bonding.

(b) Earthing
Each assembly shall be connected to any bonding strap connector or other bonded materials which are within 50 mm of conducitve materials, 3 m spacing and connected to building earth system.

1.24 Miscellaneous Metal Items

(a) Bonding

Normal assembly connections will act as bonding.

(b) Earthing

Each metal item 1.37 m or longer shall be connected to any bonding strap connector or other bonded materials which are within 50 mm of conductive materials, 1.37 m spacing and connected to building earth system.

1.25 Air Conditioning, Heating and Ventilation

(a) Bonding

- (i) Metal piping with screwed or flanged fittings will act as bonding.
- (ii) Metal hangers and supports shall be connected to piping with brazed jumpers.
- (iii) Sheet metal ducts shall have connectors at joints and jumpers to hangers.
- (iv) Ducts and piping shall be connected to any bonded materials which are within 50 mm of any conductive materials, 3 m spacing.
- (v) At flexible connections, jumpers are required in accordance with drawing.

(b) Earthing

Items of equipment, and hangers and supports shall be connected through adjacent systems that lead to building earth grid system, 3 m spacing.

1.26 Electrical Distribution

(a) Bonding

- (i) Normal connections of conductors will act as bonded connections.
- (ii) Screwed connections of metal conduits will act as bonded connections. To ensure the integrity of the metallic connection throughout the entire conduit system, it is essential that every section of screwed conduit be screwed up tight into its coupling or the threaded hub of its fittings.
- (iii) Metal hangers and supports shall be connected to metal conduits with brazed jumpers.
- (iv) Metal conduits shall be connected to any bonded materials which are within 50 mm of any conductive materials, 1.37 m spacing within transmitter room areas, and 3 m spacing outside transmitter areas.

(b) Earthing

Bonded metal shall be connected directly to, or through adjacent systems that lead to building earth grid system, 3 m spacing.

1.27 Shielded Test Rooms

The complete enclosure shall provide a minimum through attenuation of 80 dB over the frequency range 100 kHz to 1000 MHz. This attenuation level shall apply at all points in the enclosure and with all lighting, ventilation equipment and all other accessories in place and operating.

Pits and chases required for cable and service access purposes shall be constructed as an integral part of the enclosure.

Ventilation inlets and outlets shall be fitted with waveguide type windows, specially engineered for this purpose.

All lighting, power and communication wires shall enter via suppression filters, properly engineered for the purpose.

The enclosure and entry services shall be bonded and earthed strictly in accordance with drawings and manufacturers' recommendations.

1.28 Wiring Duct Metalwork

(a) Bonding
  (i) Ducts, pits and chases shall be lined throughout with copper sheet.
  (ii) All overlapping sheet joints shall be continuously soldered.
  (iii) Lids shall be covered with copper sheet on the underside and normally fixed in position by brass screws at 30 cm spacing to ensure positive connection between copper sheet of the lid and copper lining of the duct in accordance with drawings.
  (iv) Where duct metalwork is within 50 mm of any other conductive building material it shall be bonded thereto at 1.37 m intervals.

(b) Earthing
Duct metal lining shall be connected directly to or through adjacent systems that lead to the building earth grid system.

1.29 Power Generating Plant

(a) All metal components going into the construction of the power plant shall be electrically earthed and bonded so that a continuous electrical path exists to the exterior earth grid system for all induced r.f. currents.

(b) All concrete reinforcement and other metallic elements, including form ties, sleeves and inserts steel structures, ladders, crane rails, anchor bolts, pipe railings, machinery frames and bases, generator and transformer pads, fuel storage tanks, piping systems, metallic raceways, electrical apparatus enclosures, equipment panels and cabinets shall be bonded to this earth system.

(c) Each bed-plate shall be electrically continuous by welded straps, as necessary. Components mounted on the bed plate shall be bonded to the bed plate by similar straps. All other components, provided they are in firm metallic contact (bearings and the like) shall be deemed to be electrically continuous and will not require additional bonding.

(d) Metal piping (fuel pipes and the like) shall be connected to any bonded materials which are within 50 mm of any conductive materials, 1.37 m spacing. Metal pipework with screwed or flanged fittings will act as bonding.

(e) Duct work associated with air intake systems and jackets over exhaust pipes, shall have connectors at joints and jumpers to supporting hangers. At flexible connections, jumpers shall be provided. Ducts shall be connected to any bonded materials which are within 50 mm of any conductive materials, 3 m spacing.

(f) An interior bus and exterior bus system shall be used to provide low impedance earth points for all equipment inside the power house building. The interior bus shall connect to the exterior bus and its associated earth grid and rod system in accordance with the drawings. The earth for the a.c. power generating source shall also be connected to this earth bus.

(g) The power house earth grid system shall be tied to the transmitter earth grid system by a buried copper cable of at least 1.6 cm^2 cross sectional area and connected to 2 m deep earth stakes, at 6 m intervals.

1.30 Fuel Storage Facilities

(a) Bonding

- (i) All metallic members in fuel supply, storage and handling facilities including petrol, and oil storage tanks shall be bonded in accordance with drawing details.
- (ii) Fuel lines which are buried in the ground shall be bonded at their terminal ends upon entering a building or pumping station.
- (iii) All metal work of petrol and distillate bowsers used for refuelling vehicles, shall be thoroughly bonded to the outer case of the bowser and connected to a low impedance earth system.
- (iv) Metal fuel piping shall be tied to any bonded materials which are within 50 mm of any conductive materials, 1.7 m spacing.

(b) Earthing

- (i) Storage tanks shall be bonded to an external earth bus around each tank with ground rods in accordance with drawings.
- (ii) Metal items of the internal fuel installation shall be connected through adjacent systems that lead to the building earth grid system, 3 m spacing.
- (iii) Outside buildings, metal items including pipes shall be connected to earth rods in accordance with drawings.
- (iv) For vehicle refuelling bowsers, a brass lug embedded in a concrete block and connected directly to the bowser frame by a low impedance strap connector shall be provided in a suitable position to allow convenient attachment of an earthing lead to vehicle bodywork during refuelling operations.

1.31 Security Fencing

(a) Bonding

- (i) Horizontal support wires passing through steel posts shall be tied or clamped securely to the support post so that positive and permanent contact between wire and post is established.
- (ii) Chain wire mesh may be tied to support wires by any convenient metallic device but each post and chain wire shall be securely clamped to the post at 70 cm spacing.
- (iii) Gate hinges shall be electrically bypassed with a flexible brazed strap.
- (iv) A positive bolt device shall be used for locking or securing the gate to the fixed support post. Chains shall not be used.

(b) Earthing

- (i) An earth conductor of not less than 0.25 cm^2 shall be installed around the fence, approximately 30 to 60 cm away from it and about 30 cm deep. This shall be brazed or welded to earth rods installed at 6 m intervals. All metal fence posts shall be connected to the earth conductor, care being taken to connect the wire fence strands also at these points.
- (ii) The fence earth conductor shall be tied to any building or antenna earth system which may be located within 10 m of the security fence.

1.32 Manholes and Cable Tunnels

(a) Bonding

- (i) Steel reinforcement, in slabs, walls, floors etc.

Intersections of bars, laps or wire fabric and connections between bars and wire fabric shall all be connected 1.37 m spacing.

(ii) Metal items 1.37 m or longer shall be connected 1.37 m spacing.

(iii) Cable support brackets, manhole covers and frames shall be bonded in accordance with drawing details.

(b) Earthing

Bonded metal shall be connected directly to, or through adjacent systems that lead to building earth grid system.

1.33 Metallic Structures Near Buildings

(a) Bonding

Normal assemblies of the structure will act as bonded connection.

(b) Earthing

(i) The base of the structure shall be connected directly to the station building earth system with wide low impedance metal sheet ribbons via the shortest route.

(ii) In addition the base of the structure shall be connected to a properly engineered earth rod system around the base in accordance with drawings, for lightning protection purposes.

1.34 Direct Buried Cables

Direct buried cables such as metal covered telephone, control and power cables shall have the metallic sheath bonded and earthed at manhole entrance points and also at the building entrance points.

Additionally, bare copper guard wires shall be placed over all direct buried cables to act as collectors for the r.f. currents tending to flow in these members. The guard cables shall be connected to the main building earthing system in accordance with drawing details.

MEDIUM FREQUENCY BROADCAST TRANSMITTERS

EXAMPLE 47.2

This example covers the technical conditions of a range of medium frequency broadcast transmitters from 100 W to 10 000 W output suitable for unattended and fully automatic mode of operation. It does not include details of programme input equipment, automatic monitoring equipment and remote control and supervisory facilities.

1.1 General

The transmitters are to be delivered complete in all respects so that connection of primary power supply, programme input equipment, transmission lines and antenna equipment will render them fully operative. The transmitters shall therefore include:

(a) Power equipment for converting the primary power supply to forms suitable for energising the transmitters.

(b) Electron tube, semi-conductor and artificial antenna cooling systems.

(c) Control, protection, supervisory, antenna switching equipment.
(d) Cabling busbars and hardware but with the exception of the main earth busbar.
(e) Base plates, sills, holding down bolts and other assembly devices for the transmitter.
(f) Artificial antenna.

The unmodulated output power (over the specified frequency range) of each transmitter shall be not less than:

Item 1	100 W
Item 2	250 W
Item 3	500 W
Item 4	1000 W
Item 5	2500 W
Item 6	5000 W
Item 7	10 000 W

Transmitters shall be supplied complete in all respects. The essential features of the design of the transmitting equipment sought shall allow its use under continuous 24 hours service, without attention by staff. In this regard it is envisaged that solid state devices should be used whenever practicable. Where a transistor is used in the final r.f. stage, conclusive evidence should be given that this transistor is adequately protected against damage due to lightning strikes on the radiator. Wherever possible, overload protection, should be an inherent feature of circuit design and should be such as to restore the equipment to service automatically after overload facility operation.

1.2 Transmitting Equipment

(a) System of Modulation
The tenderer is free to offer any system of amplitude modulation provided that it is capable of modulating the carrier substantially linearly to a depth of 100% and all other requirements of the Special Conditions of this Schedule are met. A system which provides the above modulation requirements with maximum overall efficiency is preferred. The type of transmission shall be double sideband broadcasting (A3).

(b) Frequency Control and Generation
The method of frequency control shall preferably be by a quartz crystal mounted in a constant temperature oven. The carrier frequency of the transmitter shall remain within 10 Hz of the assigned frequency.

(c) Tuning Range
The transmitter shall be capable of adjustment to any carrier frequency within the band 530-1600 kHz. Frequency determining components to cover the whole band need not be provided with the transmitters, but sufficient components must be provided initially to enable the transmitter to be adjusted to any frequency within plus or minus 10% of the operating frequency. The design of the transmitters shall allow any alterations necessary for a change from one carrier frequency to another in the band 530-1600 kHz to be made easily, and for the process of aligning the transmitter on a new frequency to be accomplished within a period of two hours. The

contractor shall supply full information regarding the procedure necessary for changing the operating carrier frequency to any frequency in the band specified above. Each selective circuit in the transmitters shall incorporate a variable fine tuning control capable of operation from the front panel of the transmitter and covering a range of plus or minus 10 kHz.

(d) Carrier Frequency

The nominal carrier frequency of each transmitter will be notified at the time of ordering.

(e) Radio Frequency Output Circuits.

(i) Transmission Line Impedance

The final output circuit of the transmitter combining unit shall be designed to operate into a radio frequency transmission line having an impedance of 50 ohm unbalanced or 200 ohm balanced or an artificial antenna, as specified at the time of ordering.

(ii) Power Output and v.s.w.r. Meter

A radio frequency power output meter, together with a voltage standing wave ratio meter, shall be provided to permit the output circuit and transmission line matching conditions to be observed during the normal operation of the transmitter. Means shall be provided for preventing damage to the final radio frequency amplifier should unsafe mismatch conditions arise at the transmitter output terminals.

(iii) Output Circuit Switching

Switching arrangements for an artificial antenna in the output of each transmitter are required together with switch arrangements for a separate artificial antenna at the output of the combining equipment.

(f) Input Circuit

The audio input circuit of the modulating equipment shall be designed to operate from a balanced line having a characteristic impedance of 600 ohm. The input circuit shall incorporate an attenuator, adjustable in $\frac{1}{2}$ dB steps, to enable the transmitter to be modulated to 100% when any input frequency in the range 50 Hz to 10 000 Hz at any level between 0 dBm and +16 dBm is applied to the input terminals.

(g) Transmitter Output Combining Equipment for Transmitting Systems

Equipment is sought to combine the outputs of two transmitters, and shall include an r.f. output power combining network, and the necessary carrier frequency detection device as follows:

(i) The r.f. power ouput combining network shall be capable of accepting two sources of r.f. power and shall deliver an output suitable for connection to a transmission line. The design shall be such that the combining network, its associated equipment and the transmitters shall not be damaged in the event of the network remaining in circuit and one of the transmitters being closed down for an extended period.

(ii) Manual r.f. switching arrangements shall be provided to carry out the following functions:

Connect the two transmitters to the power output combining network.

Connect the output of the combining network to a transmission line for normal antenna operation.

Connect the output of the combining network to an artificial antenna.

Connect either transmitter directly to the transmission line and the remaining transmitter to an artificial antenna.

Connect both transmitters to individual artificial antennas simultaneously.

A switch position indicator, capable of extension, to show which selection of the switching arrangements has been made.

(iii) Provision shall be made for the following adjustments:

Correction of the phase relationship of the r.f. output of the transmitters. A means shall be provided to carry out manually the phase adjustment and to indicate the phase relationship of the transmitters, together with an indication of the desired phase conditions required for correct operation of the power output paralleling network. Correction of the modulation balance of the transmitters. A means shall be provided to carry out manually the modulation balance adjustment, together with an indication of balance.

Correction of the drive phase and modulation balance shall preferably be carried out at full power.

(iv) A radio frequency device for audio monitoring purposes shall be provided.

1.3 Cooling Equipment

(a) The cooling system supplied with transmitters shall be furnished complete with all thermometers, alarms, fans, air filters, heat exchanges and internal ducting, piping etc. In the case of forced draught air cooling, provision shall be made to exhaust the warm air from the transmitter enclosure or cubicles. All rotating machines used in the transmitter cooling system shall have a high degree of dynamic balance to reduce the transmission of vibration to the transmitters and to the buildings.

(b) The tenderer shall supply complete information of the cooling system proposed including the range of temperature and humidity over which the guaranteed performance of the equipment is obtained, and the acoustical noise levels at locations close to the transmitter.

1.4 Power Equipment

(a) The 100, 250 and 500 W transmitters shall be suitable for operation from a single phase 50 Hz primary power supply in the range 220-260 V.

(b) The 1, 2.5, 5 and 10 kW transmitters shall be suitable for operation when connected to a 3 phase 50 Hz primary power supply within the range 380 to 460 V.

(c) Provision shall be made by means of transformer tappings or other means to enable the transmitters to be readily adjusted for operation at any voltage within the ranges stated. The power drain of the transmitter shall produce an approximately balanced load on the power mains and the power factor of the load shall be 0.9 or better.

(d) The power supply to the various parts of the transmitters shall be distributed from a power control panel supplied by the contractor and incorporated as an integral part of the transmitter. The operation of any protective device should remain indicated when the main or following circuit breakers have tripped. The power control panel shall be fully equipped with all necessary overload protection, switching and control apparatus and measuring instruments.

1.5 Artificial Antenna

An artificial antenna capable of continuously dissipating the full rated output power of the transmitter, modulated to a depth of 100% at any frequency within the transmitter's range, shall be supplied with each transmitter. The artificial antenna shall present a resistive load to the radio frequency output circuit of the transmitter of 50 or 200 ohm ± 10% (as ordered). A separate artificial antenna shall be provided for the output of the combining equipment. The tenderer shall state the artificial antenna cooling arrangment proposed.

1.6 Control System

(a) The tenderer shall supply a full description of the control system and its operation in the application and removal of power for the transmitters in a controlled sequence.

(b) The control system shall incorporate a device which will operate automatically and return the transmitter to the normal transmitting condition after momentary primary power supply interruption. The maximum allowable interruption time for this to operate should be stated.

(c) The following facilities shall be extended to a terminal strip to permit fully remote operation of the transmitters.

   (i) All push button circuits provided for starting up, closing down and antenna switching of transmitters.

   (ii) All alarm indications.

   (iii) Audio frequency monitoring of the output stage.

   (iv) Transmission line power output metering circuit.

(d) The transmitters shall be capable of operating continuously in a lower power output condition. Reduced power operation achievable by methods such as delta to star connection of transformers would be satisfactory.

(e) The tenderer is invited to offer a transmitter control system which includes automatic facilities for the purposes of fault detection and location, performance checking, monitoring and supervision. The facilities should apply to separate sections of the transmitter, the tuning functions, the frequency source, the antenna switching system, the protection circuits and the overall operation of the transmitter. The objectives of the facilities should be to provide the transmitter operator with an indication of the immediate performance of the transmitters and, under fault conditions, the location and identity of the fault.

1.7 Protection of Personnel and Equipment

(a) An adequate system of protection shall be provided whereby all apparatus, especially if delicate or costly, is guarded from electrical conditions liable to cause it to be damaged.

(b) The transmitters shall be designed to ensure complete protection of all station personnel against contact with apparatus carrying dangerous voltages. All equipment employing dangerous voltages shall be completely enclosed with covers of either safe insulating material or earthed metal. The doors or gates of enclosures surrounding live equipment shall be fitted with safety switches that will remove dangerous voltages, including those due to charges on capacitors, before access to the enclosures can be obtained.

(c) A device shall be provided for instantaneously removing the carrier power automatically in the event of an arc being formed to ground at any part of the transmission line, antenna coupling equipment or radiating system, power being restored automatically immediately the arc is extinguished.

(d) Each transmitter shall be provided with overload circuit breakers preferably of a type similar and equal to the Westinghouse 'deion' type, for protecting and isolating various sub-circuits of the transmitter power supply and shall include the following:
    primary mains supply
    control and supervisory circuits
    cooling motors
    filaments or heaters
    each high tension and bias supply.

(e) The rupturing capacity of the main a.c. circuit breakers shall be stated.

(f) The equipment shall employ an 'under voltage' protection system.

(g) All high tension and bias power supply should be of the semi-conductor type adequately protected against 'over voltage' and 'over current' transient conditions and capable of withstanding a short circuited output for the period required to operated the circuit breakers. The use of mercury vapour and similar rectifier tubes shall be avoided.

(h) The protection system shall incorporate indicator systems to enable the faulty equipment or circuit function to be quickly located. All fault indicator lamps are required to remain illuminated after a fault has occured, until manually reset.

1.8 Supervisory Equipment

The transmitter shall be designed to enable regular testing to be easily and quickly undertaken, so that departures from normal operating conditions may be detected before these become serious. In particular the following facilities shall be provided:

(a) A radio frequency monitoring output having a nominal source impedance of 50 ohm shall be provided at the output of the combining equipment. The radio frequency output power available at the 50 ohm monitoring terminals shall be not less than 3 W.

(b) A carrier failure alarm operating from the output of the final radio frequency amplifying stage and having an alarm circuit interlocked with the transmitter h.t. supply shall be provided, with both visual and audible alarms in the event of carrier failure.

(c) A radio frequency detection device coupled to the output circuit of the transmitter and capable of delivering an audio output of at least +14 dBm to a 600 ohm line, when the transmitter is modulated to 100%, shall be provided. The frequency response of this device shall be ±1 dB over the range 50–10 000 Hz and the distortion introduction shall be less than 0.5% at any frequency in that range for any modulation depth up to 96%.

1.9 Instrumentation

(a) Instruments shall be provided on the transmitter to measure transmitter operating conditions preferably including the following:
    (i) Cathode currents for every electron tube in the transmitter.
    (ii) Control grid and screen grid currents for every radio frequency tube

    having a plate dissipation of 20 W or more, including the modulated amplifier.
  - (iii) Output voltage for each and every power converter for filament, plate and bias supplies.
  - (iv) Radio frequency output power and transmission line v.s.w.r. when the transmitter is connected to either the combining equipment or the artificial antenna.
  - (v) Audio input and demodulated output levels by means of a v.u. meter employing a scale calibrated in volume units and percentage modulation.
  - (vi) The voltage of each phase of the primary power supply, together with the relevant power factors.
  - (vii) Air exhaust temperature.
  - (viii) 'Elapsed time' meter indicating progressively the total operating hours of the electron tube filaments.
- (b) Voltage and current meters shall preferably read approximately half scale under normal working conditions. Where an earth return is required on a meter, the return shall not be established by connection to the chassis.
- (c) All instruments shall be easily visible from the front of the transmitter without the necessity of entering any protected enclosure. As a general indication of essential requirements, it is desired that any instrument which must be watched closely whilst a control is being operated should be brought to the face of the transmitter.

1.10 Guaranteed Performance

- (a) The guaranteed performance of the equipment shall be maintained under every combination of the following conditions:
  - (i) Ambient operating conditions within the limits specified.
  - (ii) Variation in the primary power supply voltage within the limits ± 10% of the nominal voltage with simultaneous variations in the frequency of the power supply between 46 and 54 Hz.
  - (iii) Replacement of any electron tube or semiconductor with a tube or semiconductor of similar type selected at random.
- (b) Voltage regulating equipment shall be supplied by the contractor if closer voltage limits are required for the transmitter to maintain its guaranteed performance.

1.11 Power Rating

Each transmitter shall be capable of delivering the unmodulated carrier output power, specified in Section 1.1, into the artificial antenna or transmission line.

1.12 Carrier Frequency Tolerance

The carrier frequency shall be maintained within 10 Hz or better under any of the following conditions, taken separately, or together in any combination whatsoever:

- (a) Variation of primary power supply voltage by ± 10% of the nominal voltage.
- (b) Variation of the plate voltage of any electron tube in the crystal oscillator and buffer amplifier stages by ± 10%.

(c) Variation of the filament current of any electron tube in the crystal oscillator and buffer amplifier stages by ± 10%.
(d) The replacement of any electron tube or semiconductor in the crystal oscillator or any other radio frequency amplifying circuit of the transmitter by an average tube or semiconductor or similar type and rating selected at random from stock.
(e) Changes of ambient temperature between −5 °C and 55 °C.

1.13 Carrier Regulation

Modulation of the carrier to a depth of 100% by a sine wave tone within the range 50 Hz to 10 kHz shall not cause the amplitude of the carrier to vary from its unmodulated value by more than 5% at full rated power output.

1.14 Stability

After having been lined up to deliver its full rated power output into its artificial antenna at the operating frequency, the transmitter shall show no sign of drift, instability, dynamic variation or any unsafe condition when any of the following tests are applied:
(a) Cutting in and out the primary frequency controlling element of the master oscillator.
(b) Detuning any selective circuit in the transmitter to the full extent of the fine tuning adjustment.
(c) Applying sine wave audio-frequency modulation at any frequency between 50 Hz and 10 000 Hz of amplitude sufficient to modulate the transmitter to 100%, and then abruptly stopping and starting the modulation a number of times as in keying the transmitter with tone.
(d) Replacing any electron tube or semiconductor in the transmitter by a device of similar type and rating selected at random from stock.
(e) Increasing overall feedback by 3 dB where applicable. The transmitter shall also meet the above stability requirements when connected to a transmission line as specified in Section 1.3.

1.15 Audio Frequency Response

With the transmitter input level adjusted to give a modulation depth of 75% at a frequency of 1000 Hz and for a constant input level, the output level as measured at the audio frequency monitoring point shall not vary from that at 1000 Hz by more than 1 dB for any frequency within the range 50 to 10 000 Hz. Beyond 10 000 Hz the output shall fall sharply so that at 12 500 Hz the output level is at least 12 dB below that at 1000 Hz, and at 15 000 Hz the output level is at least 30 dB below that at 1000 Hz.

1.16 Distortion

With the transmitter adjusted to deliver full rated carrier power into its artificial antenna, the total harmonic distortion as measured at its output or at the output of any combining equipment shall not exceed 2% for a modulation depth of 96% at any frequency in the range 50 to 10 000Hz.

1.17 Carrier Noise

The total r.m.s. noise level (unweighted) as measured at the output of the combining equipment, when operating at full rated carrier power into the artificial antenna, shall be at least 60 dB below the output level corresponding to 100% modulation with a 1000 Hz sinusoidal signal over the frequency range 20 to 10 000 Hz.

1.18 Spurious Radiation

When the transmitter is delivering its full rated carrier output power, at any frequency within its operating range, the power of any single harmonic or parasitic emission measured at the output terminals of the combining equipment shall not exceed 40 dB below the rated power of the transmitter, or 50 mW whichever is the lower. In addition the tenderer shall state any special provision which is made in the design of the transmitter to reduce the possibility of interference to television reception.

1.19 Stray Radiation

The transmitter shall be adequately screened to prevent the possibility of interference to other radio equipment operating in the same building.

1.20 Intermodulation

When two audio frequency signals differeing in frequency by 180 Hz, and their mean frequency being in the 5000 to 8000 Hz band, are applied to the transmitter input at a level such that each frequency, applied individually, will modulate the transmitter to 30%, the intermodulation percentage, measured in a demodulated signal from the radio frequency output terminals of the transmitter, shall not exceed 2% of either audio signal for the individual second, third and higher order intermodulation products.

1.21 Modulation Capability

The transmitters shall be capable of being modulated continuously for 24 hours per day by any sinusoidal tone or speech waveform in the audio frequency range 50 Hz to 10 000 Hz under the following conditions of modulation:

(i) 75% modulation continuously,
(ii) 100% modulation continuously for 10 minutes in every 60 minutes and at 75% continuously during the remaining 50 minutes.

1.22 Heat Run

A heat run for a continuous period of 24 hours shall be conducted at any frequency to be specified by the Inspecting Officer within the operating frequency range of the equipment. For this test, the transmitter shall be adjusted to deliver full rated unmodulated carried power to an artificial antenna and shall then be modulated to a depth of 75% with a sinusoidal tone of 1000 Hz, except that during each 60 minutes of the test the modulation depth shall be increased to 100% for the last 10 minutes. The tone shall be kept applied during the whole of the 24 hours. Should this test period be interrupted for any reason other than for short periods required for the above test, a further period of 24 hours must be commenced; i.e. it must be demonstrated that the transmitter is capable of operating continuously and maintaining the required performance for a continuous period of 24 hours. During and after the heat run, the ratings and limits indicated in this specification shall not be exceeded.

BROADBAND RADIOCOMMUNICATION RELAY EQUIPMENT FOR TELEPHONY AND/OR TELEVISION

EXAMPLE 47.3

This extract comprises part of the technical conditions prepared for a specification for the supply of broadband radiocommunication relay equipment providing capacities from 300 to 2700 telephony channels or colour television bearers.

1.1 Environmental Conditions

Equipment is required to operate under either of two environmental conditions. Equipment to meet category A specification is preferred. However, equipment to category B specification will be acceptable for use in air-conditioned buildings.

Environmental Condition	*Specification Category A*	*Specification Category B*	*Notes*
(a) Temperature Range	0 °C-50 °C	0 °C-45 °C	Tests will utilise a sinusoidal temperature between the extremes indicated
(b) Daily Cycle	20 °C-50 °C	20 °C-45 °C	
(c) Relative Humidity	95% (0 °C-35 °C) 75% (> 35 °C)	95% (5 °C-35 °C) 75% (> 35 °C)	This temperature for the period stated must cause no measurable permanent deterioration in the condition of any component or in equipment performance. The equipment shall be capable of operating at this temperature, for the time stated.
(d) Altitude (Maximum)	1500 m AMSL	1500 m AMSL	
(e) Dust particles (minimum size)	5 micron	5 micron	
(f) Six hour survival	55 °C	55 °C	

The tenderer shall state for each type of equipment offered the environmental category for which the guaranteed characteristics shall be maintained.

1.2 Technical Characteristics

The technical characteristics of the equipment offered shall be in accordance with the following table. Tenderers shall indicate any equipment that does not comply with these characteristics and the revised specification that shall be applicable.

Characteristic	
(a) Baseband and video interconnection	CCIR rec 380-2 except note 7, and CCIR rec 270-1.
(b) Telephony pre-emphasis	CCIR rec 275-2
(c) Television pre-emphasis	CCIR rec 405-1 curve B
(d) Intermediate frequency characteristics	CCIR rec 403-2 with a tolerance of ± 1 dB for the nominal input and output levels; and the return loss to be measured over a bandwidth which includes twice the sum of the top baseband frequency plus the peak deviation of the white noise busy hour signal, assuming a peak to r.m.s. ratio of 12 dB.
(e) Telephony frequency deviation	CCIR rec 404-2
(f) Television frequency deviation	CCIR rec 276-1
(g) Television sense of modulation	At IF shall be positive, i.e. a positive going (black to white) transition at the video interconnecting point shall correspond to an increase in intermediate frequency.
(h) Continuity pilots	CCIR rec 401-2 (other frequencies and deviations will also be considered).
(i) Single sound channel characteristic	CCIR rec 402 except the maximum audio frequency level at a zero relative level point shall be +16 dBm to produce 140 kHz r.m.s. deviation of the sub-carrier and the upper limit of the audio frequency bandwidth shall be 15 kHz.
(j) Line regulating and other pilots	CCIR rec 381-2
(k) Limits of signals outside the television bandwidth	CCIR rec 463, except the alternative in paragraph 3 is not accepted.
(l) Local oscillator stability	1 part in 10^5

(m) a.m./f.m. characteristics	less than 0.5 degrees/dB for each major unit of equipment, e.g. a transmitter or a receiver, and less than 0.6/dB for two or more major units in series, e.g. a transmitter-receiver combination.
(n) a.g.c. range	to be greater than 55 dB to maintain the IF output level within the range specfied in (d) above.
(o) Limiter compression	to be greater than 10 dB for each limiter unit.
(p) r.f. branching	to be greater than 30 dB return loss at the antenna port.
(q) Diversity requirements (i) Switched diversity	1. Disturbance effects in the baseband shall be less than 2 microseconds in duration and the peak to peak voltage of the disturbance shall not exceed the peak to peak voltage of a sine wave, at the emphasis neutral frequency, applied to the system at a level of $(-22 + 10 \log N)$ dBmO, when N is the system channel capacity.
	2. Provision for differential time equalisation between the two switch i.f. outputs of greater than 100 nanoseconds shall be included and shall be able to be adjusted to within 2 nanoseconds.
	3. Switching circuits shall be able to be adjusted to switch on a r.f. level difference between the two receiver inputs from 3 to 7 dB. The switch hysterisis shall be between 2 to 3 dB.
(ii) r.f. combining diversity	The operating speed of the phase combiner shall be greater than 400 degrees per second with a static error of less than 5 degrees.
(r) Interchangeability	1. The maximum effect of the change of any one unit or subunit without realignment shall be within the following limits: Noise figure ± 0.5 dB Transmit power ± 1.0 dB

Mute level	± 1.0 dB
Group delay	± 1.0 ns
i.f. output level	± 0.5 dB

The TWTs may be adjusted for minimum helix current or correct plate current.

2. The guaranteed limits for the modem performance shall be maintained for any combination of modulators and demodulators.

1.3 Power Supplies

Power supplies for the operation of equipment will be either:

(a) Nominal 240 V a.c.
(b) Nominal 24 V d.c.
(c) Nominal 48 V d.c.

Equipment tendered shall be capable of guaranteed operation when operated anywhere within the limits in the following table:

Parameter	*Specification*			
	Nominal 240 V a.c.	*Nominal 48 V d.c.*	*Nominal 24 V d.c.*	
Mid. Voltage	240	52.1	26.0	d.c. supplies float charged
Max. Voltage	270	59.2	29.6	d.c. supplies gas charged
Min. Voltage	261	44.4	22.2	
Frequency	50 Hz ± 5%			
Polarity		+ve earth	+ve earth	

The equipment tendered shall be protected from damage under the following circumstances:

(a) reversal of the power supply polarity.
(b) application for any duration of a voltage outside the limits quoted above.
(c) application of an a.c. supply with a frequency outside the limits quoted above.

The tenderer shall state, for each power supply offered, any of the above characteristics that are not met and the limits under which the performance shall be guaranteed.

1.4 System Performance Calculations

For tender assessments, tenderers are required to show by calculations for each type of equipment offered that the telephony and service band performance is obtained for a reference modem section and the television performance is obtained for a reference video modem section.

A telephone reference modem section comprises two (2) terminals and six (6) i.f. repeaters. Each of the seven (7) hops is normally 40 km in length. Each terminal and repeater includes service channel insert and dropping facilities.

A reference video modem section comprises two (2) terminals and six (6) i.f. repeaters. Each of the seven (7) hops in nominally 40 km in length. Each terminal includes sound, vision combining and separating equipment.

The equipment parameters used in the calculations shall be those stated in the tendered information and shall also be tabulated with the calculations.

For telephony performance calculations, each type of noise contribution, in each of the three measuring channels specified in the following table for the particular system capacity, is to be listed separately in the calculations.

System Capacity (channels)	*Lineup Level dBm*	*Equivalent Peak Power of Conventional Load dBmO*	*Frequency of Measuring Channels*		
			Lower	*Middle (kHz)*	*Upper*
300	−42	23	70	534	1248
600	−45	25	70	1248	2438
960	−45	27	70	2438	3886
1200	−37	28	534	2438	5340
1800	−37	30	534	3886	7600
2700	−37	32	534	5340	11 700

The following additional information is provided for use in the telephony performance calculations:

(a) a 4 dB simultaneous fade on all hops,
(b) average feeder length of 60 metre per feeder
(c) feeder intermodulation distortion of 30pWOp per hop at frequencies below 2.6 GHz and 10pWOp per hop above 2.6 GHz.
(d) multipath propagation distortion of 3pWOp per hop for 1800 channel telephony systems and above.
(e) six service channels in the sub-baseband (or super baseband) with at least 2 available on an omnibus basis at each station and a further two stations.
(f) radio frequency interference of 5 pWOp per hop.

For television performance calculations, the tenderer shall calculate the performance of the following parameters:

(a) Continuous random noise:
    luminance channel
    chrominance channel
(b) Non-linear distortion of the picture signal:
    luminance channel
    chrominance channel differential gain
    chrominance channel differential phase
(c) Non-linear distortion of the synchronising signal

(d) Linear waveform distortion (k factor):
    Luminance field time
    Luminance line time
    Luminance short time
    Chrominance short time
    Chrominance line time
(e) Luminance-chrominance inequality:
    gain
    delay
(f) Chrominance into luminance crosstalk
(g) Sound channel weighted signal to noise ratio
(h) Vision into sound crosstalk

The following additional information is provided for use in the television performance calculations:

(a) a 4 dB simultaneous fade on all hops
(b) average feeder length of 60 metre per feeder
(c) feeder and antenna peak return loss figures of

	feeder	*antenna*
below 2.6 GHz	28 dB	28 dB
above 2.6 GHz	30 dB	32 dB

1.5 Equipment Stability

The stability of the technical parameters of the equipment offered, due to time and environmental conditions, shall be in accordance with *Table 47.1*. The stability limits due to the two effects shall apply as follows:

(a) The stability limits due to time effects, shall be maintained over 12 months of operation when tested at substantially the same environmental conditions at the time the equipment was aligned, but the equipment may have been subjected to any environmental condition and power supply limits allowed for its category during the 12 month period.
(b) The stability limits due to environmental effects shall be maintained under any combination of conditions allowed for its environmental category and the power supply limits.

Tenderers shall state any equipment that does not comply with these stability limits and the revised limits that would apply.

1.6 Equipment Information

The tenderer shall provide for each unit of equipment offered the following:

(a) A functional block schematic diagram showing each basic maintenance module, each sub module, all the principal module interface impedances, levels and frequency bands, main test and metering points and the power supply arrangements.
(b) Sufficient information on the equipment in his tender to enable the principal to judge its performance.

Table 47.1

Parameter	*Stability Limits*	
	Time Effects	*Environmental Effects*
Tx output power	± 0.5 dB	
Receiver noise factor	± 0.5 dB	
Local oscillator frequency (Including shifter where applicable)	$\pm 1 \times 10^{-5}$ of nominal	$\pm 3 \times 10^{-6}$
Mute level	± 1.0 dB	± 1.0 dB
Mute/unmute hysteresis	± 0.5 dB	± 0.5 dB
Receiver IF output level	± 0.5 dB	
Diversity switch criterion	± 0.5 dB	± 0.5 dB
Equalization of absolute delay	± 1.25 ns	± 1.25 ns
Service band insertion osc. centre freq.	± 100 kHz AFC off	± 100 kHz AFC off
Modulator centre frequency	± 100 kHz AFC off	± 100 kHz AFC off
Modulator i.f. level	± 0.5 dB	
Modulator sensitivity	± 0.3 dB	± 0.2 dB
Sound modulator frequency	± 20 kHz	± 5 kHz
Sound modulator sensitivity	± 0.5 dB	± 0.2 dB
Bearer equivalent per modem section	± 0.5 dB	± 0.5 dB
Noise fail setting	± 1.0 dB	± 1.0 dB
Pilot fail setting	± 0.5 dB	± 0.5 dB
Noise fail hysteresis	± 0.5 dB	± 0.5 dB
Pilot fail hysteresis	± 0.25 dB	± 0.25 dB
Service Band Terminal to Terminal	± 0.5 dB	± 0.5 dB
Service Band Repeater to Terminal	± 0.5 dB	± 0.5 dB

DUAL CHANNEL TELEVISION TRANSMITTING ANTENNA

EXAMPLE 47.4

A dual channel television transmitting antenna with specified radiation pattern to operate on the combined output from two transmitters on different frequencies.

The antenna system is to be installed by the principal's staff on a guyed mast which is to be supplied by others.

1.1 General

The antenna system shall be complete with all components essential to its performance as guaranteed by the contractor, and with all components and fittings necessary to install it on the supporting structure and to connect it to the main feeders.

1.2 Material and Services to be Supplied by the Principal

(a) The mast surmounted by a structural support column of square cross-section to support the antenna system.
(b) The panel 'mounting bars' that connect the antenna panels to the mast proper.
(c) The main transmission lines or feeders between the transmitter and the antenna system, terminating at the input connectors of each half of the antenna system.
(d) The assembly, installation, adjustment and testing of the antenna system.

1.3 Material and Services to be Supplied by the Contractor

The contractor shall provide the following:

(a) The antenna system, complete with reflecting screens, radiating elements and distribution feeder systems commencing at the points of entry to the main input connectors of each half of the antenna system.
(b) Fittings required to fix and support all components of the feed system in and on the support column.
(c) Technical information necessary for the installation, assembly, adjustment, testing and maintenance of the antenna system.
(d) If so desired by the principal, the services of technical experts to advise the principal concerning the assembly, installation, adjustment and testing of the antenna system.

1.4 Type of System

The antenna system shall be of a type suitable for mounting on the exterior vertical faces of a support column of square cross-section of lattice braced steel construction.

The aim is to provide an antenna system which will not require maintenance over an estimated life of 20 years. The quality of components and workmanship shall be consistent with this aim.

It is preferred that the specified horizontal radiation pattern should be met by the use of equal or almost equal power distribution amongst four identical arrays in a square arrangement on the four faces of the support column and not by an unequal distribution of arrays amongst the four faces.

If the horizontal radiation pattern cannot be met by arrays mounted in a strictly square arrangement, and angular slewing of the arrays is necessary, the degree of slewing should be kept to a minimum.

The antenna system shall be in the form of two approximately identical 'halves' stacked vertically, each 'half' being connected to a separate main feeder.

Under normal operating conditions, each 'half' of the antenna system will be fed with half the total input power.

It is preferred that the antenna system should incorporate the principle of phase rotation feed where it provides an advantage in regard to the impedance specification and permits compliance with the specification on the horizontal radiation pattern.

1.5 Support Column

The principal will endeavour to arrange that the structural details of the support column will conform to the contractor's recommendations. In order to permit this, the tenderer shall forward all essential constructional details of the antenna system.

The information to be supplied shall include the following:

(a) Fully dimensioned mechanical drawings and the overall weight of each radiator and its associated reflector screen to permit the principal to calculate the wind load and weight forces on the supporting structure.

(b) The fully-dimensioned geometrical arrangement of the panels forming the antenna system and the orientation of the antenna system with respect to North.

(c) The required arrangements for mounting the radiators, reflectors and associated fittings to the outside of the support column, together with full details of the sizes and disposition of bolt holes or other mounting provision that must be made by the mast designer.

(d) The recommended dispositions of the interconnecting cables and other components to be located on the inside and outside of the support column.

(e) Full details of the methods of mounting or fixing all components of the feed system including the minor feeders.

(f) The recommended bracing arrangements for the support column which, in the tenderer's experience, are best suited to the efficient support and installation of the antenna system he is offering.

(g) Full electrical and mechanical details of the components of the feed system, including dimensions and weights, electrical and mechanical lengths, impedances of transmission line components, component type numbers, points of attachment and the detail thereof, details of connectors and recommended bending radii of the flexible feeders.

All fittings necessary for mounting the antenna system with its associated components and feeders shall be supplied by the contractor. These shall include the attaching bolts and associated hardware, but shall not include the antenna panel mounting bars.

1.6 Termination of the Antenna Feed System

The principal will provide the two main feeders between the transmitter and the main input connectors of the two halves of the antenna system, and will ensure that the relative phases of the currents into matched terminations at these points will be in accordance with the contractor's specified requirement.

The principal will provide two U-links (cable separator fittings) to permit separate testing of the main feeders and the antenna system. Each U-link will connect directly to the main input connector of the relevant antenna half, and the U-links will be mounted within the support column at heights approximately 1 m above the bottom of each antenna half respectively.

The reflection co-efficient of the antenna system shall be assessed by measurements taken at the U-links. The principal will ensure that the U-links do not contribute more than $\frac{1}{2}\%$ to the reflection co-efficient measurement.

1.7 Gas Pressure Facilities

The contractor shall state whether he recommends the antenna feed system to be put under gas pressure, and the degree of gas pressure he requires. If the contractor so recommends, the antenna system shall incorporate all facilities for operation under gas pressure.

The main feeders will be operated under gas pressure up to the U-links. When the antenna system is to be operated under gas pressure the principal will arrange the through or by-pass gas connection to the antenna system as the contractor recommends.

The gas pressure systems associated with the upper and lower sections of the antenna system shall not be interconnected in any way.

The main station gas pressure system will operate an alarm when leakage occurs and therefore all fittings subjected to gas pressure shall, as well as possible, be completely gas tight. The contractor shall state the maximum leakage rate and/or 24 hour pressure drop figures to which the antenna system shall conform.

1.8 Reflector Screens

The antenna system shall be supplied complete with such reflecting screens as are necessary to obtain the desired performance when the support column is designed as a structural support without regard to its electrical properties.

1.9 Inspection of Fittings and Connections

The antenna systems shall be designed to allow easy inspection of electrical fittings and connections for maintenance purposes, and for the replacement of faulty fittings with a minimum of time and effort.

1.10 Insulating Materials

Insulating materials used in the antenna systems shall have satisfactory electrical and mechanical properties. Insulators for exposed locations shall be of materials that will not deteriorate with exposure to sunlight, water, ice or dust, or to the temperatures specified.

If exposed insulators are used, the contractor shall state the chemical compositions of the insulating materials used.

1.11 Structural Design

The antenna system and its method of attachment shall be designed to safely withstand the maximum wind velocity of 200 km/h.

The tenderer shall state the wind velocity at which the weakest structural component attains its designed working stress and the load factor (factor of safety) applicable to the component at that velocity.

Because the loading due to wind on the antenna system largely governs the cost of the supporting structure, variations in the cost could easily outweigh the price difference between offered antenna systems which are otherwise equivalent in performance. The principal will consider this factor, among others, in assessing the merits of tendered designs, and the tenderer is advised to choose a structural and electrical panel design and arrangement aimed towards minimising this loading consistent with adherance to the other conditions of the specifications.

1.12 Corrosion Prevention, Ferrous Metals

Unless the principal approves otherwise, all parts of the antenna system fabricated from ferrous metals shall be galvanised after fabrication by the hot-dip process. If, for manufacturing or other reasons, the tenderer proposes to use a treatment other than galvanising for certain ferrous parts of the antenna system, he shall state specifically the fittings to be so treated and the process to be used.

When galvanising has been damaged during transport, the member so damaged shall be re-galvanised by the contractor.

Painting or cadmium plating shall not be used in any instance as a means of protection against corrosion.

1.13 Corrosion Prevention, Non-Ferrous Metals

The antenna system shall be designed in such a way that contact between fittings fabricated from non-ferrous metals and fittings that are galvanised shall be reduced as much as possible in order to reduce galvanic corrosion. To this end, also, means shall be taken to prevent water from being retained in spaces between non-ferrous and galvanised fittings; such spaces shall be adequately drained or sealed with a suitable compound.

The contractor shall forward full details of the compositions of all components of the antenna system which are manufactured from non-ferrous metals, with particular reference to the external surface materials of feeders, distributors and connectors, and to those components and fittings, clamps etc., which are in contact with the supporting structure. The contractor should note that the supporting structure will be fabricated from hot-dip galvanised steel members, not necessarily painted. The principal reserves the right to reject any design feature that, in its opinion, may lead to a severe corrosion hazard. In such cases, the contractor shall modify his design to the satisfaction of the principal.

The contractor shall state what protective means he recommends or incorporates into his design to prevent galvanic corrosion to components of the antenna system and to the support structure at or near the junctions of dissimilar metals.

1.14 Painting

The antenna system shall not be painted.

1.15 Impedance

The input impedance of each half of the antenna system shall be nominally 50 ohm at the main input connectors.

Over each of the two channels concerned, the reflection coefficient relative to 50 ohm shall not be greater than the values shown in drawings forming part of this Specification as measured at the U-links.

1.16 Design of Feed System

The nominal impedance of all interconnecting feeders and connectors at the main interconnections shall be 50 ohm. Should the contractor be unable to conform to this requirement he shall state in detail the nominal impedances he intends to use.

The principal prefers that major and minor distributors be mounted separately and that all interconnections be made with flexible type cables to facilitate installation. These interconnecting cables shall be served with a tough and impervious plastic sheath over their full length.

The feed system between the main distributors and the radiating elements shall be designed so as to minimise degradation of the quality of the transmitted signal caused by internal reflection. A feed system which absorbs or partially absorbs reflections within the feed system is preferred.

1.17 Power Input

The antenna system will be fed with the combined powers from two transmitters on different channels. The antenna input power from the Channel 3 transmitter will be 16 kW and that from the Channel 5 transmitter will be 13.5 kW, peak-vision power.

The input power will be divided equally between the two main feeders connecting to the two antenna 'halves'.

1.18 Ambient Temperature

The antenna system shall be capable of operating over an air temperature range −10 °C to 50 °C without deterioration to the transmission performance. While the upper limit of this temperature range is the maximum expected summer shade temperature, the contractor should note that, depending on surface condition, the temperature of a component exposed to the sun may rise to 66 °C in still air.

1.19 Horizontal Radiation Pattern

The required limits of the horizontal radiation pattern for the antenna system at each operating channel are as specified in drawings forming part of this Specification.

If the antenna system that is proposed fails to meet the tolerances given, the tenderer shall state clearly which tolerance are not met and by how much.

Certain regions of the horizontal radiation pattern have not been specified as to the requirements for the upper limits. In such unspecified regions, effective radiated power shall change as smoothly as possible between the levels within specified regions, and the e.r.p., averaged over 360° of azimuthal angle shall be as close as practicable to 100 kW on each operating Channel.

Power in this context shall mean vision power alone at the peaks of the synchronising impulses.

Horizontal radiation patterns shall be determined at the appropriate vision carrier frequencies.

Horizontal radiation patterns shall be plotted to a dual scale of relative field (to a linear scale), and kilowatts of e.r.p. based on the appropriate total input power to the antenna system.

The tenderer shall indicate the North direction in the submitted radiation patterns.

1.20 Vertical Radiation Pattern

In the vertical plane, the angle of maximum radiation shall be approximately 0.5 degrees below the horizontal plane.

The field intensity (V/m) in any vertical plane within the sector between the horizontal plane and 8 degrees below the horizontal plane shall be not less than 10% of the maximum field intensity at the same angle of azimuth; the first null of the vertical pattern of the full array shall be filled to not less than 10% field.

The vertical radiation patterns shall be determined at the appropriate vision carrier frequencies.

The manner of obtaining the specified vertical radiation pattern shall be such that, when the full input power is applied to either half of an antenna system, the field intensity at any angle within the sector between the horizontal and the highest specified depression angle is not more than 4 dB lower than the corresponding field intensity with normal antenna operation.

The antenna system shall maintain an approximately constant vertical radiation pattern throughout all angles of azimuth.

There shall be a substantially uniform change of effective radiated power from the maximum value down to the value obtained at the largest specified depression angle.

1.21 Variation of Radiation with Frequency

The variation in radiated power over each operating channel frequency band separately shall not exceed 1 dB at any angle of azimuth and at any vertical angle between the horizontal and the largest specified angle of depression.

1.22 Physical Limitations

The antenna system shall be suitable for mounting on an antenna support column to be provided by the principal, and having the following physical dimensions and orientation:

(a) Support column will be square in cross-section and orientated with one face on a bearing of 35 degrees True.

(b) Maximum available vertical aperture of column will be 23 m.

(c) Column cross-section outside dimensions will be 1.67 m^2, and the antenna panels shall be clear of the column by adequate dimensions to allow the installation of antenna mounting bars between the column and the antenna panels. To ensure that the horizontal radiation pattern is not unnecessarily dependent on frequency, the antenna panels shall be parallel to a column face, within ± 10 degrees.

1.23 Frequency

The antenna system is to operate on the combined transmission from two transmitters, one on Channel 3 with an offset of + 1 MHz (86-93 MHz) and with a vision carrier frequency of 87.25 MHz, and the other on Channel 5 (101-108 MHz) with a vision carrier frequency of 102.25 MHz.

1.24 Polarization

The radiation from the antenna system shall be vertically polarized.

SYSTEM PERFORMANCE CALCULATIONS

EXAMPLE 47.5

System performance calculations are usually required when a tender calls for the complete design, installation and commissioning of a multi hop radiocommunication system. The following extract from a schedule for a radiocommunication system for communication and control along a pipe line is typical. The system sought was to operate in the u.h.f. band.

1.1 General

The object of these performance calculations is to provide an estimate of the quality of communications that would be obtained in the worst voice channel of the tendered radio system with the multiplexing equipment necessary to provide the facilities.

Since there are several methods of calculating system performance, a standard set of forms is included and must be used to avoid any variables that may result in technical misunderstandings.

The Radio Path Data form *Table 47.2* presents performance calculations on a per hop basis.

The Overall System Performance form *Table 47.3* summarises the per hop information to give an indication of the noise level performance of the overall system. In this form it is assumed that the 80% condition per hop noise can be added to obtain a value for the overall system noise.

1.2 Basis of Performance Calculations

The performance calculations are used to assess the estimated behaviour of the complete system under the worst conditions:

(a) It is preferred that the calculations be based on an actual system using the same frequency band and operating on a route where the terrain is similar.

(b) All data must show a source. If data is derived from a graph a copy of the graph must be included and its source indicated. If it is derived from published information, the source of the information should be listed.

(c) The median path loss per hop between isotropic radiators shall be listed. The maximum path loss between isotropic radiators during a deep fade assumed to occur 0.01% of the time in the worst month should be stated. The basis of both of these figures should be clearly outlined, since the whole system performance will be based upon the accuracy of these figures. It must be assumed that fades to the value listed will occur simultaneously in one hop in five.

(d) The system performance calculations shall be based upon the full loading of all channels, For example, if the equipment is capable of 24 channel

Table 47.2 RADIO PATH DATA

Hop No. ....

Radio Site Locations	A		Lat.	Long.
	B		Lat.	Long.
Antenna Height	A	Path Length		
	B	Frequency		

Considerations	*Reference*	*Dimension*	*Gain*	*Loss*	*Remarks*
Transmitter power					
Free space loss					
Loss due to insufficient clearance					
Directional filters					
Connectors + interconnect cables					
Transmission lines					
Antenna at A					
Antenna at B					
Totals (without fade margin)					

Median condition	Received Signal	=	Gains – losses
	Strength	=	dBm – dB
		=	dBm
	Per Channel	=	dBmOp
	Noise	=	pWOp
Faded condition (not exceeded for 80% of any month)	Received signal	=	Median signal – Fade
	strength	=	dBm – dB
		=	dBm
	Per channel	=	dBmOp
	noise	=	pWOp
Faded condition (not exceeded for 99.99% of any month)	Received signal	=	Median signal – Fade
	strength	=	dBm – dB
		=	dBm
	Per channel	=	dBmOp
	noise	=	pWOp

operation, the performance calculations shall be based upon 24 channel loading, since this will show the result of using the ultimate capacity. A second set of calculations shall be provided and this shall be based upon the exact channel loading as required by this Specification plus two channels for future expansion.

Table 47.3 OVERALL SYSTEM PERFORMANCE

Hop	*Total noise per speech channel (pWOp)* *Median conditions*	*Not exceeded 80% Month*	*Not exceeded 99.99% Month*	*Multiplexing*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Total	(1)	(2)	(3)	(4)

Total Channel Noise

1	Median Conditions	(1) + (4) =	pWOp
2	Faded Conditions (not exceeded 80% Month)	(2) + (4) =	pWOp
3	Estimated Faded Conditions	=	pWOp

(e) It is assumed that the busy hour multiplex signal can be represented by a white noise signal, the mean absolute power of which at a point of zero relative level is equal to $(-1 + 4 \log 10^N)$ dBm, N being the number of channels for which the relay system is designed. White noise at this level shall be used to determine the total intermodulation effects.

(f) With white noise loading as in (e) for the maximum system capacity, the total noise measured in any 3.1 kHz quiet slot on an end-to-end basis shall not exceed the values below which take into account fading:
  (i) 12 000 pWOp one minute mean power for more than 20% of any month.
  (ii) 1 000 000 pWOp one minute mean power for more than 0.1% of any month.

1.3 Muting

The system shall be so arranged that loss of carrier in any one hop will not disable the balance of the system due to noise injection in the baseband. The muting system, which retains the service channel facility on either side of the break will be preferred.

1.4 Gain Stability

The manufacturer shall state the base band gain of the system proposed, on an end-to-end basis, over a two month period. Gain stabilisation must be guaranteed.

In addition to specifying gain stabilisation the manufacturer shall also state the method by which frequency stabilistion is ensured and the frequency stability of the equipment shall be stated. If the system is a heterodyne repeater type, this should also be stated and the frequency stability of the terminals which control the heterodyne stability must be stated.

1.5 Equipment Reliability

The equipment reliability must be 99.8% or 18 hours total outage per year, but no one single outage shall exceed five minutes. Standby equipment with automatic switchover facilities and the location of spare parts and maintenance depots shall guarantee these figures. The point-to-point radio equipment shall be all solid state equipment, unless it is not commercially available. The equipment must be easily installed and removed. The tenderer shall state the rate of fault incidence per repeater per annum that he will guarantee and should include system reliability calculations showing allowances for radio equipment, power equipment and propagation outages. The tenderer should also submit a reliability figure he is prepared to guarantee for periods of one year and two years after acceptance.

ENGINEERING PRACTICES, DESIGN AND WORKMANSHIP

EXAMPLE 47.6

The following example of engineering practices, design and workmanship is typical of a Section included in specifications for a wide range of radio engineering equipment but in particular to broadcast and television transmitters.

1.1 General

The design, workmanship, material and finish of all equipment shall be of the highest quality as appropriate to the particular application. The best features and latest developments in electrical communications practice shall be embodied, and all power supplies and low power stages to the maximum power practicable shall employ solid state devices.

1.2 Equipment Design

(a) The equipment design shall ensure that each amplifying stage is basically linear in all parameters so that overall performance shall not require compensation of one stage for another and so that the need for special correction circuits is minimised.
(b) Units and sub-units shall be readily removable to facilitate maintenance.
(c) Units and sub-units shall be designed with standard interface conditions at input and output to permit maximum bench or test jig adjustment, and shall be designed such that subsequent insertion into operational equipment may be effected without re-adjustment.
(d) Where necessary to ensure freedom from impedance interactions, isolators such as circulators should be inserted between stages.

1.3 Equipment Protection

(a) The equipment shall be protected as far as possible against unsafe conditions and damage that may otherwise result under fault conditions such as from the failure of components or other groups of auxiliary equipment including air circulating systems or circuits supplying bias voltages. To obtain this, the necessary overload and guard devices and interlocks shall be incorporated, and current limited, voltage limited, and short circuit protected power supplies should be used for low power stages wherever practicable.

(b) In order that non-standard or fault conditions may be investigated readily, the control circuits shall include a means of giving a permanent indication of the specific area of occurrence of a fault condition. For this reason also, individual circuit breakers, fuses, SCRs, or similar protective control devices shall be provided for each major power source and each major tube plate or grid bias power converter. Where appropriate, lock-out switches shall be provided in the control circuits so that individual circuits can be disconnected readily during investigation of fault conditions.

(c) The overload protection circuits for the final radio frequency stages of the transmitters shall include a facility such that when an overload occurs, the plate voltage supply to that stage shall be reduced for a short period and then restored to the normal value.

Should the overload occur again, a similar sequence of operations shall take place. After three such cycles, the circuits shall automatically remove the plate voltage supply and render it necessary to restore the transmitter to service by manual operation after clearing the fault.

(d) In the event that a fault causes the equipment to close down, all power shall be disconnected from the equipment with the exception of crystal oscillator ovens.

(e) A failure of the primary power for a period exceeding eight seconds may cause all control circuits ot revert to the 'close-down' condition so that the full normal starting procedure shall be necessary to place the equipment in operation when power has been restored. However, during a failure of primary power for a period not exceeding eight seconds, the control circuits shall not release and the equipment shall be restored to the operating condition automatically and without the function of time delay circuits. Tenderers shall specify the maximum duration of a power break allowable to enable an immediate restoration of normal operating conditions.

(f) The equipment shall be designed to limit the extent of a fire outbreak. Fail safe shut down methods shall be used such that earth contacts due to fault conditions cannot re-apply voltages. All materials used for insulation and mounting shall be self-extinguishing, even when cooling fans in the equipment remain operating. Component mounting arrangements shall minimise the possibility of ignition by arcing or through component failure. If it is considered essential to use components containing oil or other similarly flammable material, these components shall be separated from the main equipment and mounted in a fire proof container even if the components are themselves sealed.

(g) The design of the equipment shall be such that all components are operated well within the rating recommended by the manufacturer for the particular conditions under which the component will be required to function.

(h) The type and rating of each component shall be selected with the object of securing reliable operation and long life.
(i) Solid state devices shall be used wherever possible.
(j) The equipment shall be fully protected against damage by lightning induced transients on the primary power supply or earthing systems.

1.4 Personnel Protection

(a) Complete protection shall be afforded to maintenance and operating personnel against contact with apparatus or other fittings upon which exist dangerous voltages and/or high temperatures.
(b) A dangerous voltage is defined as any voltage in excess of 50 V RMS or 70 V peak a.c. or d.c. and high temperature as in excess of 80 °C.
(c) Provision shall be made either to prevent inadvertent access to any terminals, apparatus or fittings upon which dangerous voltages may exist, or, alternatively, to provide a means of positively removing dangerous voltages before gaining access.
(d) High temperature surfaces shall be inaccessible by the use of appropriately designated shields.
(e) Shields or covers provided to prevent inadvertent access to dangerous voltages shall bear the following caption in prominent red letters:

DANGER – LIVE TERMINALS ENCLOSED

(f) Facilities for positively removing dangerous voltages may be provided by door-operated safety switches or by a safety isolator switch operated by the door keys or by some similar device. When a security system of this type is provided, the closure of doors or gates or the operation of the device shall not in itself cause the dangerous voltage to be applied; some other act must be performed and such act shall be performed outside the protective doors from a position where the operator may observe the effect of his action.
(g) The functioning of any safety switch, isolator, or safety device to the 'Safety' position shall not only remove dangerous voltages from the associated equipment and lock out any control functions either local or remote but shall also positively discharge all capacitors in the associated equipment that might otherwise retain dangerous charges. Where door-operated safety switches are provided, these shall be of the highest quality in design and manufacture and shall be provided in duplicate at each safety point. Doors fitted with such switches shall be fitted with positive mechanical latches. A testing circuit shall be provided to locate quickly any faulty door switch.
(h) Lamp caps should be coloured in accordance with the following code:
Urgent alarm condition, RED
Non-urgent or alternative operation condition, AMBER
Normal operation condition, GREEN
Starting sequence indication, PURPLE
'Power On' condition on power distribution panels, GREEN
(i) Pushbuttons incorporated in the transmitter shall be coloured in accordance with the following code:
'On' buttons, GREEN or BLACK
'Off' buttons, RED

Chapter 48

Inspections and Acceptance Tests

INSPECTION STANDARD

Having decided on the necessary requirements in the form of a specification for material, equipment, plant or service, the method by which these requirements will be checked has to be considered. The inspecting officer has to be given guidance to avoid disputes and misunderstanding with contractors. He may check the requirements by visual inspection or chemical analysis or by tests and measurements directed to ascertain any of the physical or chemical properties of the material or work. Appearance, finish and workmanship as well as uniformity and the absence of flaws are checked by visual inspection, consequently any information possible to make known the standard required, should be embodied in the specification. Failing any guidance in the specification, the inspecting officer is left to use his own experience and judgement in deciding whether the standard offered is satisfactory, having regard to the prevailing commercial standard and the work for which it is required.

The inspecting officer has an over-riding responsibility to control the scope, level and severity of inspection. The expenditure on any inspection should not exceed the cost of the wastage material, labour and revenue which result from not performing that inspection. As any inspection is never 100% efficient, it should always be significantly less costly than the probable field repairs. Any particular case is indeterminate, but keeping the principle constantly in mind, will assist the inspector in achieving a balanced control of the inspection activity.

In practice it is invariably found that it is not practicable to obtain material, equipment or plant which complies in every respect to the ideal standards which are often laid down. Some of the reasons why the contractor may be unable to produce items which conform exactly to the specification may be summarised as follows:

(a) The specification may set an impracticable standard.
(b) The raw materials to be used in the manufacture or construction of the item and which are supplied to the contractor from outside sources may vary beyond limits set down in the specification. Also, alternative materials may have to be used owing to shortages, for various reasons.
(c) The skill of the contractor's workforce may vary due to staffing problems or pressures on works of higher priorities.
(d) The design of the equipment, plant or material may have shortcomings.
(e) Dies, machine tools etc. wear, and when nearing the end of their useful life, will often result in a product of inferior standard.
(f) The contractor may have offered and had accepted his standard material or product which was manufactured to a different specification.

MINOR AND INCIDENTAL DEFECTS

It often happens that some material or work fails to comply with the specification in some minor points but would be satisfactory in service. In these cases the principal may not insist on rejection but may give a warning to the contractor to rectify the defect in future work. If for example, urgent work is being held up because of late delivery of material, it may become economic to accept the material in spite of some minor defects. Acceptance on the grounds of urgency of materials and work which would otherwise be rejected, however, is to be strongly deprecated, as it tends to open a way to unscrupulous contractors to get materials and workmanship of low quality accepted and it may even result in a supplier who falls behind with deliveries of work being rewarded by acceptance of materials or work which would otherwise be rejected.

In the case also of work which would entail an expense to put it right, quite out of proportion to its importance, the fair course might be to give a warning rather than reject the work. However, each case would have to be properly considered by the principal. As is the case with many engineering problems, the solution frequently involves a compromise between conflicting requirements of what we want, what we can afford and what we can get.

As examples, typical minor and incidental defects which have been noted during factory inspections of radio equipment and which at various times have been accepted by inspecting officers include:

(a) Damaged screwdriver slots in screw heads.
(b) Missing cover screws.
(c) Soldering iron burn marks on capacitors, resistors r.f. chokes, terminal strips and printed circuit boards.
(d) Improper wire dress
(e) Obliterated component designation and identification markings.
(f) Upside down or incorrect identification of non critical items.
(g) Poor plating finish on chassis, coils and other metal components.
(h) Dented cover.
(i) Corroded metalwork.
(j) Missing or wrong type locking device.
(k) Distorted mechanical components such as potentiometer shafts, capacitor drives, insulator metal end caps, lids and doors.
(l) Deformed and chipped printed circuit boards.
(m) Poor alignment of part, cover etc.
(n) Scratched and dirty paintwork.
(o) Hardware too long or too short.
(p) Small chips broken from porcelain insulators.
(q) Finger loose component or hardware.
(r) Poorly finished welding and soldering.

On the other hand, some typical defects which have been located but not accepted by inspecting officers include:

(a) Broken components and wiring.
(b) Malfunction of line current meter.
(c) Distorted antenna strain porcelain insulators.
(d) Dented coaxial cable sheath.

(e) Incorrect designation of components and wiring in transmitter.
(f) No transmitter output power when power supplied.
(g) Damaged or distorted relay springs.
(h) Short circuit at tube base due to solder bridge.
(i) Cracked semiconductor glass bases.
(j) Unsoldered connection, wire loose.
(k) Faulty tubes and transistors.
(l) Illegible markings for strapping pins or contacts.
(m) Damaged speaker cone and armature.
(n) Cracks in printed circuit boards.
(o) No reception or no oscillation.
(p) Noisy power transformers, water pumps and fans.
(q) Slipping clutch of antenna switch drive mechanism.
(r) Leaky oil transformers, electrolytic capacitors, batteries and water cooling systems.
(s) Mechanical defect in antenna switching matrix.
(t) Corroded electrical components such as pig tail lead, switch and relay contacts, plug and socket pins, tube pins and sockets, printed circuit board tracks.
(u) Intermittent contact of antenna switch wiper springs.
(v) Fracture of inner conductor of coaxial connector.
(w) Metallic whisker growth on relay springs and amplifier chassis.
(x) Threads stripped on captive screws.
(y) Silver migration across insulation of silver plated components.
(z) Inoperative transmitter safety device.

LEVELS OF SEVERITY

The inspecting officer normally uses three levels of severity in inspection: normal, tight and reduced. Normal severity is used as long as the material offered is generally satisfactory. Tight severity is applied for inspection of material or work which has been re-offered, after a previous rejection, and reduced severity may be used where high rate of acceptance has been obtained on normal severity or the inspector considers it to be desirable. The main reason for choosing an inspection other than normal would be that the principal needs reassurance before giving a contractor the benefit of the doubt that arises due to sampling variability or that a contractor has shown by past performance that his product or workmanship may be expected to be better than the acceptance quality level and the principal might reasonably accept a greater risk of this not being so.

If it were unnecessary to take any account of economy of time or labour, inspection and acceptance testing would consist of taking each item and subjecting it to a series of tests to ascertain whether or not it complied with every individual requirement of the specification. This may of course not be possible in practice. For instance, the specification of a capacitor may require it to pass a series of a dozen or more tests in relation to capacitance, impedance, leakage, power factor, dielectric constant etc. Consideration of economy in time or labour makes it impossible to do all these tests manually where large numbers are concerned. *Table 48.1* shows typical tests which may be carried out on some radio components.

Table 48.1 TYPICAL COMPONENT TESTS

Component	*Tests*
Loudspeakers	Power handling capacity, frequency response, distortion, resonance, flux density, robustness.
Meters	Calibration accuracy, damping, robustness, zero error, temperature coefficient, effect of external electrostatic and magnetic fields, sensitivity
Capacitors,variable	Capacitance law, insulation resistance, voltage rating, power factor, capacitance drift, robustness, mechanical operation.
Capacitors, fixed	Insulation, leakage current, power factor, voltage rating, temperature coefficient.
Resistors, variable	Resistance law, power rating, operating and end-stop torque, voltage rating, angles of resistance.
Radio frequency transformers	Frequency characteristics, inter-winding capacitance, wave shape distortion, selectivity, leakage inductance, power capability.
Quartz crystals	Frequency accuracy, drift, spurious oscillation, capacitance, activity, sealing.
Relays	Current rating, voltage rating, insulation resistance, speed of operation, contact bounce, release time.
Coaxial cables	Loss factor, attenuation, insulation resistance, voltage rating, reflection co-efficient, frequency range.
Tube sockets	Socket gauging, voltage breakdown, insulation resistance, contact resistance, power factor, capacitance, tracking.
Switches	Voltage rating, current rating, insulation resistance, robustness, mechanical operation.
Plugs and sockets	Voltage rating, current rating, insulation resistance, contact resistance, impedance matching, insertion and removal forces.

Figure 48.1 Production line testing of amplifiers (Courtesy JETCO)

Acceptance testing thus resolves itself into a problem of making reasonably sure with the least possible number of tests that supplies are up to standard and making these tests as simply applied as possible. If the performance of unnecessary work is to be avoided on the one hand and the acceptance of defective goods is to be avoided on the other, constant vigilance and the exercise of judgement are necessary. Some properties of materials such as appearance cannot be measured and are left to the judgement of the inspecting officer.

Any inspection activity that the inspecting officer might carry out in the contractor's factory during manufacture of a product does not replace or form part of a contractor's own inspection. The contractor is expected to submit a product which will meet the specifications. *Figure 48.1* shows a production line testing of audio frequency amplifiers being carried out prior to submission for acceptance testing.

Table 48.2 TESTS AND CHECKS FOR EVALUATION OF PROTOTYPE RADIOCOMMUNICATION EQUIPMENT

Unit	*Tests and checks*
Transmitter	RF return loss Output power Deviation Frequency and stability Spurious output Power consumption Alarms and metering Baseband return loss
Receiver	Noise figure r.f. return loss Local oscillator frequency Local oscillator stability Local oscillator radiation r.f. overload point r.f. bandpass characteristic Spurious responses Mute operate time Mute adjustment range Alarms and metering Power consumption i.f. amplifier characteristic Baseband return loss
System	Baseband frequency response Baseband spurious n.p.r. basic noise, and overload Baseband pre-emphasis, de-emphasis Worst channel noise versus RX r.f. input level
Order wire	Frequency response Signal/noise ratio Distortion Deviation Call tone
Duplexer	Losses Return loss Filter responses

In the development of new equipment, prototypes are often made and provided by the contractor for approval before mass production is implemented. These inspections of prototypes are made independently of the normal submission of the material offered for inspection prior to delivery and generally do not form part of the acceptance inspection. *Table 48.2* shows typical electrical tests and checks which may be performed to evaluate a new type of radiocommunication equipment.

CLASSIFICATION OF DEFECTS

The classification of defects often forms the basis of statistical sampling methods and is the first step in the assessment of quality. Each defect is classified according to its importance into one of the following catagcries:

(a) Critical defects.
This includes defects which in use or storage could directly cause loss of life or serious bodily injury, for example a split in the stile of a lineman's ladder, defective insulation in a power supply unit etc.

(b) Special defects.
Included in this class are those defects which make the item useless for the purpose for which it was designed, for example a hose to be used in a transmitter water cooling system which would not withstand the high water temperature.

(c) Major defects.
Major defects are those which could seriously affect the proper functioning or performance of an item and for specific reasons would make the item unacceptable, for example a porcelain insulator end cap which exhibits corona at high ambient temperatures.

(d) Minor defects.
Those defects which will not materially affect the proper functioning or performance but involve a minor departure from the specification. Obliterated component designation and identification markings are typical of this category.

(e) Incidental defects.
Included in this class are those defects caused by departure from good workmanship which, though not affecting the functioning of the item, are nevertheless undesirable, for example untidy wiring, dirty and scratched paintwork, non-professional signwriting etc.

ACCEPTANCE TESTING OF SYSTEMS

Acceptance testing of systems such as radiocommunication systems, broadcast stations and television stations is required to prove that the system meets all applicable performance and/or contractual specifications. Some equipment and plant debugging and correction of minor discrepancies is normally to be expected during these tests. However, on completion of the testing programme and acceptance of the system, it should be operating at peak performance. *Figure 48.2* shows factory tests being conducted on a 200kW medium frequency broadcast transmitter before shipment to site for commissioning.

Figure 48.2 Factory tests being conducted on 200 kW m.f. transmitters (Courtesy Continental Electronics)

Most acceptance tests place importance on operational performance of the system. This can best be demonstrated to the inspecting officer by a repetition of selected pre-acceptance system tests. For formal acceptance testing of a high capacity radio relay system for telephony purposes, it may be desirable to spot check the audio circuits rather than completely test every channel, for example demonstrate frequency response of say 10% of the channels. These details should be clearly defined in the acceptance testing schedule.

Two other important requirements of the schedule which are necessary only when the system fails to meet only one or more of its specified minimum limits, are:

(a) The procedure to be followed in the event of such a situation.
(b) The responsibilities of the contractor and the principal must be clearly defined.

One of the important factors in scheduling acceptance tests is the duration of the operational tests. The time the system must be in operation prior to acceptance should be specified. Some organisations require thirty days of continuous operation while monitoring critical tests points for acceptance testing, in the case of, for example, a microwave radio relay system. Others have a practice whereby the system is accepted immediately on satisfactory completion of the tests, with a three months guarantee cover period whereby the contractor, at his own expense, makes any necessary adjustments and replacements to restore the system to the performance level at the time of acceptance. There may be even a further cover whereby the contractor returns after 12 months operation of the system, to restore it to its acceptance or commissioning performance level.

The acceptance schedule should also set down the conditions for acceptance of items covered under the contract, other than the system performance. Such conditions include provision for:

(a) Test equipment.
(b) Spare parts inventories.
(c) Handbooks.
(d) Drawing transparencies.
(e) Special tools, touchup paint, oils, greases etc.
(f) Documentation.

STANDARDISATION

Standardisation is now recognised as being of paramount importance to economic production, improvement in quality and design, to the reduction of maintenance charges and for inter-changeability of parts. The existance of Standards greatly simplifies materials commerce in an industrialised society. Their absence would greatly complicate the tasks of the consumer in specifying his requirements and of the producer or contractor in meeting them. Some of the benefits derived from the use of Standards may be summarised as follows:

(a) Improved communication between principal and contractor.
(b) Greater confidence of the purchaser in the material or of facilities provided.
(c) Better understanding of how to use the material, equipment or plant.
(d) Greater public safety in the use of the material, equipment or plant.
(e) Better quality control in products using materials made to Standards.
(f) Lower inventories for both producer and consumer through the elimination of unnecessary grades and classifications.
(g) Earlier delivery of materials because of ability to keep standard stocks in inventory.
(h) Better performance at lower prices through reduced need for negotiations and more efficient inspection and testing.
(i) Lower prices to purchaser through a more rational basis for competitive tendering.

These benefits add up to an enormous savings for industry, through more efficient operations, greater safety and convenience and lower prices for purchasers, through specified quality levels for the materials used in consumer products and improved materials technology, through availability of more refined and controlled test methods, and reliable data on properties.

THE STANDARDS

Standards are documents prepared and issued through the procedures of the Standards Associations, Societies, Institutions and the like, to meet the needs of industry, for specifications, test methods and codes which will assist in orderly production, marketing and development. The preparation of these standards is undertaken by the associations or institutions or similar bodies, when there is a generally recognised want and the producers, manufacturers, constructors and users are prepared to co-operate. These organisations exist for the purpose of preparing and promulgating standard specifications and codes. They do not however embark on such work on their own initiative, but in response to a request from an authorative source.

Standards may relate to one or more of several aspects of industrial practice and the standard glossaries of terms serve to eliminate confusion in terminology reference. Standard test methods are designed to provide a uniform and assured means of describing or checking composition or performance. Also the Standard Specifications aimed at defining a generally suitable quality or dimension provide a uniform and equitable basis for tendering and may serve to eliminate diversity in qualities and sizes, thus simplifying the task both of producers and purchasers.

The Standard Codes contain rules for working practice which may be directed towards safety in operation, towards sound installation or construction practices and performance or towards a combination of these. The Codes of Practice represent a standard of good practice and therefore take the form of recommendations. Compliance with them, however, do not confer immunity from relevant legal requirements, including bye-laws. The Standard Specifications deal with the standardisation of materials, appliances and components whilst the Codes of Practice are concerned with the methods of using them.

These Standards are based on what is considered to be best in current practice. They do not attempt to attain an ideal which might be too costly to adopt under industrial and commercial conditions. They are constantly revised to take account of new developments and to eliminate outmoded practices.

The specifications, test methods and codes, gain recognition as national standards from the fact they are prepared and accepted by all interested parties represented on the drafting committees. Committees are composed of experts representative from the interests associated with the particular subjects for which Standards have been requested. The Standards are thus developed by co-operative effort and negotiation on the part of those concerned whether as producers or as users. In general, Standards derive authority from voluntary adoption based on their intrinsic merit but in special cases where safety of life or property is involved they may have compulsory application through statutory reference.

Standardisation cannot be attained by one secton of the community endeavouring to impose its opinions on other sections. Effective agreement can be secured only by common consent of all parties interested, who must take full part in the discussions and in the initiating and working out of the actual details of the specification.

The voluntary adoption of Standards may be affected in several ways. For producers, it is a matter of a decision to make products in compliance with the relevant Standard and to use Standard terminology, Standard tests and Standard Specifications in quotations, while for purchasers it is a matter of citation of Standard Specifications as a condition of tendering and contract.

In using Standards, the engineer should keep in mind the fact that they are written for average conditions and situations. In some situations, amendments to clauses may be necessary when special requirements are being sought but in others the Standards may be entirely unsuitable as a whole. This emphasises the need for the engineer to have a complete understanding and appreciation of the particular Standards before incorporating them in specifications.

Standards under which equipment and plant for radio engineering purposes may be supplied are very many indeed, owing to the large number of organisations which prepare Standards. In the United States alone, there are nearly four hundred organisations of various types preparing Standards. Organisations with whose Standards the radio engineer may from time to time become involved include the British Standards Institution, American Society for Testing Materials, United

States of America Standards Institute, Standards Association of Australia, South African Bureau of Standards and Standards Council of Canada.

TYPICAL INSPECTION AND ACCEPTANCE TESTS

The inspections and tests to be carried out on an item of equipment or plant will vary with the nature of the item and the specification requirements. The following examples however, are typical of inspections and tests which would generally be carried out on some items of radio engineering equipment and plant.

EXAMPLE 48.1

A high power high frequency broadcast transmitter designed for both sinusoidal and trapezoidal modulation capability.

1.1 Introduction.

The inspection and tests described hereunder are to be made on the transmitter after completion of installation on site. The purpose of the inspection and tests is to verify that the installation has been properly carried out and that the overall performance of the equipment is in accordance with the specifications.

1.2 Visual Inspection.

This inspection is made before power is applied and consists of a thorough visual inspection to verify that the installation has been carried out in accordance with the installation drawings, designs and instructions, and that all workmanship and materials are of acceptable quality.

The inspection should be sufficiently comprehensive to verify that the installation is complete in every respect, that unused materials, components, parts, litter and tools are removed and that the transmitter and power vault area, and the surrounds are clean and tidy.

Particular attention should be paid to the following items:

(a) Cubicle and frame earths on sub-assemblies and separately mounted components where these are designed to be at earth potential.
(b) Proper mechanical assembly of the radio frequency, audio frequency, power supply and auxiliary equipment units.
(c) Proper mechanical assembly and operation of all panel, door and capacitor shorting switches and interlocks, and of the main circuit breaker for primary power connection.
(d) Loose contacts, terminals, busbars and connections.
(e) All insulators, and bushings for dust, dirt, cracks and chipping.
(f) Free movement of manual adjustment devices.
(g) Excessive wear, incorrect adjustment or backlash of moving parts.
(h) Proper fitting of panels and access plates, and proper operation of doors and hinged panels.
(i) The free rotation of all fans, blowers, pumps and other devices intended to rotate.

(j) Mechanical security of overhead ductwork, coaxial transmission lines, busbars, cabling supports, wall bracing, pipes, tubing etc.
(k) Leakage of oil and water from transformers and cooling systems.
(l) Correct tubes installed, and installed in the recommended manner.
(m) Proper installation of all plug-in components, sub assemblies, lamps, fuses etc.
(n) Correct installation of earthing wands and other safety equipment.
(o) Installation of High Voltage warning signs near exposed high voltage conductors.
(p) Air inlet filter, for proper installation and type.
(q) Free movement of mechanically operated louvres.
(r) Water drains are free of obstructions.
(s) Low impedance earth connections established to the main building earth grid system.
(t) Proper installation of auxiliary services such as d.c. battery system, deionised water supply, air scavenging plant, a.c. supply for lamps, tools and test equipment etc.
(u) Heavy oil filled transformers and reactors installed on a level base, all wheels checked, drip trays fitted and oil at correct level.
(v) Supply of all fire extinguishing equipment associated with transmitter and power vault areas.
(w) All motors, gearboxes and other similar items correctly lubricated.
(x) Correct designations on lamps, switches, keys, meters etc.
(y) Correct air pressure in tanks or cylinders.

Figure 48.3 shows a 250 kW vapour cooled, computer controlled transmitter with covers and panels removed, preparatory to commencement of the visual inspection during acceptance testing in accordance with these guidelines.

Figure 48.3 250 kW transmitter prepared for visual inspection during acceptance testing

1.3 Primary Power Source.

This test is made to ensure that the voltage, frequency, phase balance and capacity are proper for the transmitter installed.

1.4 Control System.

The inspection and tests are to verify that the control system is in proper working order, so as to allow the main equipment tests to be conducted properly and safely.

The following operations should be verified:

(a) The proper switching operation of all blowers and fans, including those attached to transformers for booster cooling.
(b) The proper switching operation of water pumps.
(c) Water flow, temperature and level indicator alarms.
(d) Interlocking circuits including gate switches, door keys, and earthing wand interlock circuits.
(e) Operation of fire, smoke and arc detection equipment and alarms which form part of the transmitter.
(f) The correct operation of local and remote emergency-off push button circuits.
(g) Filament control circuits and verification of correctly applied voltages.
(h) Bias supply circuits and verification of the correct output voltages.
(i) Air flow control equipment operation for all blowers where fitted.
(j) Correct reading of all meters in operation at this step, including those associated with oil filled transformers.
(k) The proper operation of control circuits associated with vacuum switches power supply and transmission line disconnect circuits.
(l) The proper adjustment and operation of voltage regulating systems associated with the supplies at this step.
(m) Correct operation of all remote control circuits from the control room and other remote localities.
(n) Correct operation of key control and interlocking circuits associated with antenna switching system.
(o) Proper operation of two-way communication system between transmitter and control room.
(p) Low voltage plate supplies and verification of correct voltage.
(q) Correct operation of the monitoring circuit associated with cooling water resistivity circuit.
(r) Buchholz relays in transformer tanks correctly adjusted.
(s) The proper operation of crowbar protection circuits.
(t) Operation of voltage standing wave ratio sensing circuits.

1.5 Transmitter Cooling System.

This inspection and test is made to verify that the cooling system is installed correctly and is operating properly, preparatory to full power tests. Inspections and tests should include the following with filament voltage only applied:

(a) Check of cooling water for freedom of solid matter and correct resistivity levels. A specific resistance of 500 000 ohm or greater must be achieved.
(b) Correct adjustment and operation of water level indicators.
(c) Proper fitting of all water seals around tubes and insulating sections, and

absence of leaks throughout the whole cooling system.

(d) The formation of condensation in the glass or fibreglass tubes above the boilers.
(e) Correct operation of heat exchanger fan.
(f) Correct operation and freedom from vibration of all blowers and fans.
(g) Correct mechanical operation of water pumps.
(h) Thermostat operation of booster fans associated with transformer cooling.
(i) Proper operation of air operated shutters.
(j) Correct operation of pressure differentials switch associated with air filters.
(k) Correct rated speeds of fan shafts.
(l) Correct operation of air interlock switches.
(m) Properly installed air duct supporting and distribution arrangements.
(n) Localised cooling of tube seals etc. properly directed.
(o) Targets correctly installed in water system.
(p) Oil samples from transformers and reactors tested for breakdown and acidity level.

1.6 Radio Frequency Performance Tests.

Before the overall radio frequency performance tests are conducted, the following inspections and tests should be made:

(a) The transmitter load, whether liquid cooled elements, dissipative line or an antenna, should be checked for correct impedance over all the operating bands or at frequencies listed in the specifications, also for absence of earths and continuity, where these latter two are applicable.
(b) All high voltage circuits should be checked with a high voltage testing instrument for correct resistance above earth.
(c) All plug-in parts, modules and items such as lamps, indicators, fuses, including fuses wires in filter capacitors, tubes, printed circuit cards, crystals etc. should be checked for correctness of type and location.
(d) Sliding contacts on coils, conductors and switches should be checked for correct pressure.
(e) Servo tuning elements should be operated manually to verify operation of dependent components.
(f) The correct termination and continuity of r.f. output monitoring cables should be verified with an r.f. testing instrument at selected frequencies.
(g) Where a frequency synthesiser is provided as a frequency source, correct output level at selected frequencies should be verified.
(h) Where crystals are provided, the oscillator and multiplier circuits should be energised and correct r.f. output level and frequency verified for each crystal.
(i) The transmitter should be made fully ready for operation by removing earthing wands, fitting all covers, panels, closing doors and ensuring load has been connected and warning signs displayed, and appropriate warning signal given.

After completion of the above inspection and tests, the audio input circuit should be terminated, and the following tests conducted:

(a) On high power mode, the carrier output power capability should be measured at selected frequencies indicated in the specifications. These would generally include one frequency in each of the International broadcast bands, as well as the lower and upper frequency limits of the transmitter. At this stage the transmitter should be operated for about 10-15 minutes on each frequency.

(b) During these tests all meters should be read or the status conditions printed out to determine whether operating conditions are normal.

(c) Where automatic tuning facilities form part of the transmitter, verification of the rated tuning time should be made in conjunction with the above tests.

1.7 Audio Frequency Performance Tests.

To test the sinewave and trapezoidal waveform capability of the transmitter, the audio frequency performance tests should be made with both undistorted sinewave input and a clipped sinewave using an audio peak clipping amplifier. The following tests to verify the modulated r.f. output capability should be made at one or more selected radio frequencies:

(a) The sinewave audio frequency response measured at frequencies and modulation percentage set down in the specifications. Typical frequencies would be 50, 100, 400, 1000, 3000, 5000, 7500 and 10 000 Hz with modulation of approximately 50 or 98% at 1000 Hz.

(b) The harmonic audio frequency distortion measured at frequencies and modulation percentages set down in the specifications. Typical test frequencies would be 50, 100, 400, 1000, 3000, 5000, 7500 Hz with modulation of 50% and approximately 98% levels.

(c) The carrier noise level measured.
This measurement is generally carried out with a noise measuring meter with the transmitter audio input terminals terminated with a 600 ohm load. The reference output is the reading for 100% sinewave modulation at 1000 Hz.

(d) The trapezoidal waveform observed on an oscilloscope when the transmitter is modulated with a clipped sinewave using a speech clipping amplifier at approximately 98% peak modulation. The waveform is observed for agreement with specified waveforms. About 9 dB of clipping at 100, 1000 and 3000 Hz is a typical test level.

(e) The carrier shift measured.
This would normally be measured with an audio frequency tone of about 1000 Hz, and at levels to cause modulation depths of 50, 75 and 98%.

Figure 48.4 shows a typical instrument requirement for carrying out these and various other performance tests during acceptance testing.

1.8 Heat Run Test.

The heat run test should be conducted at full carrier power at a frequency or frequencies to be selected and under various modulation conditions. The test should consist of a 24 hour essentially continuous operation, but up to three interuptions of a maximum of 5 minutes each may be allowed.

A typical heat run may be programmed as follows:

(a) Four hours with 50 Hz sinusoidal tone modulating the transmitter essentially 100%.

(b) Four hours with 1000 Hz sinusoidal tone modulating the transmitter essentially 100%.

(c) Four hours with 10 000 Hz sinusoidal tone modulating the transmitter essentially 100%.

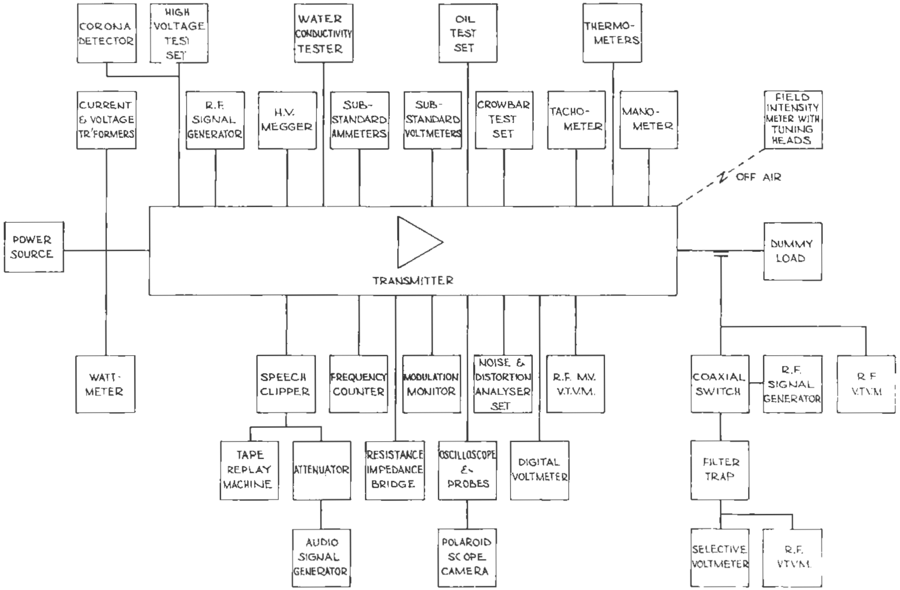


Figure 48.4 Typical test equipment used for high power h.f. transmitter

(d) Twelve hours of a typical programme with nominal 9 dB clipping.

For the whole period of the heat run the transmitter should be kept under continual observation and complete logs taken at regular intervals. After completion of the test, an immediate check should be made to detect any excessive temperature rise in such items as motor and fan bearings, insulators, panel walls, transformer cases, busbars and cables.

EXAMPLE 48.2

External plant of a high frequency broadcast station comprising antennas, matrix switching system, and transmission lines.

1.1 Introduction.

The inspection and tests described hereunder are to be made on the plant after completion of all, construction, erection and installation works. The purpose of the inspection and tests is to verify that the works have been properly carried out and that the overall performance and facilities are in accordance with the specifications.

1.2 Visual Inspection.

This inspection is made before power is applied and consists of a thorough visual inspection to verify that the works have been carried out in accordance with the construction, erection and installation drawings, designs and specifications and that all workmanship, plant, equipment and materials are of acceptable quality.

The inspection should be sufficiently comprehensive to verify that the work is complete in every respect, that unused materials, components, parts, litter, rubbish, spoil and tools have been removed and the work areas have been left in a tidy manner.

Particular attention should be given to the following items:

(a) Earths on sub-assemblies, structures and separately located components where these are designed to be at earth potential.

(b) Lightning protection equipment.

(c) The proper mechanical assembly and security of masts, towers and other structures and equipment mounted thereon such as ladders, conduits, cables, waveguides, lighting etc.
Civil engineering aspects of the work which are difficult to test or inspect after completion of the work, such as concrete foundations, placement of reinforcement, testing of aggregates, water, concrete sampling etc. should be inspected and tested during progress of the work.
Figure 48.5 shows a mast thrust block being prepared for trowelling off of the surface after clearance by the inspecting officer.

(d) The proper mechanical assembly, orientation, security, adjustment, alignment and tensioning of the antenna systems including associated winches and tensioning systems.

(e) The proper mechanical assembly, security, adjustment, alignment and

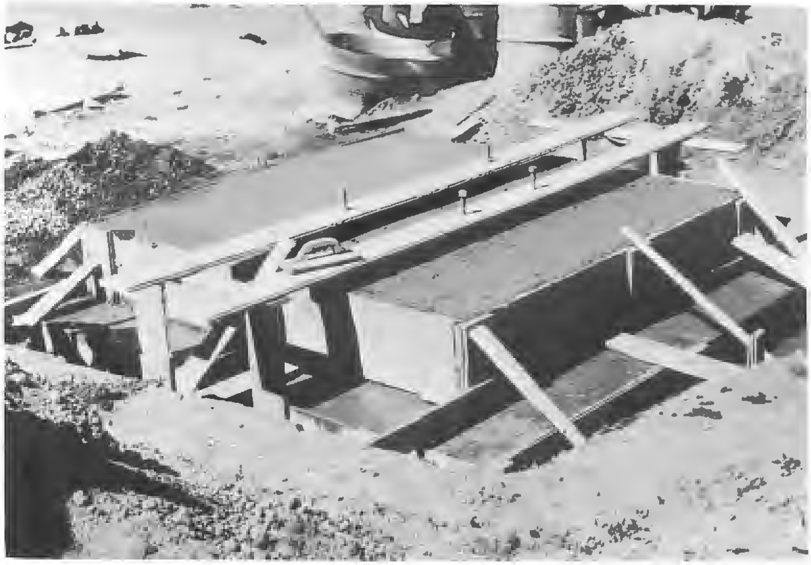


Figure 48.5 Mast thrust block prior to trowelling-off

tensioning of transmission lines, including matching sections and line anchoring structures.

(f) The proper mechanical assembly and security of the line matrix system including remote control equipment.

(g) The proper assembly and installation of earth mats and all structure earthing systems.

(h) Installation of mast lighting systems.

(i) All insulators including strain, lead-through, stand-off and spacers, for correctness of type and size and for cracks, chipping and cleanliness.

(j) Turnbuckles and take-up screws for lubrication, correct adjustment and corrosion protection.

(k) Proper mechanical assembly, adjustment and operation of catenaries and counterweight systems.

(l) Free movement of all manual adjustment facilities and devices.

(m) Proper mechanical assembly, pretensioning, adjustment and correct tensioning of all guy ropes.

Figure 48.6 indicates a typical field set up for pretensioning guy ropes on the ground before placement on the mast.

(n) The security and workmanship of all clamped, brazed, welded, soldered and crimped connections of cables, ropes and wires.

(o) The free rotation and proper operation of all motors, sheaves, winches, pulleys and wheels.

(p) The correct installation of conduits, ducts, pipes, pits, manholes and cables associated with the plant, for correctness of size, depth, grading and standard of workmanship.

(q) All corrosion protection coatings including hot dip galvanising, plating, cold galvanising, epoxy tar coatings and paint work.

Where dissimilar metals are in contact and galvanic corrosion is likely to

Figure 48.6 Pretensioning a guy rope prior to erection

occur, they should be closely inspected to ensure that the joints are made and protected in the same manner set down in the specification.

(r) The proper clearance of conductors etc. above ground and from structures.
(s) Provisions for electrical and mechanical personnel safety.
(t) Neatness and mechanical security of cabling, cable supports and feeders of switching matrix.
(u) Proper installation of all plug-in parts and items including relay sets, transistors, tubes, fuses, indicating lamps and connectors of switching matrix.
(v) Correct adjustment, alignment and contact pressure of matrix line switches.
(w) All welding, brazing, soldering, crimping, clamping of antenna elements.
(x) Correct air pressure in tanks, cylinders, coaxial cables, waveguides, communication cables, etc.

1.3 Control and Safety Systems.

Inspections and tests on the control and safety systems associated with the switching matrix and other electrical works should be carried out to verify that they are in proper working order and in accordance with the specification.

Proper operation of the following should be verified:

(a) All motors should be checked for correctness of operation, proper rotation and speed, during this test.
(b) Adjustable voltages for differential relay operation and the like should be set for correct value during this test.
(c) Proper operation of the complete matrix switching system for both local and remote positions. This should include capability of connecting any transmitter to any antenna or the artificial load.
(d) Proper operation of all supervisory, interlocking, protective, and alarm facilities including lamps relays, keys and push buttons.

(e) Proper operation of all motor driven and manually controlled switching systems, including those associated with antenna slewing, transmission line shorting or earthing. *Figure 48.7* shows a bank of line switches assembled and ready for test.

Figure 48.7 Transmission line switches

(f) Proper operation of mast lighting equipment. If the installation is controlled by photo-cell, the complete equipment should be tested for correctness of operation.
(g) Correct operation of transmission line disconnect devices at the line transition section.
(h) Correct operation of interlocking gate switches where installed with combining huts, antenna matching huts etc.
(i) Installation of High Voltage warning signs near exposed high voltage conductors, particularly at vehicle crossings, insulated structures etc.

1.4 Performance Tests.

Prior to the application of power from the transmitter the following checks should be made:

(a) All high voltage conductors of transmission lines, switching matrix and antennas should be checked for proper assembly, security continuity, insulation resistance and corona by the application of test voltages to verify voltage and current capabilities.
It may be necessary to remove static bleed devices if test voltages are d.c. or mains frequency.
(b) The input impedance and v.s.w.r. of each antenna and line system should be measured over the designed frequency range to check correctness of matching adjustments.
Tests carried out during acceptance testing do not always include radiation pattern tests on the completed installation. The antenna electrical tests may be limited to the establishment of total antenna impedance and v.s.w.r. as

measured at the point of feed line connection at selected frequencies over the design range of each antenna.

For new designs, scale model tests are conducted during development and patterns recorded therefrom. The calculated patterns for the full scale antennas are determined from these model tests. However, flight tests, to confirm the pattern would in some cases be carried out, usually after commissioning.

(c) Cross talk measurements should be made to determine the degree of coupling between adjacent transmission lines and switching elements through the matrix switch.

(d) Switches associated with the matrix system should be manually operated to verify proper operation of motor-fail emergency facilities.

After satisfactory completion of the above tests the following tests should be conducted with r.f. power supplied by a transmitter:

(a) Full rated power capability should be verified at selected frequencies in the designed frequency range of each antenna to test the proper operation of the system. Full carrier plus 100% modulation should be applied at each selected frequency for a minimum period of one hour. During these tests forward and reflected powers should be logged and all elements of the system kept under close observation for corona problems.

(b) At one selected frequency the long term capability should be verified. This test can take various forms but a typical test comprises full carrier power, modulated 100% with sinusoidal tone for four hours followed by four hours of a typical programme with nominal 9 dB clipping. This eight hour test is repeated three times to give a total 24 hour operation. During these tests forward and reflected power meters should be logged to determine that operating conditions are normal and field tests should be conducted to check for any corona formation. After completion of the test an immediate check should be made to detect any excessive temperature rise in selected insulators, contact, conductors, guy ropes, spacers etc.

SITE AND FACILITY INSPECTIONS AND STUDIES

As well as the inspection of materials, equipment, plant and systems the radio engineer is frequently required to carry out on-site inspection and studies for the design of radiocommunication, broadcasting or television stations, the upgrading or expansion of existing stations, the restoration of service following damage by natural disasters etc, assessment of the value of an installation for insurance purposes, transmission engineering studies and many other reasons.

The format to be followed in preparing the inspection report will vary with the nature of the particular exercise but some guidelines can be developed for typical cases. The following examples have been used in practical situations for:

(a) the preparation of a site report for a line-of-sight radio relay station

(b) a transmission engineering study and

(c) the expansion of facilities at an established major point-to-point radiocommunication station. With minor amendments, the guidelines can be adapted for tropospheric scatter, broadcast and television station investigations.

EXAMPLE 48.3

Site Report.

As a general rule a site survey is conducted in two stages: the reconnaissance survey and the final survey. The reconnaissance survey is carried out to verify in the field aspects of a map study which can only be resolved by physical inspection of the site. During this survey informal concurrence on site location is obtained and preliminary site acquisition data collected. The final survey, based on the findings of the reconnaissance survey, engineering guidance and on the results of refined programme definition, is conducted for the purpose of furnishing to the engineering and design group the needed input to permit exact system determination. A specific survey would of course be tailored to the requirements of the particular system and site.

1.1 Introduction.

(a) Observation Date.
(b) Names of Officers Participating in the Survey.
(c) Purpose of Survey and Objectives.
(d) Short Synopsis of Site Findings.
Including the overall rating of each site as Excellant, Good, Poor or Unsatisfactory.

1.2 Site Report.

(a) Co-ordinates.
Latitude,
Longitude.

The establishment of latitude and longitude of a station site can be carried out by several approved methods. The most common methods are map scaling, traverse survey, triangulation survey and celestial observations. The particular conditions may warrant giving precedance to one procedure over another,

(b) Elevation.

The methods of establishing site elevation above sea level are intended to include all elevations on site, in the near zone of the antenna beam path and in the region of the radio horizon. The method of levelling to be performed at a particular location depends on field conditions. Therefore, any of several procedures may be used in establishing the vertical control. These are trigonometric, differential and altimetry levelling.

(c) Description of Site Locale.

Describe the general area in which the site is located, including fire hazard. Include an area map or sketch if possible.

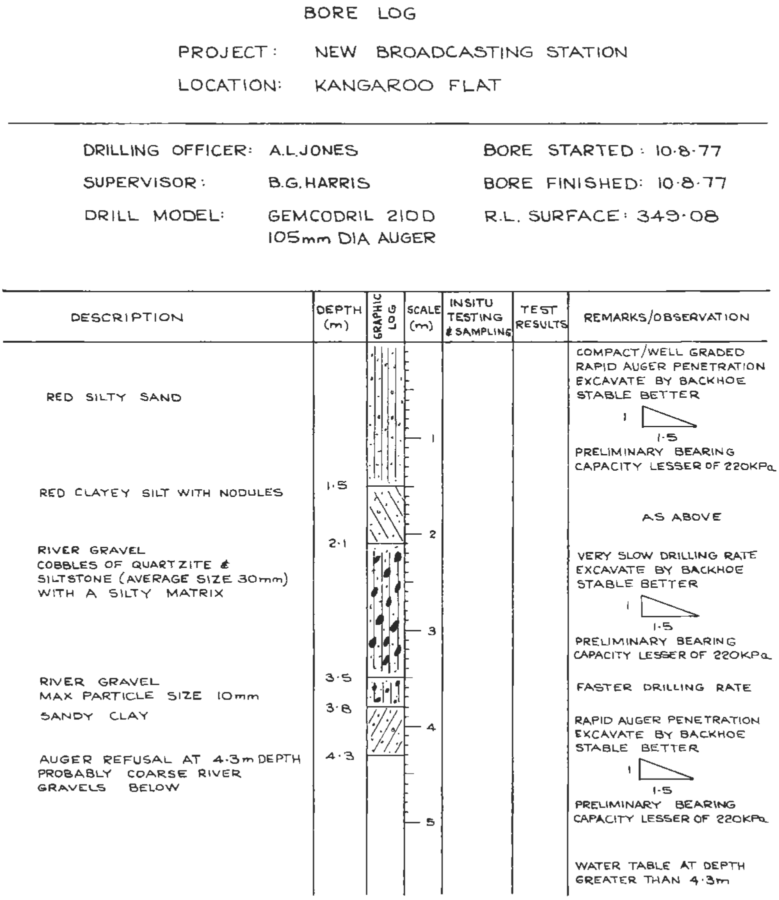
(d) Description of Topography at Site.

If not available a topographic map that will serve as the basis for development of a site plan must be prepared. Site configuration, placement of physical plant, drainage, grading requirements will be determined from this topographic map. The topographic survey map should show property lines, utility lines, roads existing structures, trees etc.

(e) Soil Condition.

Describe soil conditions, particularly those that may affect the buildings, antenna support structure and earthing.

In order to obtain the essential information regarding soil conditions, borehole soil exploration must be conducted. The information provided from this borehole log includes such things as nature of the soil deposit, thickness and composition of each soil stratum, location of ground water, depth, thickness and composition of each soil stratum, location of ground water, depth to rock, rock characteristics, and engineering properties of the soil that affect performance of structures.



BORE LOG

PROJECT: NEW BROADCASTING STATION
LOCATION: KANGAROO FLAT

DRILLING OFFICER: A.L.JONES
SUPERVISOR: B.G.HARRIS
DRILL MODEL: GEMCODRIL 210D 105mm DIA AUGER
BORE STARTED: 10·8·77
BORE FINISHED: 10·8·77
R.L. SURFACE: 349·08

DESCRIPTION	DEPTH (m)	GRAPHIC LOG	SCALE (m)	INSITU TESTING & SAMPLING	TEST RESULTS	REMARKS/OBSERVATION
RED SILTY SAND			1			COMPACT/WELL GRADED RAPID AUGER PENETRATION EXCAVATE BY BACKHOE STABLE BETTER 1 1·5 PRELIMINARY BEARING CAPACITY LESSER OF 220KPa
RED CLAYEY SILT WITH NODULES	1·5		2			AS ABOVE
RIVER GRAVEL COBBLES OF QUARTZITE & SILTSTONE (AVERAGE SIZE 30mm) WITH A SILTY MATRIX	2·1		3			VERY SLOW DRILLING RATE EXCAVATE BY BACKHOE STABLE BETTER 1 1·5 PRELIMINARY BEARING CAPACITY LESSER OF 220KPa
RIVER GRAVEL MAX PARTICLE SIZE 10mm	3·5					FASTER DRILLING RATE
SANDY CLAY	3·8		4			RAPID AUGER PENETRATION EXCAVATE BY BACKHOE STABLE BETTER 1 1·5 PRELIMINARY BEARING CAPACITY LESSER OF 220KPa
AUGER REFUSAL AT 4·3m DEPTH PROBABLY COARSE RIVER GRAVELS BELOW	4·3		5			WATER TABLE AT DEPTH GREATER THAN 4·3m

Figure 48.8 Typical borehole log

Figure 48.8 is a typical borehole log. It resulted from investigations at a site for a proposed medium frequency broadcasting station requiring a 150 m mast radiator.

(f) Site Preparation Required.

Cover in detail, with estimates of cost, if available, all site preparation needed.

(g) Site Ownership.
The name of the owner of the site and his authorised agent should be shown together with mailing addresses and telephone numbers.

(h) Index of Site Photographs.
List all site photographs that will be attached to the report by number or other identification and give a short statement of what each photograph shows of interest.

(i) Availability of Telephone Circuits near the Site. List circuits which could be utilised or expanded.

(j) Land Line Routing.
Determine route and ground conditions for proposed land lines if no present circuits are available. Attach sketch showing sufficient detail for support planning groups to evaluate and plan facilities to meet requirement.

(k) Proximity and Direction to Airfields.
Indicate also what type of traffic control is used, volume and type of air traffic and names of commercial carriers using airfield.

(l) Fungus and Humidity Effects.
Describe probable effects on equipment, buildings, antenna towers and power equipment. Cover any equipment used in the area to counteract these effects.

(m) Insects.
Describe types of insects observed in the area which could damage plant (termites, borers etc) or be a problem with air filters (moths, grasshoppers, flies beetles etc).

1.3 Transmission Path Report

(a) Path Identification.
From,
To.
(b) Mode of Transmission.
(c) Path Azimuth.
(d) Distance to Radio Horizon.
(e) Take-off Angles to Radio Horizon.

Centre Line =

R15′ =	L15′ =
R30′ =	L30′ =
R45′ =	L45′ =
R1° =	L1° =
R1°15′ =	L1°15′ =
R1°30′ =	L1°30′ =
R1°45′ =	L1°45′ =
R2° =	L2° =

Thereafter, intervals of 5° around the horizon.

(f) Locations of Critical Points.

Location	Kilometres from Site
(i)	
(ii)	
(iii) etc.	

From the position established by the survey as the antenna location, theodolite observations should be made to the horizon on the surveyed azimuth of transmission. After positioning the theodolite as close to the calculated antenna centre as possible, a series of observations along the path azimuth for equiangular distances should be taken. Angles of azimuth and elevation or depression should be recorded. Significant points, intermediate to the chosen intervals, should also be recorded. Recorded data should be plotted to form a horizon profile, the entire segment being centred on the path azimuth. Where several paths emanate from the site, observations should be taken for each path.

Figure 48.9 shows a few of the instruments used for site selection survey purposes. Others would include tripod mounted telescope, levelling staff, survey barometer and geodimeter.

Figure 48.9 Site selection survey equipment

(g) Ground elevations.
    Site
    Radio Horizon
    Critical Points

(i) Description of Terrain Between Site and Radio Horizon.
Skyline panoramic photography will provide a pictorial representation of the visible horizon as viewed from the site. It will show the terrain of characteristics comprising the reflection surface and can be used to supplement the horizon profile.

(j) Clearance Required at Critical Points.

	Critical Point	Clearance
(i)		
(ii)		
(iii) etc.		

1.4 Logistic Data.

(a) Transportation.

Indicate equipment and personnel transportation available in the area to the contractor.

Availability and rates for various types of transport vehicles and mechanical aids.

Local public transport and taxi services.

Any special transport regulations governing use of vehicles, for example, bridges with limited load capacities.

Licensing arrangements for drivers.

(b) Personnel Activites.

Indicate the availability of the following types of personnel facilities:

Medical services, including hospitals, doctors, ambulances etc.
Post Offices.
Banks.
Theatres and other entertainment facilities.
Clubs, including sporting clubs.
Boarding houses, motels, hotels and availability of houses for rental.
Food markets and stores.
Schools.
Churches.
Vehicle fuel and service facilities.

When the site being investigated is not to be associated with an existing staffed establishment, personnel support may be an important consideration if staffing is essential for operation and maintenance. Personnel facilities are therefore important issues.

(c) Site Accessibility.

Record information on access to the site by road, air or water, including continuity to access throughout the year. Key this information to pertinent maps and references. Include comments on time required for travel to and between sites, billeting and messing at the remote sites.

Site accessability must be considered from all aspects; from placement of the survey team on the site, through movement of heavy construction plant, materials and equipment to the site and finally the routine transport required for the normal operation and maintenance activities.

This factor is a significant one, particularly in the selection of radio relay station sites, because terrain and propagation advantages which may be found on isolated mountain top sites, are often negated by the magnitude of logistics problems.

(d) Local Suppliers.

Record information as to the availability of local supplies for procurement, if necessary in emergency, of hand tools, hardware, electrical supplies, cement, timber, general building materials and electronic supplies.

Availability of construction and installation materials, such as sand, gravel, cement or ready mixed concrete must be considered when local construction is a programme requirement. Determination in this area will include an evaluation of the adaptability, quantities and costs of available local construction materials.

(e) Local Sub-contractors.
Record information on local subcontractors, rates for services and personnel availability for rigging, hauling and trades, as in the following listing:

Concrete workers.
Carpenters.
Electricians and radio technicians.
Airconditioning mechanics.
Engine fitters.
Riggers.
Painters.
Winch operators.
Ironworkers.
Labourers.

Request names from local Consulting Engineers, District Engineers etc of sub-contractors who have been used before.

The economic advantage of using qualified local labour and resources is an important consideration. However, a thorough investigation of the capability of local talent to perform to acceptable standards of quality should be made before recommending this course of action.

(f) Communication Facilities.
Record information on communication facilities such as:

Public telephone, telegraph and data services.
Armed services facilities.
Civil aviation facilities.
Outpost radio etc.
Civil defence facilities.

(g) Warehouse and Storage Facilities.
Record information of the following nature concerning warehouse facilities:

Location.
Shipping address.
Availability and amount of storage area adjacent to work locations.
Secure outside space.
Non-secure outside space.
Availability of warehouse moving equipment such as fork lifts, pallets, dollies, rollers, cranes etc.
Cost of storage space.
Procedures for delivering and withdrawing materials from storage.

(h) Project Administration Facilities.
Record information of the following nature concerning administrative requirements:

(i) Availability of furnished office space for the Project Engineer; a minimum area of 25 m^2 is desirable where one assistant is provided.

Ascertain if the office will be fitted with desks, filing cabinets and drawing table.

(ii) Availability of telephone for the Project Engineer and where practicable a telephone for each of the work locations.

(i) Additional Items.
Check availability of drinking water, construction water for concrete etc, sanitation facilities, diesel and gasolene fuels, bottled gas.

1.5 Commercial Power supply.

(a) Commercial Power Supply Authority.
  Name
  Address
  Name of Manager and Chief Engineer.
(b) Distance from Site to Nearest Substation.
(c) Electrical Power Characteristics.
  Voltage
  Phase
  Frequency
  Number of wires.

(d) Stability of Power Supply.
  Frequency of power outages
  Length of power outages, over past two years
  Fluctuation of voltage, range
  Fluctuation of frequency, range
(e) Power Supply Adequacy for Use on Non-technical loads.
(f) Proximity of Power Lines to Site.
(g) Additional Capacity Existing Lines Can Furnish.
  If none, how much must line capacity be increased.

1.6 Meteorological Data survey.

Obtain data as available for previous ten years.

(a) Temperature.
  Mean Temperature
  Mean Minimum
  Mean Maximum
  Absolute Maximum
  Absolute Minimum
(b) Relative Humidity.
  High
  Low
  Mean
(c) Rainfall.
  Annual Average
  Duration of Rainy Season
  Maximum Rainfall over One Hour Period
  Maximum Rainfall over Ten Minute Period

(d) Isoceraunic Level.

(e) Prevailing Wind Direction.
For sites near the coast or salt water lakes, external plant may be subject to the effect of wind blown salt spray.

(f) Wind Velocity.
Average
Maximum
Cyclone, hurricane, tornado and typhoon track data

(g) Probability of Flooding or Erosion with Heavy Rain.
Climatological conditions will have an obvious and definite influence on the physical equipment and plant design concept, and construction practices employed in its implementation. Wind and ice loading will affect antenna design, transmission lines and supporting structures. Construction works for buildings, antenna support structures and access roads will be influenced by climatological considerations. Meterological conditions of the area also have considerable influence, since transmission can be seriously affected by adverse atmospheric conditions. Knowledge of the existence of stratified atmospheric conditions with permanent or seasonal character will be a determinant in selecting frequencies, repeater spacings and site locations.

EXAMPLE 48.4

Transmission Engineering Study.

The transmission engineering study should result in concrete requirements for the application of a specific system to the radio relay route including factors relating to future utilisation of the route. In particular the following should be examined:

(a) Confirm planning requirements.
(b) Select the appropriate frequency band in accordance with current regulatory or licencing policies.
(c) Determine the preferred equipment type.
(d) Collect equipment performance parameters (including antennas and feeders).
(e) Define equipment branching network arrangement and assess attenuation.
(f) Determine the long-term (e.g. 20 year) development for each site to enable assessment of number of antennas at each site, and other requirements for, say, v.h.f. u.h.f. translators which occasionally use mesh parabolic reflectors.
(g) Calculate antenna heights assuming development as in (f).
(h) Assess space diversity requirements.
(i) Optimise tower heights.
(j) Determine expected feeder length.
(k) Determine antenna size required to meet thermal noise objective for each path.
(l) Calculate feeder intermodulation noise contribution.
(m) Calculate system noise performance (not to be exceeded for more than 20% of any month) for telephony, signal-to-random-noise for television (video) and signal-to-noise of the television audio channel.

(n) If computer program is applied to this work then an iterative process may be applied to achieve the optimum arrangement. (Steps (h) to (m) refer).

(o) Estimate monthly cumulative fading distribution for each path using:

  Results of propagation measurements.
  Data collected from working systems in similar climatological areas.
  Empirical methods.

(p) Calculate bearer and system performance for small percentages of the month.

(q) Estimate bearer outage due to propagation in percentage of any month and year.

(r) Review space diversity requirements.

(s) Calculate levels of r.f. interference due to:
  Overshoot
  Adjacent paths
  Branching systems
  Other systems
  Communication-satellite and space research earth stations.

(t) Calculate levels of r.f. interference into other systems and facilities from the proposed system.

(u) Prepare recommendations for special system requirements.

  r.f. attenuators
  High performance antennas
  Space diversity
  Signal strength recording facilities.

(v) Prepare draft frequency plan.

(w) Check system design against standards.

(x) Prepare documentation.
  Tower and antenna height drawing
  List of tower heights and types

(y) Prepare transmission engineering report.

A number of aids are required for transmission engineering studies. One of these is the computer to assist in calculations. The computer is an invaluable aid in the planning and design of complete systems because of the extent and iterative nature of the calculations. The extreme reliability of the calculations is also of importance as the correction of calculation errors after the system has been installed could be very expensive.

There are now available many computer programs. The following list taken from one library is typical of many programs being used:

Calculation of Interference Noise due to Overshoots.
Calculation of Noise for Small Percentages of the Month (Telephony, Television and Programme Circuits).
Calculation of Outage Time.
Interference to/from Earth Stations.
Data Files for Radio Equipment Parameters.
Data Files for Antenna/Feeder Parameters.
Data Files for Route Parameters.
System Analysis for Overall System Design.
System Analysis for Propagation Data Processing.
Telephony Noise Performance of Radio Relay Systems.

Performance of Microwave Radio Relay Systems for Television.
Calculation of Interference Protection between two Microwave Paths given Co-ordinates and Antenna Patterns.
Intermodulation Products of Radio Relay Systems.
Microwave Fading Predictions (Pearson).
Pearson and Takasu/Tanaka Methods of Microwave Fading Predictions.
Television Noise Performance.
Calculation of Distance Apart and Relative Bearings of two Points on the Earth's Surface given their Co-ordinates.
Path Bearings by ATT Method.
Great Circle Distance, Bearings and Protection of the Synchronous Orbit.
Overshoot Angles of Microwave Routes.
Calculation of First, Second and Third Overshoot Distances and Relative Angles for Microwave Routes.
Interference Angle.
Calculation of Ground Reflection Angles of Microwave Routes.
Microwave Antenna Heights Calculated from Path Profiles ($K = 0.8$).
Microwave Antenna Heights Calculated from Path Profiles ($K = 0.6$).
Analysis of Sweep Frequency Reflection Co-efficient Measurements.
Bearings, Distances and Free Space Loss.
Radio Link Frequency Plan.

EXAMPLE 48.5

Facility Expansion Report.

When an established station has to be expanded, upgraded or reworked, the collection of the appropriate station data information to allow the design work or specification preparation work to proceed is an important aspect of the overall task. A specific station survey report would be tailored to the requirement of the proposed new work, but the following Example shows the format which would generally be followed in the preparation of a report for expansion of an established radiocommunications station.

1.1 Introduction.

(a) Observation Date.
(b) Name of Officers Participating in the Survey.
(c) Purpose of the Survey and Objectives.
(d) Short Synopsis of Station Findings.
Including any disruptions to services which may occur as a result of the work.

1.2 Site Report.

(a) Co-ordinates.
Latitude
Longitude.
(b) Elevation.

(c) Description of Site Locale.
Describe the general area in which the site is located. Include such information as housing and industrial development and include an area map pinpointing the location of the station.

(d) Description of Topography of Site.
Include contour map of the site as held in station records.

(e) Soil Condition.
Describe the soil conditions particularly those which may affect buildings, tower foundations etc. Obtain from previous data, soil bearing figures used in foundation designs, and make comment following an inspection of the installation, whether these values need review.

(f) Site Preparation Required.
Cover in detail, with estimate of cost any additional site preparation works, such as levelling, drainage, roadworks, clearing etc.

(g) Index of Site Photographs.
List all site photographs that will be attached to the report, by number or other identification, and give a short statement of what each photograph shows of interest.

(h) Local Station Personnel.
Record the names and designations of key operations and maintenance personnel associated with the station and the period that each has been stationed there.

(i) Enviromental Effects.
Describe the effects which the local environment factors such as temperature, humidity, rainfall, fungus, soil corrosion, termites, insects etc. have had on the installed facilities. List measures which have proved successful and also those which have been unsuccessful in combating these effects.

1.3 Technical Information.

(a) Facilities.
A copy of the drawing held at the station showing all the point-to-point communication circuits. If not contained in the drawing, information should be sought on circuit designations, type of circuit (whether speech, programme, television, telegraph, data etc.) and other pertinent information, Land line point-to-point circuits terminating at the station should also be listed.

(b) Intersite Block Diagram.
This should show all radio and land line system numbers, channel capability and frequencies including standby, back-up and emergency facilities.

(c) Interference charts.
All potential sources of interference to proposed new installations should be pinpointed on an area map. This should include such sources as communications systems operated by other authorities and private persons, broadcast stations, television stations, frequency modulation stations, satellite earth stations, radar stations, arc furnaces, dielectric heaters, diathermy and X-ray plant, electric welding plant and other similar type equipment. The report should give details of the characteristics of the possible interference source, if this can be readily obtained.

(d) Operating Frequencies.

All frequencies used for circuits should be tabulated. Each frequency should be shown against the related circuit.

(e) Building Floor Plan.

All relevant building floor plan drawings should be obtained and the following important aspects verified:

- Equipment locations, in two dimensions
- Room dimensions, and in particular ceiling height
- Location of building pillars, air ventilation and heating ducts, fire protection pipes, and other obstructions
- Power distribution boards
- Cable terminating frames
- Antenna port assignment
- Windows
- Fire escape doors
- Ceiling manholes
- Suspended light fittings.

(f) Equipment listing.

This item should be prepared using the building floor plan to identify location. It should indicate:

Specific nomenclature, designation, suite and rack number.

All equipment not in operating condition, and reason for malfunction.

All back-up and emergency equipment.

Type of individual equipment, manufacturer's name and model number, date installed and major modifications incorporated since installation, and reasons for carrying out those modifications.

Indicate width of mounting space in racks 48 cm, 58 cm etc.

Indicate height of racks and rack sections not being used.

Obtain functions of all miscellaneous equipment and indicate if equipment presently in use.

Indicate all building alarms and source for operation of alarm.

All equipment on order but not yet installed, together with details and location where to be installed.

Details of area reservations for future equipment and plant, not yet programmed.

(g) Overhead Runway.

Show on sketch or verify with drawing, location of all overhead runway.

Show location of all other facilities using ceiling space, such as light fittings, ductwork, piping, fire detectors, ceiling manhole etc. If additional runway has to be provided for the proposed new work, determine how the ironwork can be attached to the ceiling.

(h) Cable Distribution Rack.

Verify the location of the cable distribution rack, in two dimensions. Detail the size, type, maximum capacity and present wired capacity. Indicate cabling arrangements into and out of the rack.

(i) Power Supply.

Obtain Drawings of power supply arrangements including both primary and standby or no-break sources. In particular, detail the following:

- Voltage
- Capacity

Frequency
Regulation

Present station power drain for technical and non-technical equipment.
Number and size of spare breakers on low voltage distribution system.
Location of spare power conduit runs from power source to proposed new load point.
Known future additional loading on the power source.

(j) Distribution Boards.
List and identify all buildings a.c. and d.c. distribution boards as to:
- Type
- a.c. or d.c.
- Capacity
- Voltage
- Switch ratings
- Identify spare switches
- Identify working switches and indicate equipment assigned to each switch.

(k) Earthing.
Obtain drawings of station earth system, including other systems, for example tower lighting earth, tied to it. Note location of earth bar distribution in the equipment room. Check whether station has any unusual separate earthing arrangements, such as 'quiet' or 'noisy' earths, a.c. earth etc.

(l) Landlines.
Tabulate all landlines terminating at the station and identify the purpose of each, for example telephone, teletype, order wire, control line, programme line, fire alarm line etc. Locate the cable terminating box or frame and indicate expansion capabilitiy.

(m) Jackfields.
For each jackfield of each bay, list the following information:
- Circuit assignment
- Equipment connection
- Other relevent information marked on the bay
- Number of unused jackfields and their location
- Obtain photographic record of front and rear views, showing layout and markings.

(n) Terminal Strips.
Show equipment terminated on each block, strip or frame. If no drawing is available, make a sketch, giving general information about the units:
- Size of block , strip or frame
- Per cent used
- Maximum capacity

(o) Station Test Equipment.
Obtain complete list of all test equipment including rack mounted and portable units. Indicate nomenclature, serial and item, model number, date of manufacture, manufacturer and condition of each.

(p) Photographic Record.
Areas of particular interest and where problems may exist in the proposed work, should be photographed. This may include:
- Overhead runway at critical location.
- Cable racks.
- Waveguide entry.

Areas where equipment will be manoeuvred.
Hazards such as overhead exposed busbars.
Air conditioning or ventilation inlets.
Cable trench locations.

(q) Antenna Farm.

Site layout drawing, showing location of all antennas, transmission lines, waveguides etc. should be obtained. The drawing should be checked for accuracy to ensure all systems installed as correctly shown. List information on all antennas:

Length
Width
Height above ground
Frequency range
Power capability
Manufacturers number and model number
Whether heating provided
Transmission line or waveguide types.

(r) Antenna Ports and Assignments.

Port assignments should be shown on the floor plan. Following should be listed:

Antenna assignment.
Presence of monitor control boxes.
Transmitter or receiver bay number.
Type of equipment.
All antennas whether in use or not should be treated similarly.

(s) Antenna Switches.

The location and configuration of antenna switches should be verified together with the following:

Transmitters and antennas to which switches are connected.
Antenna port designation.
The controls which actuate the antenna switches.
Type and manufacturer's model of switching control panels.
Whether all antenna switches are installed over the transmitters or some, by the antenna ports.
If the antenna switch drawing is not available a sketch should be made of each group of switches.

(t) List of Drawings and Documents.

The report should contain a list of all drawings and documents referred to, if they are not bound in the report.

Depending on the nature of the proposed work at the station, additional information, relative to the site, may be necessary. If so, it may be desirable to include relevant sections of a site survey report.

FURTHER READING

ARMITT, T., 'Electrical Specifications in the Construction Industry; *Electrical Engineer,* March 1977

Chapter 49

Contract Administration

ROLES OF THE ENGINEER, LEGAL ADVISER AND ACCOUNTANT

The three people mostly concerned with the preparation and subsequent administration of a contract are the engineer, the legal adviser and the accountant. While each of these professionals is appreciative of the basic concepts of the other's work and his role, it is well known that they each have a somewhat different attitude to the contract administration activities.

The position of the engineer is clearly set out in the Code of Ethics issued by the various professional engineering bodies. The following extract issued by The Institution of Engineers, Australia[1] is typical:

"In the preparation of plans, specifications and contract documents, and on the supervision of construction work, he shall assiduously watch and conserve the interests of his client or employer. However, in the interpretation of contract documents, he shall maintain an attitude of scrupulous impartiality as between his client or employer, on the one hand, and the contractor on the other, and shall, as far as he can, ensure that each party to the contract shall discharge his respective duties and enjoy his respective rights as set down in the contract agreement."

The engineer is concerned primarily with what has to be physically provided to meet the end product, and the most economical method of achieving this objective. In the preparation of the specification or the technical conditions he has to imagine the complete work from start to finish and attempt to anticipate all problems likely to be encountered in practice when the work ultimately takes place. From the contract point of view he may feel that if all the physical situations have been catered for, and agreed to by the contractor, the contract is clear. However, in actual fact this assumption may be far from being true.

The main concern of the legal adviser is to ensure that the obligations which each party is to assume upon the signing of the contract are clearly defined and unambiguous. He, like the engineer, also has to use his imagination during the preparation of the documents but from a different aspect. He has to imagine what problems may arise in the contractual sense. For instance he has to assume that the contractor may fail to fully meet his obligations or that the principal may be in this situation, and consequently he has to ensure that the contract documents set down clearly what is to be done in such a situation. He must ensure that the contract is legal, that it can be enforced even though it may be executed in a foreign country and he must be sure of the legal contractual ability of all parties concerned with the contract. In practice, the general conditions, which usually form part of most tender documents and which are prepared by the legal adviser, go a long way towards covering normal legal contract requirements.

The accountant is interested in ensuring that all the conditions associated with the payment of money are clearly set down and also that account is taken of all matters which may bring about a change in those conditions. Such items to be included in this are exchange rates, freight charges, storage costs, customs, sales tax, insurance, labour escalation costs and alterations to the tendered price arising from changes in the basic costs. For large contracts which extend over a long period, complicated escalation clauses may be written into the contract to ensure that both parties are protected and that there is no doubt or argument in relation to payments to be made.

It is sometimes argued by persons having limited experience in the administration of large contracts that engineering, legal and financial problems should not arise. They consider that the work and documentation should be planned in such detail that no changes or extras are necessary and that situations cannot develop which allow disputes to arise. In practice this argument is unrealistic as it makes no allowance for the human element, unforeseen situations and omissions by the parties to the contract. Also, if many large and complex radio engineering projects being completed today were planned initially in such minute detail that chances of dispute were zero, then many projects would not have seen the light of day because of crippling manhour effort, the consequent cost, and the long time factor which would have been involved.

A further point is that if the terms of the contract completely exclude any variations to the work or cost, then it may not be possible to take advantage of new developments in the state-of-the-art or practices which may appear after finalisation of the planning and design work or during the course of the work. This does not mean that the engineer should go to tender or submit an inadequate design or that he should make major changes after the contract has been placed simply because there are alternative or more convenient ways of doing the work. Approval for variations which involve additional costs are always difficult to justify to top management, and it is the responsibility of the legal adviser and the accountant to ensure that in the event of the engineer being involved in this situation, that the legal and financial aspects are clearly defined in the contract document. The legal adviser, in particular, has to ensure that conditions which are capable of more than one meaning cannot be inadvertently established.

TYPES OF CONTRACTS

For the majority of modern radio engineering projects, the owner or principal generally finds it preferable to enter into a legal contract with a contractor rather than to attempt to carry out the work himself. By so doing he frees himself considerably of financial responsibility for many of the hazards inherent in many construction and installation processes, and takes advantage of the expertise, resources and experience of an organisation whose major business interest it is to cope with these hazards.

There are many forms of contracts in use, and the choice of the best one for any particular set of circumstances is an important decision. Some factors affecting the choice are:

(a) The complexity, importance and magnitude of the work to be performed.
(b) The degree of urgency associated with the need to carry out the work.

(c) The nature of the work, for instance whether design, installation, erection construction, procurement, test and evaluation, development, path survey, feasibility study, system management, operation, maintenance, quality control, etc. or any combination of these.
(d) The extent of the risk which the contractor would be required to assume.
(e) The location where the work has to be performed, for instance foreign countries, remote localities etc.
(f) The period over which the contract will be in force. Increasing material and labour costs may be a problem and be difficult to predict.
(g) The proven and demonstrated performance of the prospective contractor on a similar work.
(h) The type of response from tenderers. If tenders were called on a cost plus basis and if many received were in the same price range, it may be possible for the principal to negotiate a more satisfactory lump sum contract in lieu of the cost-plus type sought.

The more usual types of contracts encountered in radio engineering are the lump-sum, the schedule of rates, the cost-plus and the turnkey contracts.

THE LUMP SUM CONTRACT

This is essentially a fixed price type of contract and consists of a single lump sum tendered to carry out the work in accordance with the schedule, and accepted as the fixed price. The specifications and drawings generally have to be complete in all essential details to allow a lump sum to be tendered. Where important technical aspects are unknown, this type of contract is not feasible.

Such items as buildings, transmitters, receivers, masts, towers, power plant, antennas and other equipment and plant of traditional design can be manufactured or constructed under this type of contract. It can also be satisfactorily used for the supply and installation of equipment of different kinds.

The lump-sum contracts are satisfactory where:

(a) The work to be performed can be properly and adequately specified in all its important details.
(b) The risk attached to the work is either small or controllable.
(c) Changes or alterations in the work during the construction are not large.

The advantages may be classified as follows:

(a) They keep costing and field measuring work to a minimum.
(b) They give the principal assurance of a known cost of the work.
(c) They give the contractor a clear straightforward job to do.
(d) By obtaining competitive tenders the principal is assured that the work is being performed at a reasonable price.
(e) Project administration is simplified.
(f) Because the tenderer has to prepare a design detailed enough to accurately determine costs, this preliminary design offered with the tender allows the principal to assess the quality of the installation or facility being offered.
(g) Preliminary design work carried out during the tendering stage can be assumed to be part of the overall contribution to carrying out the work and so allows an early completion date, compared with contracts where

this preliminary design work is not necessary at the tender stage.

(h) Competitive preliminary design work among tenderers may develop cost reducing features not previously evident to the principal.

(i) Because of the pressure in this type of competition, technology tends to advance at a fast pace because each tenderer endeavours to apply latest state-of-the-art techniques to offer a system which meets the specifications yet is lower in capital and maintenance costs than systems offered by his competitors.

The disadvantages may be summarised as:

(a) They are difficult to control when large changes or alterations are introduced by the principal.

(b) They are likewise difficult to control if unforeseen major problems particularly in developmental areas are encountered.

(c) The tenderer may be involved in high costs in preparation of the tender. Because a considerable amount of preliminary design work is necessary, the cost of the design work, the cost of the estimate and documentation may be a significant percentage of the value of the project as a whole. It has been estimated that in many fields only one in ten tenders succeeds, and consequently these overhead costs must, in the long run, be paid for by the principal.

(d) Where the requirements are not precisely set down in the specifications or drawings, and consequently the tenderer is not able to properly assess his risk, he may add to his price, in order to provide for these contingencies.

(e) Also, where the specifications are loosely drawn or ambiguous, an irresponsible tenderer may be tempted to ignore the intended requirement, and submit a low price. If the risk which he takes materialises, he may endeavour to make do with shoddy work or inferior materials.

(f) The interests of the principal and the contractor are in opposition. The contractor often desires to make as much profit as possible out of the contract, and consequently there is a great temptation to do the poorest job he can get away with.

Although this type of contract imposes the greatest risk to the contractor it also offers him the incentive and opportunity to achieve the greatest profit. All cost savings which result from his effort and the efforts of his staff are 100% credit. To cater for possible price variations where the contract is to run for a long period, escalation clauses are often written into the contract. It is usually tied to some official index such as basic rates of raw material (copper, steel, aluminium etc), local labour rates, shipping freight rates and other indices.

THE SCHEDULE OF RATES CONTRACT

There are some radio engineering activities where it is difficult to put into the bill of quantities, measurements of the quantities based on drawings. A typical instance of this is a contract for the sinking of bore holes associated with foundation investigation work for the erection of a mast or tower on a difficult soft site. It is frequently not possible to state in advance how deep piles must be driven in order that they will produce a given load bearing capability. There are other occasions where urgency may dictate the selection of a contractor following competitive tendering before all details of design and a comprehensive bill of quantities can be prepared. This may occur, for instance, during the replacement or repair of a damaged mast or tower. Sufficient information may nevertheless be available to allow compilation of a list of the major operations and materials for the work. This would permit agreement to be reached on some basis to allow the work to commence and this would later be followed up by negotiation for fixing of a price for the items not previously covered.

The schedule of rates contract is a very useful contract when properly prepared, particularly where the full extent of the work to be carried out cannot be immediately determined but when it is essential that an immediate start be made on the work. The terms are frequently acceptable to the contractor because they protect him from loss by paying for the actual quantities of work done. However, the principal may be in the difficult situation of not being able to determine immediately what the total cost of completing the work will be.

THE COST PLUS CONTRACT

A cost plus contract is one in which the contractor is paid his actual expenses incurred in carrying out the work, plus either a percentage or a fixed fee.

This type is theoretically the fairest and best of most contract types, but the cost plus percentage, and cost plus fixed fee remove the incentive which is attached to many other types of contracts. In fact, in the cost plus percentage type the incentive is toward making the job more costly. The less efficient the contractor is, the more the cost of the work, and the more his profit. Inherent in this type of contract is the execution of the best effort by the contractor in bringing the project to finality if the principal is to receive value for money.

Another major objection from the principal's view point is that he does not know what the total cost is going to be. In an endeavour to overcome these objections, while retaining some of the advantages, variations have been proposed, notable among them being cost plus a fixed-fee, with a fixed maximum figure for the total payment. A further inherent disadvantage is the large amount of work which is necessarily involved on the part of the principal in checking costs.

The cost plus a fixed fee contract has been used to tackle several difficult radio engineering projects involving large amounts of research and development effort. When the contractor is efficient, it puts the principal and the contractor together so that they can tackle the difficult problems jointly to produce the highest quality of workmanship at the most economic outlay. It also gives a greater degree of freedom to adopt different methods of construction to manoeuvre out of difficult problems, and for handling unusual developmental difficulties.

However, there are many situations where the contractor could reasonably be expected to be compensated above the fixed fee level.

These include:

(a) Amendments to the scope of the work, such as changes in the specifications.

(b) Shortcomings on the part of the principal, in not being able to furnish critical data or facilities when required by the contractor.

(c) Unforeseen costs following problems exposed by development work.
(d) Costs outside the control of the contractor, such as war, forces of nature etc.

On the other hand, the principal can expect to require reasonable control over additional costs, and he may incorporate clauses in the contract which require:

(a) Negotiation of overhead rates.
(b) Claims for additional payments to be fully supported by appropriate documentary evidence.
(c) Concurrence before the contractor subcontracts major portions of the work.

THE TURNKEY CONTRACT

The turnkey contract, or as it is sometimes alternatively known the package deal contract, has become popular in recent years and many large and sophisticated radio projects, particularly satellite earth stations, have been carried out under this arrangement. In this type of contract the entire process of feasibility study, design, preparation of specification, tender documentation, the performance of civil engineering site and building works, the installation, construction, acceptance testing and commissioning of the radio facilities is entrusted to one large contracting organisation.

In some projects the operation and maintenance of the complex has also been included in the deal.

Four factors which have made this type of contract popular are:

(a) Some types of modern radio projects have become so complex and of such great magnitude that the principal finds it preferable to deal with one contractor, often referred to as the prime contractor, with an all-embracing contract, rather than with a multitude of separate contractors, each with his own contractual peculiarities.
(b) The principal can sometimes be faced with tremendous and difficult interfacing and co-ordination problems where separate contractors are involved, for example it is not unusual for long haul high capacity line-of-sight systems to be handled by separate contractors for site works, buildings, towers, antennas, feeders, power plant and the radio equipment. Although there are some merits in this scheme, it lacks the smooth co-ordinated work flow of the turnkey approach.
(c) Many large radio engineering manufacturing organisations which work on a world wide basis have as a result of experience developed both the technical and managerial skills to undertake complex projects. An outstanding example of this, of course, is the earth station and satellite systems but the contract also has wide application in major radiocommunication systems, complete television, broadcast and radar station complexes.
(d) Some of the world's leading contractors specialising in this type of contract will also finance the scheme, if necessary. In effect, the capital is loaned to the principal, who repays the contractor or his financier, over a period of years. The deal is therefore a type of hire purchase arrangement. There are of course other equivalent means of financing the project by the contractor.

Proponents of the turnkey approach claim that it amalgamates specialists from the two usually separated fields of design and construction so that the group ought to produce jointly a solution which represents a blending together of the best ideas for design with the best ideas for construction. Those who do not favour the approach claim that the contractor may submit something that is inclined to suit his personal preference in design and construction techniques rather than the especial needs of the project. This, the critics claim, does not give the best combination of the best design and the best construction and therefore does not produce the cheapest combination taking into account the subsequent operational and maintenance commitments of the principal.

Another problem is that the principal could be in considerable difficulty should he fall into dispute with the contractor. He may not have anyone to consult for advice and assistance, and if he were to employ his own professional inspection staff to rigidly police the work, he would nullify one of the major principles of the turnkey concept.

THE CONTRACT DOCUMENTS

It is advisable for all engineering contracts to be in the form of signed documents. Such documents should comprise everything which forms parts of the agreement. Basically, this is the description of the work or service, including relevant drawings, specifications and schedules, the tender and the acceptance. In order that the contract should be made quite clear to those associated with its administration, it is usual to compile an indenture setting out the manner in which agreement has been reached, and listing as specific appendices, the documents which evidence the agreement. These documents are:

(a) The advertisement.
The advertisement or notice is to inform prospective tenderers that a contract is to be placed for a certain work or service, and thus to obtain adequate competition among likely contractors.

(b) Instructions to tenderers.
This document, also known as 'information for tenderers', is furnished to all tenderers, and gives information on the unique features of the work and details on how to prepare the tender, when and where to send it, guarantees and sureties required etc. Some organisations include this information as part of the schedule.

(c) The schedule.
The schedule usually comprises the general conditions of contract, the specification and drawings.

The general conditions of contract define certain conditions applicable to most contracts in which the principal may be a party. It is sometimes not easy to draw the line of demarcation between the general conditions and the specification as they are of necessity, often interwoven.

General conditions are standardised by most organisations and authorities, and they include such matters as responsibility for payment of fees and royalties, compliance with local by-laws, supervision of the work, proceedings on default, removal of unsatisfactory work, cleaning up on completion of work, quality of materials and workmanship, settlement of disputes etc.

The specification is, from the engineer's point of view, probably the most important document. The specification is the direct explanation of the drawings, and details the actual work which has to be done. In a very large station or system work, this document may run to 200 to 300 pages.

The drawings must be read in conjunction with the specification and show accurately the extent of the work. Sometimes they may be complete design drawings showing full details of the construction.

(d) The tender.
Even for a high priced work, the tender may be a simple letter or form setting out the offer. A tender form is usually included in the schedule and this allows all tenders to be prepared in a similar manner. This facilitates analysis and comparison of the various tenders, particularly where qualifications and alternative offers may be involved.

(e) Letter-of-intent.
Where the work is urgent and it is essential that the contractor commence

Table 49.1 TYPICAL LETTER OF ACCEPTANCE

Contract No. 36000

Date: 10 January 1980

Schedule A. 2005–Radiocommunications System, Mt Wellington–Green Bay

Dear Sir,

Your tender dated 20 October 1979, (with associated letters dated 28 October 1979, 8 November 1979 and 7 December 1979) is hereby accepted for the design, supply, delivery, installation and commissioning of a radiocommunications system for industrial control purposes from Mt Wellington to Green Bay in accordance with the terms and conditions of Schedule A.2005, as follows:

Item 1	Radio link equipment to provide a medium capacity bearer system between Mt Wellington and Green Bay	£ 350 000
Item 2	Carrier system for Mt Wellington and Green Bay and omnibus carrier system for all radio sites	£ 160 000
Item 3	Telegraph systems, voice frequency telegraphy	£ 5 000
Item 4	Guyed masts, foundations and erection on site, fitting of antennas and the station/mast earth system	£ 380 000
Item 5	Antennas, feeder cables and fittings	£ 40 000
Item 6	Supervisory system for supervision of radio and power plant equipment	£ 25 000
Item 7	Battery systems	£ 34 000
Item 8	Power generating plant and rectifiers	£ 200 000
Item 9	Equipment shelters, including transportation to site and erection	£ 200 000
Item 10	Site selection survey and preparation of path profiles	£ 40 000
Item 11	Systems engineering, transportation, installation, training, insurance, project management, site fencing and contingent liabilities	£ 570 000
Item 12	Spare parts for radio and power equipment	£ 56 000
Item 13	Test equipment	£ 10 000
	Total	£2 070 000

Please sign the accompanying form of acknowledgement and return it as soon as possible.

Yours faithfully,

. . . .

immediately, a letter-of-intent, along with a notice to proceed, may be forwarded to the contractor pending the preparation of a letter-of-acceptance. The letter obligates both parties to enter into contract at a later date, and allows the work to proceed in the meantime. It is not an acceptance of the tender but may be likened to a contract to enter into a contract.

(f) Letter-of-acceptance.
The letter-of-acceptance, or agreement as it is sometimes called, is the actual deed of contract. With this document and the acknowledgement, the parties agree that the work will be carried out in accordance with the schedule and the offer. *Table 49.1* shows a typical letter-of-acceptance associated with a £2.07 million contract for a multi station radiocommunication link system for industrial gas pipeline control purposes.

(g) Acknowledgement.
The acknowledgement of, and agreement with the letter of acceptance, is signed by the contractor and returned to the principal. A typical form is shown in *Table 49.2*.

Table 49.2 ACKNOWLEDGEMENT OF LETTER OF ACCEPTANCE

This acknowledgement must be returned to:	Contract Number:
- - - - - - - - - - - - - - -	Letter of Acceptance Dated.
- - - - - - - - - - - - - - -	
- - - - - - - - - - - - - - -	

Reference : Schedule

My tender dated with associated letter(s) dated

The goods and/or services referred to in the 'Letter of Acceptance' relating to the above-numbered contract will be supplied in accordance with the conditions therein.

Name of Contractor: Signature of Contractor:

Date: / /

DRAWINGS

Drawings which accompany specifications or which show details of construction or design have always been the basis of legal contracts. Such drawings must be specific, clear and unmistakable in their meaning. The drawing is a legal document and if it is subject to more than one interpretation, litigation may arise causing unnecessary delays and expense to both parties of the contract.

The contract document may indicate that the owner is responsible for the sufficiency and accuracy of the drawings; however, if nothing to the contrary is stated, it is generally accepted that the owner furnishing the drawings is responsible for their sufficiency and accuracy. Robert Abbett[2] in discussing this subject says

"The approval of the contractors' shop drawings may place considerable risk on the engineer when mistakes are encountered later. The engineer's approval of shop drawings is required to ensure compliance with the plans and specification.

It should never imply responsibility for their accuracy, particularly when the drawings contain data relating to fabrication or construction techniques which are outside the scope of the engineer's duties and responsibilities. The engineer's approval should be limited to the extent required by the contract documents and it should not indicate general approval."

Engineering drawings are the basic tools with which practically every engineer must operate. No matter how much design or development work is carried out in developing new ideas and concepts, little can be built or manufactured without the aid of drawings. It does not require much effort to convince one that it would be an almost impossible task to describe in oral or written language a piece of plant such as a mast or tower with data and dimensions sufficient to make possible its manufacture and construction through all the various sections of an engineering workshop. Engineering drawings, however, can supply all the information needed with exactness and detail to allow manufacture and construction no matter how complex.

In the preparation of drawings for association with a design specification or tender, the engineer is not only responsible for the design of the work, but he is also responsible for ensuring that it has been correctly recorded in detail on the drawing. One of the main functions of the drawing is to convey information from the designing engineer to the principal or contractor. The engineer cannot delegate any of his responsibility to the draftsman—the engineer alone is responsible for the basic design work. The draftsman assists the engineer by providing the drafting effort but he should not be allowed to make fundamental design decisions for want of guidance or instruction. Because of the large amount of detail which must be incorporated in specification or contract drawings, a very close relationship is necessary between the engineer and the drafting group. Frequently a draftsman becomes highly competent after years on the drawing board, and working in close association with engineers, but this gives the draftsman no licence to run away with the design along lines which he considers it should take. If the draftsman is competent and reliable, much routine work can be left in his hands, particularly in the finishing stages of a drawing, but the engineer, no matter how inexperienced he may be, must be sure that he guides the design work the way he wants it. The engineer is responsible for the whole job, the drafting effort is only one phase, and if anything goes wrong, he must be sure that it was not because he inadequately supervised his draftsman.

No drawing should be distributed to field staff or workshops for action or for incorporation in any tender or contractual document until it has been checked and signed by the engineer. Needless to say, the engineer should thoroughly check the drawing for accuracy and sufficiency before signing. For proper control over the work, the engineer should check and sign the drawing every time an amendment is made, particularly where these are contract documents. The drawings must tell the whole story of what has to be done. It must be drawn up and marked so that it can be fully understood but it must also be so specific in meaning that it cannot be misunderstood either by accident or intention.

After the drawing has been checked, it has to be signed. There is nothing routine about signing drawings. The fact that the draftsman has checked the drawing in no way relieves the engineer of his responsibility to ensure that it is in accordance with his design requirements and his instructions to the draftsman. Three and sometimes four signatures may be required on a drawing before it is released for action. The significance of the signature is evidence of the following:

(a) The Draftsman.
His signature signifies that details set down on the drawing are in accordance with the design data, and standard drafting practices.

(b) Checking Officer.
His signature signifies that he has checked all information shown on the drawing as to correctness of dimensioning, standard drafting practice, accepted manufacturing practices, design data, tolerances, finishes, notes and completeness.

(c) Engineer.
His signature signifies that the work is an accurate interpretation of the design.

(d) Engineering Head.
The need for signature above the level of design engineer will be dependent on the policy of the engineering department. Where a higher level engineer is required to sign, his signature will signify concurrence in the design philosophy.

CONTRACTOR SELECTION

The selection of the right contractor for the project is probably just as important as obtaining a reasonable offer. The quality of the work put into the project is influenced to a very large extent by the individual persons assigned to it by the contractor. The value of the tender cannot be used to any great extent as an indication of the quality of the finished work. This is particularly important in the design and research areas and those field supervision areas where the experience and skill of the contractor's key personnel have a strong influence on the success of the project.

Another important aspect to be considered is the extent of the contractors resources and experience in similar fields. It is not unusual when examining tenders to find organisations with very small resources, and little experience in the project work proposed, tendering at ridiculously low prices. Some cases have shown tenders for multi-million pound complex works as low as half of the value of the next lowest tender. Sometimes a number of small organisations will combine as a consortium but very few of these ventures have succeeded. Too frequently the small contractor will run into difficulties if he takes on a project which is too large for his organisation at its current state of development. The size of the work undertaken should be of the order of magnitude to which the organisation is geared.

Many organisations, particularly government departments and instrumentalities, have a rule that the contract should be awarded to the lowest responsible tenderer. The problem of course is to determine what is meant by 'responsible tenderer'. It is usually interpreted to mean that:

(a) The tenderer has the necessary capital or the ability to raise it to satisfactorily carry out the contract.
(b) He has a reputation for successful projects, excellence in engineering and has a record free of defaulted contracts.
(c) He can furnish sureties required by the contract. Evidence of previous experience may be required in some particular works.

THE PROJECT ENGINEER

A most important role of the project engineer is to ensure that the proper material for the job is purchased at a reasonable cost, delivered to the site and set to work in accordance with the planned time table. The stores or purchasing branch of the organisation will arrange for the procurement of the necessary material but not without the prior advice and assistance of the project engineer. Experienced staff of the stores branch are generally conversant with the technological terms associated with engineering specifications and materials sheets but this gives them no licence to make a decision regarding the purchase of any item of plant, equipment or service where engineering judgement is required. The project engineer is the person responsible for this decision.

The engineering and procurement phases of a project can seldom be completely separated. Very few basic materials can be purchased without drawings and specifications. In fact, a principal reason for the preparation of a drawing is to indicate the materials required to make up the plant, equipment or device. All the materials shown on the drawings have to be purchased or manufactured within the organisation workshops or contracted outside. Because of the close tie-up of the technical requirements therefore, it is necessary for the engineer to participate in the procurement arrangements right up to the time of placement of the supply order. However, the engineer must be careful not to become too involved in commitments with material suppliers and manufacturers during the equipment selection process. The commercial and legal aspects of tendering or bidding are best and more appropriately handled by the procurement specialists. Also the purchasing officers are generally more aware of price trends and market fluctuation and should maintain the right to take advantage of selections from various suppliers, provided that the technical requirements are satisfactorily fulfilled.

In securing material supplies or services from outside sources, all large organisations have certain important principles which must be observed. Typically, these may include:

(a) Adherence to relevant regulations and instructions in obtaining quotations and placing orders.
(b) Observance of commercial methods and practices.
(c) Follow-up of payments to suppliers.
(d) Correct internal organisational documentation.
(e) Control of funds and their proper authorisation.
(f) Reduction in number of points of contact between the supplier and the organisation.
(g) Purchase of supplies and services at the lowest price, consistent with satisfactory quality, quarantee and delivery time.
(h) The need to have the work completed as soon as practicable.

To ensure attention to these principles generally, the stores or purchasing branch is invariably constituted as the main buying authority for the great majority of the organisations' requirements. The procedure for obtaining prices will depend upon policy guidelines but are generally fixed on the basis of verbal quotes, written quotes and the calling of tenders. Verbal quotes from suppliers are usually approved for items up to a certain value with written quotes being required for items up to a second value level and beyond that tenders may be necessary.

After receipt of the quotations or tenders in the stores branch they are referred to the project engineer for evaluation. In his evaluation he must consider specification requirements, price, delivery time, guarantees applicable, freight and handling charges, labour variation clauses and terms of payment.

The analysis of submissions by tenderers in terms of their ability to meet the specifications is probably the most important part of the project engineer's examination work, and it is essential that this phase be carried out in a methodical and detailed manner. Although compliance with the specifications is of paramount importance, there are other features of the tender which the project engineer will look for in his evaluation. These include:

(a) The tender must be a creditable presentation for it is to serve as tangible evidence that the requirements have been carefully considered.
(b) The points of advantage of the proposal should be set out in a manner which can be appreciated by the examining engineer.
(c) The tender must be explicit and definite, because it will form the basis of a contract to do certain things.
(d) The form of the tender should be in accordance with the highest standards of business procedure. That is, it should have a professional appearance, the materials such as paper, jackets and drawings should be of good quality, the contents should be well organised and neatly set out, typing should be first class and the degree of detail should be in keeping with the needs of the particular case.
(e) The proposal should be elaborate to an extent, and only to an extent, justified by the circumstances surrounding the particular job. For example, a million pound tender for the surveying and installation of a long haul microwave radiocommunication system would be much more elaborate than one for the same amount of maintenance spares for a large broadcast station network.

Evaluation should be a relatively simple and straight forward operation where only a few quotes of inexpensive equipment are involved, but for a large and complex project where world wide tenders may be invited, the examination may extend over a period of many months and it is vital to properly and systematically tabulate all the aspects so that each can be properly compared with the equivalent items of the other tenders.

The price is, of course, also important and the evaluation of this may involve considerable effort. All prices must be brought to a common and uniform basis for comparison purposes. Such factors as sales tax, import duty, shipping charges, exchange rates, labour escalation clauses are all important, and must be identified and classified. An efficient commercial group in the stores branch will ensure that most of this information has been tabulated before referring the papers to the project engineer. This will allow him to devote his full effort to those aspects requiring his engineering knowledge, experience and judgement.

Subject to the technical requirements being met or being acceptable, the contract would as a general rule go to the lowest tenderer. However, where there is not a great deal of difference in the prices, intangibles may often be taken into consideration and the contract awarded to a tenderer other than the lowest. Such intangibles as proven experience on similar types of projects, specific technical expertise, promptness in supplying data and drawings, and general co-operative attitude of the company as a whole may outweigh a slight additional cost outlay. In a cost-benefit analysis an appropriate monetary value could be attached to these factors.

The project engineer must be very cautious in making recommendations of low tenders from unknown or inexperienced organisations. Although the tenderer of a very low price may be sincere, the problems and unforeseen situations which invariably occur in large project works, particularly where development is involved may result in efforts or omissions which later lead to the creation of an untenable situation. However, proving irresponsibility on the part of the tenderer is often a difficult and delicate matter, except in the most obvious cases.

The progressive and co-ordinated delivery of material and plant to the site is essential for any project to progress in accordance with a planned schedule. Materials such as sand, gravel, and cement are generally available on an immediate delivery basis but items such as radio transmitters, antenna masts, microwave systems and test equipment are long lead items and the manufacturing progress of the contractor must be closely watched by the project engineer. For critical items, an alert inspecting officer at the works of the contractor can keep the pressure on to ensure delivery on schedule.

Material deliveries should not be made too far ahead of schedule. The contractor will probably require payment on delivery to site, and unless the plant can be installed immediately unnecessary interest payments on the capital cost may be incurred by the principal before effective use could be made of the plant. Costly storage space may also be necessary in some instances, particularly if it is equipment which must be stored under cover. Delivery before the schedule date may also involve double handling and this can be costly, wasteful of manpower and may result in damage.

The effectiveness of the project engineer's supervision of his professional and field staff, and also the contractor is influenced by many factors. Insufficient supervision could result in laxity, schedule slippage, poor work by contractors and low morale among the workforce because of poor group contact. At the other extreme, too much supervision could result in the professional staff, in particular the resident engineer, being the 'work boys' of the project engineer and not accepting their proper professional responsibilities. This limits their freedom, restricts their authorities, results in loss of initiative and a failure to grasp the tough aspects of the work situation.

What is required is an intermediate level of management surveillance to ensure effective engineering, proper integrated performance of the project group and high morale. The determination of this intermediate level—the optimum condition for the proximity of supervision—is difficult to determine, but experience has shown that the level can be gauged by the feedback from the project workface. Every project team must feel its way during the initial stages of the work and the project staff can best get the 'feel' for the work by learning from their early mistakes. The experienced project engineer will realise this and will use this as an indication of his proximity by the level of feedback of mistakes. He must be close enough to know what aspects of the work would cause difficulties and he must accept some difficulties as inevitable. If he is too close, however, there is a tendency for him to become too involved in the technicalities and detailed day-to-day activities instead of the overall project outlook. On the other hand if he is too far removed he will not be sufficiently abreast of the work, slippages may escalate before control measures can be effected and he will tend to have a incorrect picture of the real situation as it exists.

THE RESIDENT ENGINEER

In practically every radio engineering work which is large enough to justify it, it is usual for the principal to have a permanent representative on site to ensure that the work carried out by the contractor is in accordance with the specifications and conditions of contract. The permanent representative, or resident engineer as he is more often designated, is generally referred to in the contract as 'the engineer' or in some instances as 'the inspecting officer'.

Whether or not a resident engineer is employed on the site is governed by many circumstances, the main ones being the complexity, importance, extent and cost of the project. The cost of employing an engineer for the full period of the work may be high, but experience has shown that it is highly desirable to employ a resident engineer on most radio engineering projects of about £1 million and above.

It must be appreciated that there is no contract between the resident engineer and the contractor. It is between his employer and the contractor. The resident engineer may have very little, if any, power to order extras, he has no power whatsoever to approve alterations to the contract, he cannot authorise payment for work done and is not the final arbitrator in disputes, or even what is poor workmanship. The only extras which the resident engineer can authorise are those which can be encompassed within the contingent nature of an item in the contract for contingenices. These may include the authorisation of deeper foundations for a radio mast, if subsequent excavations show this as being necessary, but he could not, for instance, authorise an increase in the height of the mast. Also, he has no authority to include any items which may have been overlooked or forgotten in the compilation of the tender. If provision has not been made for this in contingencies, then he will have to arrange for contract amendment.

However, notwithstanding these legal limitations on the resident engineer, he plays a most important part in the management of the contract. Also, being the representative of the principal on site, he has a vital overall responsibility which far outweighs any restrictions which may be imposed in relation to contractural matters.

It is not unusual for a large radio engineering project work to be thousands of kilometres from the project engineer's headquarters, and under these circumstances the resident engineer carries a great responsibility. He must therefore be sufficiently experienced, knowledgeable and competent to make important decisions within the guidelines of instructions set down by his project engineer. He must ensure that his decisions are sound and that he can support them. However, it is not his job to take upon himself responsibilities and decisions which properly lie with his immediate superior, the project engineer. The resident engineer must be absolutely clear as to whom he is responsible, and to whom he must refer important matters. His duties may include:

(a) Supervision of Contract Works.
The prime job of the resident engineer is to ensure that the contractor carries out his obligations in accordance with the specifications and conditions of the contract, and that all finished works are free of defects, have been properly tested, are in accordance with the guarantees, and function satisfactorily. He must further ensure that the works of the project as a whole are carried out in accordance with the plans and instructions issued by the project engineer.

He must give prompt notice to the contractor for any defects, short supply or bad workmanship, otherwise the contractor may be entitled to assume that the work is satisfactory and acceptable.

Where it is necessary for the principal to arrange for permits or customers clearance of imported materials and equipment, the resident engineer should initiate appropriate action.

(b) Furnishing Progress Reports.
The compilation of reports on contract work progress is a vital part of the resident engineers' duties. He will usually be required to provide a weekly or bi-weekly report to his project engineer setting out in summary form all the main events of the period. A monthly report may also be required covering the work in a more generalised form. The project engineer will use information contained in these reports as a basis of his report to top management.

The resident engineer must be mindful of the fact that he is in reality the agent of the project engineer and consequently must report back to him on all matters of major importance and in particular on complaints and disputes involving the contractor or his sub-contractors. Although the resident engineer's primary function is to ensure that the work is carried out in accordance with the specifications, as the man on the spot he has an additional obligation, and that is to maintain a continuous survey of the project as a whole. This is to ensure that the construction installation or commissioning techniques being used are the most appropriate, that materials are the most suitable, and that the methods and designs are best suited to the site conditions and the intended function of the work. No two jobs are alike, and lessons can always be learned to improve the next. The resident engineer must therefore cover all these aspects fully by reporting them to his superior for consideration.

(c) Co-ordinating the Work of Contractors.
A large radio engineering complex may involve radio, civil, electrical, structural and mechanical engineering disciplines, and even within the radio discipline it is not unusual to have separate contractor specialists in antenna systems, masts and towers and radio equipment engaged. Where several contractors are involved, without a prime contractor, co-ordination of the work by the resident engineer is essential for smooth work follow-through. On-site meetings between the engineers of the various contractors, and perhaps in some cases some of the major subcontractor representatives, do much to develop a spirit of co-operation. This is particularly important

where the work of some of the contractors may be affected by the weather and site conditions, and it is important that all concerned be aware and appreciate the problems of the other parties involved in the project as a whole. The parties are given the opportunity to discuss matters which could affect progress, to obtain information from others in relation to their effort and timetable and, where difficulties are encountered or foreseen, appropriate action can be taken to deal with the situation.

The engineer should ensure that the proceedings of the meeting are fully documented and copies forwarded to each person attending, and also to his superior.

(d) Supplying Information to Contractors.

The resident engineer must ensure that the contractor is supplied with complete and up-to-date information necessary for him to complete the work in accordance with the contract conditions. The engineer should be watching closely the progress of the work and endeavour to anticipate the contractor's need for particular information, data and drawings to ensure work is not held up.

(e) Issuing Inspection Certificates.

All items of contract work completed, and for which payment is due in accordance with contract conditions, must be certified as to correctness and completeness by the resident engineer before payment can be authorised.

The contractor will usually prepare a claim for payment and the engineer after satisfying himself by measurement, inspection, test or other appropriate method will issue a certificate. It is on this basis that payment to the contractor will be made through the normal accounting channels.

(f) Handling Contract Variations.

Very few major contracts are carried through to finality without some alterations to the original plans. At times even the best laid plans may go astray, especially in dealing with the elements of nature. Where changes have to be made, particularly if major changes, they should first be cleared through the project engineer with the design engineer. Changes involving variations of the amount of work to be done, or material to be supplied, may require contract amendment and in such cases should be handled through the proper administrative channels.

(g) Inspecting Safety Practices.

The safety of the staff of the resident engineer and the contractor, and also of visitors to the site, is everybody's concern. Large radio station construction works involving large antenna complexes and high power transmitters are sometimes accompanied by casualities more or less serious. These can be greatly reduced by care and watchfulness, but mankind will probably never become sufficiently reliable to eliminate them altogether. On the site, every man is dependent for his safety on his fellow men and the resident engineer should be on the alert to ensure that all work is being carried out in a safe manner, and that it at least meets the minimum safety requirements of local government departments.

The contractor has both moral and legal obligations to so control the work that accidents are kept to an absolute minimum. Accidents not only result in injuries and death but also damage and destruction to plant and materials, all of which involve added expense, time lost and in many instances a serious affect on the morale of the workforce. Statistics show that on very large engineering construction projects where high risks are involved, about one man in fifty will meet with serious accident or death from accident each year on site. The erection of radio masts and towers, antenna systems, foundation blasting and high voltage work are only some of the work areas requiring particular safety supervision.

(h) Maintaining Records.

Details of all completed work must be recorded in the form of drawings. As a general rule, drawings will be prepared to indicate what work has to be done to fulfill the requirements of the contract and the resident engineer would normally use these as a basis for indicating the final form of the completed work. Amendments would be made after careful measurement of the work. He should during the progress of the work check the line, levels, layout and dimension of all construction to ensure that it conforms with the drawings. These drawings must be accurate as they will form the basis of the final permanent drawings of the completed work.

Close attention to this will also ensure that the work is carried out in accordance with the design intention. At one station the specification called for mast anchor blocks to be of size 2 m square by 2 m deep. During a cyclone some two years after erection of the structure, one of the blocks was pulled out of the ground and a check of measurements indicated that it was only 1.1 m deep.

(i) Compiling the Diary.

The diary is an important record of the project as it aims to record all the major decisions, works, meetings and instructions given. It is invaluable as a reference for back-checking of facts, particularly during contract finalisation or claims. All supervisory staff working under the resident engineer should also keep diaries so that their associated activities are fully documented.

The engineer will often be so busy with the pressure of work that he may find it difficult to record all the matters of interest in the diary. However, it is important to ensure that all matters which could later be of some argument should be recorded. The main points which would be covered in a typical diary would be:

Instructions, data or drawings given to the contractor.
Main items of work performed during the day, and major items of plant or equipment delivered to the site.
Material or work rejected, complaints and disputes.
Names of visitors to the site and the purpose of their visit.
Aspects of the work which are to be raised at the next meeting with the contractor.
Weather conditions and effect, if any, on the work.
Any major plant breakdowns and any injuries to work staff.
Any unexpected situations encountered, e.g. rock or water in mast foundation excavations where not indicated on bore hole logs.

A successful resident engineer must not only be skilled in radio engineering, but his technical proficiencies must be supplemented by other equally important characteristics. With a large project, much depends on the ability, judgement and integrity of the resident engineer. For the best results, his judgement must be developed by knowledge and experience, he must have the ability to supervise intelligently the contract works, he must be able to think clearly when under pressure, he must have sufficient character to subdue his personal pride and to secure advice on aspects of his work on which such advice is needed, and his honesty and integrity must be beyond question.

The ideal qualifications for a resident engineer can be only approximated, but experience has shown that the most important qualities are:

(a) He must be able to work harmoniously with the contractor's engineer during the life of the contract. A major contract may take some years to finalise and for the smooth and proper conduct of the work, a co-operative atmosphere must exist between these two key officers. Both engineers have their own particular problems because of the differences in types of responsibilities, but a harmonious relationship will do much towards easing the burden of each, and go a long way towards assuring a satisfactory final winding-up of the job.

(b) In all his dealings with the contractor he must have tact yet act with firmness. Depending on contractural conditions he may have power to suspend work, but he would be expected by both his employer and the contractor to exercise reasonableness.

(c) He must not interfere unduly with the contractors' methods of carrying out the work. In accordance with the terms of the contract he will be required to check the work of the contractor to ensure good workmanship. However, the contract will generally allow the contractor free rein to choose his own methods of achieving the necessary standards. The resident engineer must be careful not to unnecessarily interfere with the contractor's methods, otherwise it might lead to a claim on the principal, for extra work.

(d) He must be thoroughly experienced and competent in the type of work he is supervising. This will allow him to appreciate the reasons for particular installation and construction methods adopted by the contractor. It will also enable him to determine which are the critical areas of the work, so that special attention can be given to these areas. Also, he will be able to comment authoritatively on claims by the contractor for extra cost due to such circumstances as excavation difficulties, errors in drawing, unusual environmental conditions, failure by the contractor to meet specifications etc. The contractor's aim is to make a profit and as well to give satisfaction. The resident engineer's job is to see that contractural conditions are fulfilled, and that his employer is presented with a satisfactory job.

It generally takes a few weeks for close relationship to be established between the principal's resident engineer and the contractor's engineer. The resident engineer, particularly if it is his first such job, is often somewhat cautious until he has had time and opportunity to assess the competancy and attitudes of his opposite number on the contractor's staff. Likewise, the contractor's engineer is anxious to learn what type of man the resident engineer is, how easy he is to deal with in the interpretation of ambiguous contract clauses, his methods of working, the standards of workmanship he expects and whether he is generally co-operative and appreciative of the contractors' problems and difficulties.

Close co-operation and an attitude of reasonableness between the two engineers is essential for smooth running of the project work. The following factors are important:

(a) The resident engineer should not interfere in matters which are properly the concern of the contractor's engineer. For instance, he should not discuss important aspects of the work or criticise workmanship with the contractors' sub-contractors without first discussing the matter with the contractor's engineer. If the resident engineer is not satisfied with work being performed by sub-contractors, and particularly if their actions could result in damage to the works he should inform the engineer of his opinion, and indicate to him that should damage occur as a result of the actions, then the contractor would be liable to repair and make good at his own expense any damage that may result.

(b) If the resident engineer has any complaint about the work for which the contractor is responsible, he should discuss this with the contractor's engineer before passing on the complaint to others. He should place the facts before the engineer whose job it is to make a decision as to what action will be taken.

(c) Whilst the resident engineer must be firm in measuring the work performed against the requirements set down in the specifications, he must at the same time have an attitude of reasonableness. The intension of the specification is important too. The perfect specification has not yet been written nor has the perfect job been done on a competition bid. The contractor will seldom resent the resident engineer insisting on complete adherence to specifications for work in critical areas, such as the finish of control desk panels which are prominently displayed, but in return the contractor could reasonably expect some relaxation in areas which are not critical and where considerable extra expense, effort and real difficulty maybe involved, such as making walls and mast anchor block straight after rock blasting. It may be cheaper for the contractor to pour in more concrete where the hole has been made larger than the drawing requirements rather than build up formwork, later remove it and backfill the gaps.

(d) The resident engineer should not discuss with the contractors' workmen, areas of work in which he is not satisfied, without the contractor's knowledge. The experienced engineer, during his inspections, will realise also that some people are more efficient than others, that some people go about their work in a different way compared with others, and also there are periods when the contractor's supervision of some areas of work may not be as closely controlled as at other times, due to pressures in other areas.

The resident engineer will need support staff to allow him to carry out his duties properly and efficiently. In a large project he may require inspectors to supervise tower erection, installation of earth mats, concrete sampling, antenna and transmission line erection, installation of transmitting equipment and powerplant. He may even require subordinate engineers to take charge of various sections of the work. In a project involving an expenditure of several million pounds there may be many engineers from the principal's and the contractor's staff working on specialist activities during the life of the project. He will also require an officer to provide clerical assistance. The main assistance provided by the inspectorial and clerical staff will be:

(a) Inspectors.
Inspectors are usually highly experienced and competent officers of trade or sub-professional grouping. They provide continuous supervison over the

work of the contractor, advise the resident engineer as to the quantity of the work, workmanship and practical implications involved in the contractor meeting the requirements of the specifications. However, the inspector should not be regarded as a deputy engineer. His duty is to report to the engineer any deviation from the specifications. All decisions regarding the character of the work to be done, or material to be furnished or the interpretation of the specifications should be referred to the engineer. The duties of these inspectors are of great importance, and demand wide experience, practical knowledge and also tact in dealing with the foreman and workmen employed by the contractor. The employment of the right type of men as inspectors is essential to ensure satisfactory work and also to ensure smooth working of the contract. An inspector must have up-to-date knowledge of modern practices in connection with the work which he has to supervise, so that he may be able to secure satisfactory work without over-meticulous insistence upon unimportant details. The qualifications may, however, be nullified unless he can deal tactfully with the contractors' foreman and workmen.

Typical duties of an inspector may encompass the following:

(i) To keep a comprehensive diary and to record such matters as work inspected, progress, difficulties encountered, number of men employed, materials installed and delivered, complaints and criticisms regarding materials and workmanship, visitors, weather conditions etc.

Figure 49.1 Erection of mast radiator (Courtesy KHQ)

Figure 49.1 shows the early stage of erection of a tall mast radiator being erected at a broadcast station. The inspector is required to keep a close check on all work progress until the structure is handed over for acceptance testing.

(ii) To inspect all material and plant as installed or delivered to the site, and to satisfy himself as to quality and quantity in relation to specifications and the contract.

(iii) To inspect workmanship to ensure that it complies with standard trade practices or other standards as set down in specifications.

(iv) To check all important setting out, levels and bearings before construction work starts and to inspect all work before such work is covered up.

As well as concrete reinforcement work, many other items are placed out of site when work is covered up. Typical examples are earth mats and earth systems for station buildings and towers. If joints of dissimilar metals are inadequately protected, corrosion may take place unnoticed and it is vital that the inspector keep a close watch on the work to ensure that it is carried out in accordance with the specifications. *Figure 49.2* shows special protective wrapping material being cut up preparatory to wrapping round an earth wire and stake connector.

(v) To provide regular reports, generally at daily intervals, to the resident engineer, of all activities covered during the day.

Figure 49.2 Tape used for joint protection

(vi) To relate the actual progress of the work to the estimated programme. The inspector should be able to prepare and understand progress charts. Once the work has started, it must be the earnest endeavour of all connected with the work to see that progress is consistent with the programme. Therefore, the inspector must keep the programme and progress chart under observation and bring to the notice of the resident engineer any substantial departures from the estimated or programmed figures.

(b) Clerical Assistance.

Records must be kept in the same way as when the engineer is at his headquarters. Drawings, correspondence, handbooks and reference data must be properly stored, indexed and available for ready use. Proper and sufficient records should be kept to enable an appraisal of the work to be made at any time. They allow progress of the work to be measured against the estimated timetable, expenditure to be compared with estimated costs, materials and services to be ordered in sufficient time, and form the basis for fixing fair compensation to the contractor in the event of later claims.

Clerical activities would be handled by a suitably qualified and experienced officer. He would generally handle correspondence, registers of test results, working reports of staff, office telephone and paging system, issuing of orders for supply of materials and services, receiving and checking accounts, and in some instances, handle staff pay and petty cash.

The clerical officer must therefore be an officer of the highest integrity and ever alert to any aspects associated with the improper use of money.

THE CONSULTING ENGINEER

Consulting engineers are being employed to a much larger degree on radio engineering projects than previously, and they frequently play an important role in the administration of contracts. When lack of staff alone makes necessary the engagement of assistance by the principal, the assistance will generally take the form essentially of an extension of the principal's staff. The basic steps in the execution of the project would follow closely the normal procedure, and all of the management processes, design, the writing of specifications, the calling of tenders, placing of contracts, planning and supervision would follow the usual pattern.

The services provided by the consultant would of course depend on the agreement between the parties, and also on the extent and nature of the work. One interesting exercise undertaken by a consulting organisation was a study of satellite communications for South America for an international financing group. The consultants were to determine the technical and economic feasibility of using satellite communications to enhance the growth of regional and international telecommunication networks in South America. The exercise required that they:

(a) Study the terrestrial telecommunications networks in use and planned.
(b) Analyse the quality of existing services, future channel requirements, and financial needs for overall expansion.
(c) Evaluate economic indexes and their trends, and correlate them with

telecommunication developments to forecast the impact of telecommunications on economic growth.

(d) Explore the advantages of satellite communications for South America compared with conventional terrestrial communication modes.

(e) Determine feasible locations for satellite communication earth stations in South America for intracontinental and overseas communications, and develop a system for satellite communications.

In order to carry out this large scale investigation, and report thereon, the consultants used basically three groups of telecommunication experts.

One group comprised three economists who were charged with responsibility for the analysis and conclusions reached relative to the economic condition of each of the 10 South American Republics included in the study.

Two independent teams of four engineers each were assigned the task of collecting all of the data needed for the study. Each of these teams was headed by an expert in communications systems. The three other engineers in each team included one expert on cost and telephone plant, one on corporation finances and organisation, and one on traffic engineering.

The report prepared by the consultants was a massive document of four volumes. It was prepared in English, Portuguese and Spanish languages.

Not many consultant exercises would be of this magnitude but it does indicate that the role of the consultant is almost limitless. Their role of course is not confined to feasibility studies. Frequently they are engaged on a feasibility exercise and then retained to see the implementation of the work through to completion. Works which have been undertaken by consultants include:

(a) Broadband microwave radio relay system route survey, design, installation and commissioning.
(b) Planning and design of high frequency International broadcasting stations.
(c) Tropospheric scatter systems between land bases and between land base and oil rig platforms.
(d) Airport communication, navigational aids and radar systems.
(e) Satellite communication stations.
(f) Cable television distribution systems.
(g) Mobile radio networks.
(h) Television transmitting stations and studios.
(i) Broadcast transmitting stations and studios.
(j) Radio paging systems.
(k) Complete ship communication systems.

As a general rule, most major radio construction project works can be grouped into three main phases of activity: Feasibility study; Contract; Supervision of the work.

The consulting engineer could be engaged for any or all of these activities. The principal may decide to perform one or more of these activities with his own professional staff and engage the consultant for the remainder, or he may decide to carry out the complete work but retain one or more consultants as specialist advisers. The latter arrangement strengthens management's position with those who may be concerned with the action taken regarding execution of the work.

The services which a consultant would provide from the initial feasibility study to work completion stage would be dependent upon the type of work, and may vary considerably from one engagement to another. Typical activities may be in line with the following:

(a) The feasibility study.
    (i) Route or site selection surveys.
    (ii) Foundation investigation study for masts, towers and other structures.
    (iii) Land acquisition and easements.
    (iv) Optimum engineering solutions to meet the objectives.
    (v) Economic comparison of alternative engineering solutions.
    (vi) Preparation of installation, operation and maintenance cost estimates.
    (vii) Preparation of preliminary plans and designs.
    (viii) Recommendations to the principal.
(b) Specifications, tenders and contracts.
    (i) Compilation of drawings, tables and relevant design data.
    (ii) Preparation of particular specifications, plans, drawings and listings of relevant standard specifications.
    (iii) Preparation of tender documents or assistance in procurement.
(c) Contract supervision.
    (i) Complete supervision of all phases of the work. Provision of resident engineer supervision, if necessary.
    (ii) Detailed checking of all contractor drawings, calculations, designs and technical documents.
    (iii) Site layout and surveys including borehole analysis as necessary.
    (iv) Inspection of materials and equipment delivered to the site, or as part of the contract.
    (v) Testing and commissioning of equipment and plant.
    (vi) Issuing of inspection certificates as required by the contract.
    (vii) Consultation with, and recommendations to, the principal for variations from plans and specifications, and handling of claims for compensation variations.
    (viii) Preparation of PERT diagrams and other management aids and submission of reports to the principal in relation to management aspects of project control.
    (ix) Follow up of final documentation to incorporate changes in drawings and work at completion of the contract.
    (x) Preparation of operating and maintenance procedures.
    (xi) Recommendations for spare parts holding quantities.

A most important gain in using a consultant for a support effort is that it allows the organisations' own engineers to devote their full attention to the end engineering product rather than being inundated in the administrative networks of getting the work started and in keeping it moving. All too frequently there is opposition to taking engineering work outside the organisation because of an ego of professional pride and a desire for self-sufficiency. Unfortunately, these factors sometimes assume greater importance than the economics involved. Also, the degree to which the organisation is wrapped-up with particular engineering know-how is all too often used as an excuse for not going outside for engineering or administrative assistance.

There have been many instances where large engineering organisations have been built up without a proper and detailed analysis being made of the alternatives. A superficial study is not sufficient. A full economic analysis of both the immediate and long term considerations of staff versus consultant services should be thoroughly examined.

There are both technical and economic advantages in using consultant engineering services, for contract administrative purposes and these may be summarised as follows:

(a) The engineering department can be conducted at maximum efficiency, by employing a workforce just sufficient to meet the minimum loading requirements.

The consultant would be engaged to administer particular contract projects according to a specified timetable. This would allow handling of the peaks of activity in the works programme without causing a slowing down of the planned development. It would also relieve the organisation of problems associated with recruitment and training to meet these peak demands.

The total engineering manpower requirements related to the various radio engineering disciplines, for various phases of an installation and construction project, tends to oscillate in more pronounced cycles than it does in the less technically oriented works.

(b) Specialist engineering skill for contract project works can often by obtained more economically from consultants.

The consultant will be skilled and competent from experience in a particular technological field, and as a result of this expertise and staff availability will most likely be able to carry out the administration of the work more efficiently and economically.

The building-up of specialist groups of engineers is often uneconomic in the long term as frequently the specialists cannot be properly and economically utilised after completion of the project for which they were originally recruited.

(c) Engineering effort can be made available much more quickly to meet project demands.

The organisation's own resources may not be geared to meet the design, development and construction supervision of a new system to a short time scale. The setting up and consolidation of additional engineering effort takes time, and can have a serious effect on productivity of the engineers, whereas consultant services may ensure immediate availability of the engineering effort.

(d) Most consultants can provide engineering support either as part of an entire project effort or as a special requirement only. Such support as drafting, specification writing, estimating, contract administration and supervision can be provided economically, as it is generally a major part of their service to clientele.

(e) The consultant can share engineering and administrative responsibility for difficult projects. The organisation may be inexperienced in a field of engineering in which they are involved as part of a project work. The specialist engineering skill of the consultant would bridge the gap in this area. Also, even though the organisation may be competent to carry out the work, the engagement of an independent consultant strengths the chance of technical and economic success of a large and complex project.

(f) The employment of consulting engineers in many areas of radio engineering activity may show considerable economic advantages, if a proper comparative cost analysis study is carried out.

A study by one organisation showed that every new permanent member of the staff cost the organisation nearly twice as much as his basic salary when all overhead and support facilities were taken into consideration. The study also indicated that the organisation needed two years to amortise the overhead of a permanent staff member before he became competitive with temporary outside service.

Table 49.3 is an extract from a contract for consultant engineering services associated with a radiocommunication multi-hop system and indicates typical services provided by a consultant.

Table **49.3** PART OF CONTRACT FOR CONSULTANT ENGINEERING SERVICE

The Consultant undertakes:

(a) To prepare a specification and all necessary plans (with such particulars as may be necessary to enable the Principal to call tenders and to enter into a contract for the due execution thereof) for the radio communication system.
(b) To advise the Principal regarding the calling of tenders for the provision of the specified radio communication system.
(c) To confer with tenderers and deal with queries concerning the requirements of the specification.
(d) To examine tenders and make recommendation to the Principal concerning the acceptance of the preferred tender.
(e) To supervise the installation of the radio communication system and the erection of buildings being part thereof by means of such continual supervision or periodical inspections as may appear to be necessary.
(f) To keep the Principal advised on the progress of the project, to certify progress payments according to the terms of the intended contract, to make recommendations on the need to enforce penalty clauses, and to assist in adjusting all accounts between the Principal and the Contractor.
(g) To carry out acceptance and commissioning tests on behalf of the Principal.
(h) To advise the Principal as to the time it should issue the Notice of Acceptance and the Final Certificate of Completion in accordance with the terms of the contract to be entered into between the Principal and the successful tenderer.
(i) As soon as the Principal has entered into a binding contract for the installation of the project the said plans and specifications shall be and become the property of the Principal.
(j) The Consultant will ensure that its Officers will exercise all reasonable skill, care and diligence in the discharge of the work hereby undertaken by the Consultant and will act fairly as between the Principal and the Contractor.

PATENTS

The history of the development of radio probably includes more patents, and more litigation associated with patents, than any other engineering discipline. The efforts of Marconi to create a monopoly by controlling vital or key patents, the Fleming–de Forest controversy over the invention of the thermionic tube, the feedback circuit arguments of de Forest and Armstrong, and scores of others can be readily cited. The controversy and patent litigation in the USA over feedback circuit inventions dragged on for nearly 20 years with legal expenses running into millions of dollars, while litigation over the de Forest triode patent which was taken out in 1906 was not settled until 37 years later.

Even priority regarding the invention of radio has been the subject of much discussion, particularly in recent years. In the Soviet Union, Alexander Popoff is recognised as the inventor of radio, and Radio Day is celebrated each year on 7 May, while some consider the credit should go to Marconi. There can be no doubt however, that in the case of Marconi, whether he is recognised or not as the inventor over Popoff, he did invent a system of highly successful radio communication, and at the same time personally inspired, contributed and supervised its application until it completely covered the world.

Indemnification against patent infringement and litigation has always been an important clause in radio engineering contract documents. The clause inserted in one typical contract for the supply of a broadcast transmitter reads as follows:

"You agree that you will defend, at your own expense, all suits against the Principal for infringement of any patent or patents covering, or alleged to cover, either said apparatus itself in the form sold by you, or the normal operation thereof, where the only issue in such infringement suits involves the Principal's use of said apparatus, as so sold, for the purpose and in the manner contemplated by this agreement, and you agree that you will pay all sums which, by final judgement or decree in any such suits, may be assessed against the Principal on account of such infringement, provided that you shall be given:

(a) immediate written notice of all claims of any such infringement and of any suits brought or threatened against the Principal and
(b) authority to assume the sole defence thereof through your own counsel and to compromise or settle any suits so far as this may be done without prejudice to the right of the Principal to continue the use, as contemplated, of the apparatus so purchased.

If in any such suit so defended, the apparatus is held to constitute an infringement and its use is enjoined, or if in the light of any claim of infringement you deem it advisable to do so, you may either procure the right to continue the use of the same for the Principal, or replace the same with non-infringing apparatus or modify such equipment so as to be non-infringing. Your complete liability for any such infringement, or claim of infringement shall be limited to the agreements herein contained."

The patent is frequently called a monopoly because it gives the inventor exclusive rights to his invention. However, it is a monopoly only to the extent that all property rights are monopolies. A patent is no different from any other type of property even though it is an intangible, like a share in a business. It does, however, represent an intellectual intangible rather than an economic one, and is consequently more difficult to recognise. If he did not have the legal protection of patent laws, the inventor would probably receive very little compensation for his contribution because it could be used by others to further their own end. Whether the inventor desires to capitalise on his invention is of course a matter for the individual. A patent is not so much a right to use the invention but rather a right to exclude others from using it without the approval of the inventor.

Patents are necessary for the encouragement of research and development in all fields of engineering, as protection to the inventor and to ensure dissemination of new information for the benefit of everyone. Patent specifications provide probably the most up to date and comprehensive record on any art or discipline. Nowhere is there assembled such a wealth of technical information as in published patents which number many millions throughout the world.

A patent is official recognition to the inventor for the exclusive right to make, use and sell the invention for a limited period of time if he discloses his invention so that others may gain the benefit of his idea. The extent of the disclosure must be sufficiently complete and in sufficient depth so that other workers engaged in the particular field may understand the nature of the invention. This is the purpose of the specification in the patenting procedure.

The patentee has exclusive right to make, use, exercise and vend his patent and he may sue for infringement. If a person does what the patentee has a monopoly to do, there is a case for infringement. The patent, however, is not automatically a world wide monopoly. A patent taken out in one country, for example, has effect as a general rule only in that country and its Territories. Separate patents may need to be taken out in each country, if greater protection on the invention is required.

If difficulties of technical definition are ignored, all the following factors would be involved in an infringement:

(a) An act which is prohibited by the Letters Patent must have been performed.
(b) At least one claim of the complete specification must fit the alleged infringement. However, if this claim contains a limitation to something which is not found in the alleged infringement, then there will generally be no case for infringement.
(c) The act must have been committed after the Patent Office had published the complete specification.

A person has no right to use the patent of another for any purpose, but some latitude may be given when the invention is copied only for experimental purposes to determine whether it will work.

No large radio engineering organisation can afford to be without active participation in patent matters. There is always an advantage to be gained by possessing a patent for an invention that marks an improvement in current practice. The organisation must build around itself sufficient patents to protect its products and operations from the imposition of costly litigation and injunctions resulting from the action of competitors.

A very active and large organisation may have sufficient patent activity to justify a full time patent agent on the staff. Under these circumstances, all of the organisation patent work would be handled internally without further reference to outside agencies. Where a full time agent cannot be justified, it may be desirable to have a small staff headed by a patents engineer or an administrative officer. In a small establishment or where patent activity is not extensive, the patents engineer or administrative officer may perform those duties on a part-time basis only. It is important that all aspects associated with organisation inventions, patents and patent policy be properly documented, because there is always the possibility of legal action for or against the organisation, particularly on the question of priority.

Although a group headed by a clerically trained officer can function effectively, a technically trained man can contribute much more actively in the patent aspects. He can take some of the load off the engineer or group who originated the invention, by compiling details of the invention. He can also be invaluable to the patent agent or attorney when the specifications are being drafted. A patent engineer's function is principally one of liaison. He has to interpret the technical details for the benefit of the agent or attorney and to interpret legal matters to the engineers after consultation with legal authority. The administrative officer on the other hand is not qualified to provide these services, and can only act in a purely administrative role.

The duties of a patents group or section may be summarised as follows:

(a) To locate subject matter suitable for possible patenting from within the organisation by maintaining a close relationship with the workforce, particularly those engaged in research and design activities.
(b) To brief the patent agent or attorney on applications, and to handle all subsequent correspondence.
(c) To maintain proper and complete records and registers of organisation inventions, patents, patent policy and minutes of meetings of patent committees, where applicable.
(d) To carry out searches through patent literature.
(e) To maintain a reference library pertaining to all aspects of patents, including in particular patent specifications and abridgments.
(f) To handle all correspondence with agents and attorneys in relation to litigation, infringements and agreements.
(g) To provide information to management and internal departments relative to patents.

An alert and efficient patent section can be a great asset to any organisation. By systematic and regular examination of the latest patent specifications, it is possible to keep abreast of development of interest to the organisation at the earliest possible moment. By this means, management can gauge the extent of progress in research and development of their competitors, and may also learn of particular processes or products in respect of which it may be advantageous to negotiate for licence rights from the patentee.

ARBITRATION OF DISPUTES

Experience has shown that about 99% of radio engineering contracts are honoured, or at least not broken deliberately. There are, however, frequently disputes about the meaning or interpretation of particular clauses of the contract or about obligations of the parties in circumstances which they did not foresee.

When this situation does develop, it is not mandatory that the matter be taken to court. It can frequently be resolved by arbitration. The agreement to arbitrate in disputes is included in nearly all major contracts. It is an arrangement whereby contracting parties may submit a dispute to an impartial arbitrator for a decision, as an alternative to a suit in a court. The arbitrator is often an expert in the discipline to which the dispute relates.

The proceedings of arbitration can be quite informal, or they can be highly formal taking on much of the trappings of formal pleadings of a court. The manner in which the arbitration is to be conducted is largely a matter for the parties to decide.

An 'arbitration clause' included in one contract for a radiocommunication system was worded as follows:

"In case of any dispute, difference, controversy, claim or disagreement of any kind shall arise out of or in any way related to this Contract, its interpretation, performance or the breach thereof or in any manner connected with the work performed hereunder, then either party shall give to the other notice in writing of such dispute or difference.

At the expiration of 10 days unless it shall have been otherwise settled such dispute or difference shall be referred to the arbitration of two independent persons one to be appointed by each party or an umpire to be appointed by the arbitrators.

The submission to arbitration shall be deemed to be a submission to arbitration within the meaning, and shall be subject to, the provision of the laws relating to arbitration in force in the State or Territory in which the works are to be executed. The arbitrator shall have all the powers conferred on a single arbitrator by those laws and it shall be competent for him to enter upon the reference without any further more formal submission than is contained in this condition. Any award of decision rendered pursuant to such arbitration shall be final and binding on the parties.

A submission to arbitration shall not relieve the contractor of any of his obligations under the contract, including the obligation to proceed without delay to execute the works and, if it be reasonably possible, work under the contract or any variations of it shall continue during arbitration proceedings. The costs of the reference and award shall be in the discretion of the arbitrator who may direct to any by whom and in what manner those costs or any part thereof shall be paid and may tax or settle the amount of costs to be so paid or any part thereof."

Inadequate study of the specification and contract conditions before tendering is probably the most frequent source from which disputes arise, It has to be remembered that it is the contract document which binds the parties, and any conditions which the contractor may have attached to his tender will have no force unless they are incorporated in the contract. Pre-tender information supplied by the principal is a frequent primary source of dispute and although the principal may disclaim all responsibility for the accuracy of such pre-tender information, there will be many occasions on which a degree of reliance on such information is absolutely unavoidable in preparing a tender and an arbitrator or court will take this into account. However, the contractor may have difficulty in obtaining a favourable award if the question is decided purely on a point of law.

CONTRACT CANCELLATION

Contract cancellation fortunately is a rare occurrence. Many works have reached the stage where the contractor has lost money on the project due to circumstances beyond his control such as wet weather, transport breakdown, breakdown of machinery on site, damage during transport etc but the matter has been satisfactorily resolved between the parties concerned. Suspension of work has occurred on some projects where accidents or occurrences beyond the control of the contractor have taken place. These include riots, combined action of workmen, lockouts, political disturbances, mobilisation, wars, fires, floods, storms and other Acts of God. These situations are covered in some contracts by a 'force majeure' clause. The clause can also be worded to cover either contractor or principal in the following manner:

"In the event of either party being rendered unable wholly or in part by force majeure to carry out its obligations under the contract then on such party giving notice and full particulars of such force majeurs in writing or by telegraph to the other party as soon as possible after the occurrence of the cause relied on the obligations of the party giving such notice so far as they are affected by such force majeure shall be suspended for the period during which the party is rendered unable as aforesaid but for no longer period and such cause shall as far as possible be remedied or obviated with all reasonable dispatch."

Many contracts make provision for concillation of the contract by the Principal subject to satisfactory compensation. Also provisions are inserted to cater for the case of default by the contractor. These situations are covered by the following typical clauses:

(a) Cancellation of Contract.
The Principal shall have the right to cancel this contract on two weeks notice in writing to the Contractor in which event the Principal will reimburse the Contractor for all necessary actual costs together with irrevocably committed costs and expenses associated with the contract as incurred by the Contractor to the date of cancellation including his normal profit on the completed portions of the work, but shall not pay or be liable to pay any damage or other claim by the Contractor for his loss of expected profit or interest on the uncompleted portions. Any claims shall be made to the Principal and shall be accompanied by copies of invoices, time sheets, and other relevant documents necessary to substantiate the claim.

(b) Default by Contractor.
If the work to be done under the Contract shall be abandoned by the Contractor or if the Contract shall be assigned or the work sublet by the Contractor otherwise than is provided herein or if the Contractor shall be adjudged as bankrupt or shall become insolvent or if a receiver of the business or any part of the property of the Contractor shall be appointed on account of the Contractor's insolvency or if the Contractor shall refuse or fail to supply enough properly skilled workmen, equipment, supplies or material to perform the work or in the opinion of the Project Engineer shall fail in any respect to prosecute the work with promptness and diligence or shall fail in the performance of any of the conditions of the contract herein contained, Principal may give notice in writing to the Contractor to make good the failure, neglect or breach complained of. Should the Contractor fail to commence to comply with the notice within fourteen days from the date of service thereof then Principal may without prejudice to any other rights it may have thereunder terminate the Contract by notice in writing. All such notices are to be sent by registered mail and the Contractor shall discontinue any further work hereunder the Contractor shall then be entitled to be paid the value of the works executed or partly executed by it calculated in accordance with the Contract together with any other amounts that have been accrued due to it under the terms of the Contract and the Principal shall be entitled to set off or insofar as they exceed the amounts payable to the Contractor to recover from the Contractor the amount of all previous payments on account of the work together with the amount of any loss or damage to a value not in excess of 10% of the contract price suffered by the Principal as a result of a breach of the

Contract by the Contractor or of the taking of the work out of its hands under this condition or of the employment of another Contractor or Contractors to execute all or any part of the remaining work. In the event of termination, as stated above, the Principal for the purpose of completing the work shall have the right to take possession of and use all or any part of the Contractor's materials, plants, tools, equipment (including appliances thereon), supplied and property employed in the field, in transit to the sites and in the factory capable of being dispatched to the sites and provided that this does not apply to motor vehicles. The Contractor will be completely responsible for the default of any of his Sub-Contractors.

REFERENCES

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Appendix A

Economic Comparison Tables: Compound Interest Factors

5%

	Single Payment		Annual Series				
Period (yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	Period (yrs)
1	1.050	0.9524	1.000	0.952	1.00000	1.05000	1
2	1.103	0.9070	2.050	1.859	0.48780	0.53780	2
3	1.158	0.8638	3.153	2.723	0.31721	0.36721	3
4	1.216	0.8227	4.310	3.546	0.23201	0.28201	4
5	1.276	0.7835	5.526	4.329	0.18097	0.23097	5
6	1.340	0.7462	6.801	5.076	0.14702	0.19702	6
7	1.407	0.7107	8.142	5.786	0.12282	0.17282	7
8	1.477	0.6768	9.549	6.463	0.10472	0.15472	8
9	1.551	0.6446	11.027	7.108	0.09069	0.14069	9
10	1.629	0.6139	12.578	7.722	0.07950	0.12950	10
11	1.710	0.5847	14.207	8.306	0.07039	0.12039	11
12	1.796	0.5568	15.917	8.863	0.06283	0.11283	12
13	1.886	0.5303	17.713	9.394	0.05646	0.10646	13
14	1.980	0.5051	19.599	9.899	0.05102	0.10102	14
15	2.079	0.4810	21.579	10.380	0.04634	0.09634	15
16	2.183	0.4581	23.657	10.838	0.04227	0.09227	16
17	2.292	0.4363	25.840	11.274	0.03870	0.08870	17
18	2.407	0.4155	28.132	11.690	0.03555	0.08555	18
19	2.527	0.3957	30.539	12.085	0.03275	0.08275	19
20	2.653	0.3769	33.066	12.462	0.03024	0.08024	20
21	2.786	0.3589	35.719	12.821	0.02800	0.07800	21
22	2.925	0.3418	38.505	13.163	0.02597	0.07597	22
23	2.072	0.3256	41.430	13.489	0.02414	0.07414	23
24	3.225	0.3101	44.502	13.799	0.02247	0.07247	24
25	3.386	0.2953	47.727	14.094	0.02095	0.07095	25
26	3.556	0.2812	51.113	14.375	0.01956	0.06956	26
27	3.733	0.2678	54.669	14.643	0.01829	0.06829	27
28	3.920	0.2551	58.403	14.898	0.01712	0.06712	28
29	4.116	0.2429	62.323	15.141	0.01605	0.06605	29
30	4.322	0.2314	66.439	15.372	0.01505	0.06505	30
31	4.538	0.2204	70.761	15.593	0.01413	0.06413	31
32	4.765	0.2099	75.299	15.803	0.01328	0.06328	32
33	5.003	0.1999	80.064	16.003	0.01249	0.06249	33
34	5.253	0.1904	85.067	16.193	0.01176	0.06176	34
35	5.516	0.1813	90.320	16.374	0.01107	0.06107	35
40	7.040	0.1420	120.800	17.159	0.00828	0.05828	40
45	8.985	0.1113	159.700	17.774	0.00626	0.05626	45
50	11.467	0.0872	209.348	18.256	0.00478	0.05478	50
55	14.636	0.0683	272.713	18.633	0.00367	0.05367	55
60	18.679	0.0535	353.584	18.929	0.00282	0.05283	60
65	23.840	0.0419	456.798	19.161	0.00219	0.05219	65
70	30.426	0.0329	588.529	19.343	0.00170	0.05170	70
75	38.833	0.0258	756.654	19.485	0.00132	0.05132	75
80	49.561	0.0202	971.229	19.596	0.00103	0.05103	80
85	63.254	0.0158	1245.087	19.684	0.00080	0.05080	85
90	80.730	0.0124	1594.607	19.752	0.00063	0.05063	90
95	103.035	0.0097	2040.694	19.806	0.00049	0.05049	95
100	131.501	0.0076	2610.025	19.848	0.00038	0.05038	100

6%

Period	Single Payment		Annual Series				Period
(yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	(yrs)
1	1.060	0.9434	1.000	0.943	1.00000	1.06000	1
2	1.124	0.8900	2.060	1.833	0.48544	0.54544	2
3	1.191	0.8396	3.184	2.673	0.31411	0.37411	3
4	1.262	0.7921	4.375	3.465	0.22859	0.28859	4
5	1.338	0.7473	5.637	4.212	0.17740	0.23740	5
6	1.419	0.7050	6.975	4.917	0.14336	0.20336	6
7	1.504	0.6651	8.394	5.582	0.11914	0.17914	7
8	1.594	0.6274	9.897	6.210	0.10104	0.16104	8
9	1.689	0.5919	11.491	6.802	0.08702	0.14702	9
10	1.791	0.5584	13.181	7.360	0.07587	0.13587	10
11	1.898	0.5268	14.972	7.887	0.06679	0.12679	11
12	2.012	0.4970	16.870	8.384	0.05928	0.11928	12
13	2.133	0.4688	18.882	8.853	0.05296	0.11296	13
14	2.261	0.4423	21.015	9.295	0.04758	0.10758	14
15	2.397	0.4173	23.276	9.712	0.04296	0.10296	15
16	2.540	0.3936	25.673	10.106	0.03895	0.09895	16
17	2.693	0.3714	28.213	10.477	0.03544	0.09544	17
18	2.854	0.3503	30.906	10.828	0.03236	0.09236	18
19	3.026	0.3305	33.760	11.158	0.02962	0.08962	19
20	3.207	0.3118	36.786	11.470	0.02718	0.08718	20
21	3.400	0.2942	39.993	11.764	0.02500	0.08500	21
22	3.604	0.2775	43.392	12.042	0.02305	0.08305	22
23	3.820	0.2618	46.996	12.303	0.02128	0.08128	23
24	4.049	0.2470	50.816	12.550	0.01968	0.07968	24
25	4.292	0.2330	54.865	12.783	0.01823	0.07823	25
26	4.549	0.2198	59.156	13.003	0.01690	0.07690	26
27	4.822	0.2074	63.706	13.211	0.01570	0.07570	27
28	5.112	0.1956	68.528	13.406	0.01459	0.07459	28
29	5.418	0.1846	73.640	13.591	0.01358	0.07358	29
30	5.743	0.1741	79.058	13.765	0.01265	0.07265	30
31	6.088	0.1643	84.802	13.929	0.01179	0.07179	31
32	6.453	0.1550	90.890	14.084	0.01100	0.07100	32
33	6.841	0.1462	97.343	14.230	0.01027	0.07027	33
34	7.251	0.1379	104.184	14.368	0.00960	0.06960	34
35	7.686	0.1301	111.435	14.498	0.00897	0.06897	35
40	10.286	0.0972	154.762	15.046	0.00646	0.06646	40
45	13.765	0.0727	212.744	15.456	0.00470	0.06470	45
50	18.420	0.0543	290.336	15.762	0.00344	0.06344	50
55	24.650	0.0406	394.172	15.991	0.00254	0.06254	55
60	32.988	0.0303	533.128	16.161	0.00183	0.06188	60
65	44.145	0.0227	719.083	16.289	0.00139	0.06139	65
70	59.076	0.0169	967.932	16.385	0.00103	0.06103	70
75	79.057	0.0126	1300.949	16.456	0.00077	0.06077	75
80	105.796	0.0095	1746.600	16.509	0.00057	0.06057	80
85	141.579	0.0071	2342.982	16.549	0.00043	0.06043	85
90	189.465	0.0053	3141.075	16.579	0.00032	0.06032	90
95	253.546	0.0039	4209.104	16.601	0.00024	0.06024	95
100	339.302	0.0029	5638.368	16.618	0.00018	0.06018	100

7%

	Single Payment		Annual Series				
Period (yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	Period (yrs)
1	1.070	0.9346	1.000	0.935	1.00000	1.07000	1
2	1.145	0.8734	2.070	1.808	0.48309	0.55309	2
3	1.225	0.8163	3.215	2.624	0.31105	0.38105	3
4	1.311	0.7629	4.440	3.387	0.22523	0.29523	4
5	1.403	0.7130	5.751	4.100	0.17389	0.24389	5
6	1.501	0.6663	7.153	4.767	0.13980	0.20980	6
7	1.606	0.6227	8.654	5.389	0.11555	0.18555	7
8	1.718	0.5820	10.260	5.971	0.09747	0.16747	8
9	1.838	0.5439	11.978	6.515	0.08349	0.15349	9
10	1.967	0.5083	13.816	7.024	0.07238	0.14238	10
11	2.105	0.4751	15.784	7.499	0.06336	0.13336	11
12	2.252	0.4440	17.888	7.943	0.05590	0.12590	12
13	2.410	0.4150	20.141	8.358	0.04965	0.11965	13
14	2.579	0.3878	22.550	8.745	0.04434	0.11434	14
15	2.759	0.3624	25.129	9.108	0.03979	0.10979	15
16	2.952	0.3387	27.888	9.447	0.03586	0.10586	16
17	3.159	0.3166	30.840	9.763	0.03243	0.10243	17
18	3.380	0.2959	33.999	10.059	0.02941	0.09941	18
19	3.617	0.2765	37.379	10.336	0.02675	0.09675	19
20	3.870	0.2584	40.995	10.594	0.02439	0.09439	20
21	4.141	0.2415	44.865	10.836	0.02229	0.09229	21
22	4.430	0.2257	49.006	11.061	0.02041	0.09041	22
23	4.741	0.2109	53.436	11.272	0.01871	0.08871	23
24	5.072	0.1971	58.177	11.469	0.01719	0.08719	24
25	5.427	0.1842	63.249	11.654	0.01581	0.08581	25
26	5.807	0.1722	68.676	11.826	0.01456	0.08456	26
27	6.214	0.1609	74.484	11.987	0.01343	0.08343	27
28	6.649	0.1504	80.698	12.137	0.01239	0.08239	28
29	7.114	0.1406	87.347	12.278	0.01145	0.08145	29
30	7.612	0.1314	94.461	12.409	0.01059	0.08059	30
31	8.145	0.1228	102.073	12.532	0.00980	0.07980	31
32	8.715	0.1147	110.218	12.647	0.00907	0.07907	32
33	9.325	0.1072	118.933	12.754	0.00841	0.07841	33
34	9.978	0.1002	128.259	12.854	0.00780	0.07780	34
35	10.677	0.0937	138.237	12.948	0.00723	0.07723	35
40	14.974	0.0668	199.635	13.332	0.00501	0.07501	40
45	21.002	0.0476	285.749	13.606	0.00350	0.07350	45
50	29.457	0.0339	406.529	13.801	0.00246	0.07246	50
55	41.315	0.0242	575.929	13.940	0.00174	0.07174	55
60	57.946	0.0173	813.520	14.039	0.00123	0.07123	60
65	81.273	0.0123	1146.755	14.110	0.00087	0.07087	65
70	113.989	0.0088	1614.134	14.160	0.00062	0.07062	70
75	159.876	0.0063	2269.657	14.196	0.00044	0.07044	75
80	224.234	0.0045	3189.063	14.222	0.00031	0.07031	80
85	314.500	0.0032	4478.576	14.240	0.00022	0.07022	85
90	441.103	0.0023	6287.185	14.253	0.00016	0.07016	90
95	618.670	0.0016	8823.854	14.263	0.00011	0.07011	95
100	867.716	0.0012	12381.662	14.269	0.00008	0.07008	100

8%

	Single Payment		Annual Series				
Period (yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	Period (yrs)
1	1.080	0.9259	1.000	0.926	1.00000	1.08000	1
2	1.166	0.8573	2.080	1.783	0.48077	0.56077	2
3	1.260	0.7938	3.246	2.577	0.30803	0.38803	3
4	1.360	0.7350	4.506	3.312	0.22192	0.30192	4
5	1.469	0.6806	5.867	3.993	0.17046	0.25046	5
6	1.587	0.6302	7.336	4.623	0.13632	0.21632	6
7	1.714	0.5835	8.923	5.206	0.11207	0.19207	7
8	1.851	0.5403	10.637	5.747	0.09401	0.17401	8
9	1.999	0.5002	12.488	6.247	0.08008	0.16008	9
10	2.159	0.4632	14.487	6.710	0.06903	0.14903	10
11	2.332	0.4289	16.645	7.139	0.06008	0.14008	11
12	2.518	0.3971	18.977	7.536	0.05270	0.13270	12
13	2.720	0.3677	21.495	7.904	0.04652	0.12652	13
14	2.937	0.3405	24.215	8.244	0.04130	0.12130	14
15	3.172	0.3152	27.152	8.559	0.03683	0.11683	15
16	3.426	0.2919	30.324	8.851	0.03298	0.11298	16
17	3.700	0.2703	33.750	9.122	0.02963	0.10963	17
18	3.996	0.2502	37.450	9.372	0.02670	0.10670	18
19	4.316	0.2317	41.446	9.604	0.02413	0.10413	19
20	4.661	0.2145	45.762	9.818	0.02185	0.10185	20
21	5.034	0.1987	50.423	10.017	0.01983	0.09983	21
22	5.437	0.1839	55.457	10.201	0.01803	0.09803	22
23	5.871	0.1703	60.893	10.371	0.01642	0.09642	23
24	6.341	0.1577	66.765	10.529	0.01498	0.09498	24
25	6.848	0.1460	73.106	10.675	0.01368	0.09368	25
26	7.396	0.1352	79.954	10.810	0.01251	0.09251	26
27	7.988	0.1252	87.351	10.935	0.01145	0.09145	27
28	8.627	0.1159	95.339	11.051	0.01049	0.09049	28
29	9.317	0.1073	103.966	11.158	0.00962	0.08962	29
30	10.063	0.0994	113.283	11.258	0.00863	0.08883	30
31	10.868	0.0920	123.346	11.350	0.00811	0.08811	31
32	11.737	0.0852	134.214	11.435	0.00745	0.08745	32
33	12.676	0.0789	145.951	11.514	0.00685	0.08685	33
34	13.690	0.0730	158.627	11.587	0.00630	0.08630	34
35	14.785	0.0676	172.317	11.655	0.00580	0.08580	35
40	21.725	0.0460	259.057	11.925	0.00386	0.08386	40
45	31.920	0.0313	386.506	12.108	0.00259	0.08259	45
50	46.902	0.0213	573.770	12.233	0.00174	0.08174	50
55	68.914	0.0145	848.923	12.319	0.00118	0.08118	55
60	101.257	0.0099	1253.213	12.377	0.00080	0.08080	60
65	148.780	0.0067	1847.248	12.416	0.00054	0.08054	65
70	218.606	0.0046	2720.080	12.443	0.00037	0.08037	70
75	321.205	0.0031	4002.557	12.461	0.00025	0.08025	75
80	471.955	0.0021	5886.935	12.474	0.00017	0.08017	80
85	693.456	0.0014	8655.706	12.482	0.00012	0.08012	85
90	1018.915	0.0010	12723.939	12.488	0.00008	0.08008	90
95	1497.121	0.0007	18701.507	12.492	0.00005	0.08005	95
100	2199.761	0.0005	27484.516	12.494	0.00004	0.08004	100

10%

Period	Single Payment		Annual Series				Period
(yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	(yrs)
1	1.100	0.9091	1.000	0.909	1.00000	1.10000	1
2	1.210	0.8264	2.100	1.736	0.47619	0.57619	2
3	1.331	0.7513	3.310	2.487	0.30211	0.40211	3
4	1.464	0.6830	4.641	3.170	0.21547	0.31547	4
5	1.611	0.6209	6.105	3.791	0.16380	0.26380	5
6	1.772	0.5645	7.716	4.355	0.12961	0.22961	6
7	1.949	0.5132	9.487	4.868	0.10541	0.20541	7
8	2.144	0.4665	11.436	5.335	0.08744	0.18744	8
9	2.358	0.4241	13.579	5.759	0.07364	0.17364	9
10	2.594	0.3855	15.937	6.144	0.06275	0.16275	10
11	2.853	0.3505	18.531	6.495	0.05396	0.15396	11
12	3.138	0.3186	21.384	6.814	0.04676	0.14676	12
13	3.452	0.2897	24.523	7.103	0.04078	0.14078	13
14	3.797	0.2633	27.975	7.367	0.03575	0.13575	14
15	4.177	0.2394	31.772	7.606	0.03147	0.13147	15
16	4.595	0.2176	35.950	7.824	0.02782	0.12782	16
17	5.054	0.1978	40.545	8.022	0.02466	0.12466	17
18	5.560	0.1799	45.599	8.201	0.02193	0.12193	18
19	6.116	0.1635	51.159	8.365	0.01955	0.11955	19
20	6.727	0.1486	57.275	8.514	0.01746	0.11746	20
21	7.400	0.1351	64.002	8.649	0.01562	0.11562	21
22	8.140	0.1228	71.403	8.772	0.01401	0.11401	22
23	8.954	0.1117	79.543	8.883	0.01257	0.11257	23
24	9.850	0.1015	88.497	8.985	0.01130	0.11130	24
25	10.835	0.0923	98.347	9.077	0.01017	0.11017	25
26	11.918	0.0839	109.182	9.161	0.00916	0.10916	26
27	13.110	0.0763	121.100	9.237	0.00826	0.10826	27
28	14.421	0.0693	134.210	9.307	0.00745	0.10745	28
29	15.863	0.0630	148.631	9.370	0.00673	0.10673	29
30	17.449	0.0573	164.494	9.427	0.00608	0.10608	30
31	19.194	0.0521	181.943	9.479	0.00550	0.10550	31
32	21.114	0.0474	201.138	9.526	0.00497	0.10497	32
33	23.225	0.0431	222.252	9.569	0.00450	0.10450	33
34	25.548	0.0391	245.477	9.609	0.00407	0.10407	34
35	28.102	0.0356	271.024	9.644	0.00369	0.10369	35
40	45.259	0.0221	442.593	9.779	0.00226	0.10226	40
45	72.890	0.0137	718.905	9.863	0.00139	0.10139	45
50	117.391	0.0085	1163.909	9.915	0.00086	0.10086	50
55	189.059	0.0053	1880.591	9.947	0.00053	0.10053	55
60	304.482	0.0033	3034.816	9.967	0.00033	0.10033	60
65	490.371	0.0020	4893.707	9.980	0.00020	0.10020	65
70	789.747	0.0013	7887.470	9.987	0.00013	0.10013	70
75	1271.895	0.0008	12708.954	9.992	0.00008	0.10008	75
80	2048.400	0.0005	20474.002	9.995	0.00005	0.10005	80
85	3298.969	0.0003	32979.690	9.997	0.00003	0.10003	85
90	5313.023	0.0002	53120.226	9.998	0.00002	0.10002	90
95	8556.676	0.0001	85556.760	9.999	0.00001	0.10001	95
100	13780.612	0.0001	137796.123	9.999	0.00001	0.10001	100

15%

	Single Payment		Annual Series				
Period (yrs)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Compound Amount Factor (CAF)	Present Worth Factor (PWF)	Sinking Fund Factor (SFF)	Capital Recovery Factor (CRF)	Period (yrs)
1	1.150	0.8696	1.000	0.870	1.00000	1.15000	1
2	1.322	0.7501	2.150	1.626	0.46512	0.61512	2
3	1.521	0.6575	3.472	2.283	0.28798	0.43798	3
4	1.749	0.5717	4.993	2.855	0.20026	0.35027	4
5	2.011	0.4972	6.742	3.352	0.14832	0.29832	5
6	2.313	0.4323	8.754	3.784	0.11424	0.26424	6
7	2.660	0.3759	11.067	4.160	0.09036	0.24036	7
8	3.059	0.3269	13.727	4.487	0.07285	0.22285	8
9	3.518	0.2843	16.786	4.772	0.05957	0.20957	9
10	4.046	0.2472	20.304	5.019	0.04925	0.19925	10
11	4.652	0.2149	24.349	5.234	0.04107	0.19107	11
12	5.350	0.1869	29.002	5.421	0.03448	0.18448	12
13	6.153	0.1625	34.352	5.583	0.02911	0.17911	13
14	7.076	0.1413	40.505	5.724	0.02469	0.17469	14
15	8.137	0.1229	47.580	5.847	0.02102	0.17102	15
16	9.358	0.1069	55.717	5.954	0.01795	0.16795	16
17	10.761	0.0929	65.075	6.047	0.01537	0.16537	17
18	12.375	0.0808	75.836	6.128	0.01319	0.16319	18
19	14.232	0.0703	88.212	6.198	0.01134	0.16134	19
20	16.367	0.0611	102.443	6.259	0.00976	0.15976	20
21	18.821	0.0531	118.810	6.312	0.00842	0.15842	21
22	21.645	0.0462	137.631	6.359	0.00727	0.15727	22
23	24.891	0.0402	159.276	6.399	0.00628	0.15628	23
24	28.625	0.0349	184.167	6.434	0.00543	0.15543	24
25	32.919	0.0304	212.793	6.464	0.00470	0.15470	25
26	37.857	0.0264	245.711	6.491	0.00407	0.15407	26
27	43.535	0.0230	283.568	6.514	0.00353	0.15353	27
28	50.065	0.0200	327.103	6.534	0.00306	0.15306	28
29	57.575	0.0174	377.169	6.551	0.00265	0.15265	29
30	66.212	0.0151	434.744	6.566	0.00230	0.15230	30
31	76.143	0.0131	500.956	6.579	0.00200	0.15200	31
32	87.565	0.0114	577.099	6.591	0.00173	0.15173	32
33	100.700	0.0099	664.664	6.600	0.00150	0.15150	33
34	115.805	0.0086	765.364	6.609	0.00131	0.15131	34
35	133.175	0.0075	881.168	6.617	0.00113	0.15113	35
40	267.862	0.0037	1779.1	6.642	0.00056	0.15056	40
45	538.767	0.0019	3585.1	6.654	0.00028	0.15028	45
50	1083.652	0.0009	7217.7	6.661	0.00014	0.15014	50

Index

John F. Ross brings some 40 years of practical experience in the management of the design, construction and operation of radio engineering projects to this book.

During the period 1941–1945 he served with the Royal Australian Air Force for more than four years on VHF and microwave radar design, installation and operation of airborne equipment, high power ground stations and navigational radio aids on various assignments in Australia, New Guinea and the Pacific area.

After the War he completed a cadetship in Communications Engineering with an Australian Government Department and has since been engaged on the design, installation, operation and maintenance of sound broadcasting, television and radiocommunication network services.

He has managed and supervised the design, construction, commissioning and subsequent operation on several multi million pound projects including long haul broadband microwave radiocommunication and high power international broadcasting systems.

Mr. Ross is a graduate electronics engineer, a Registered Professional Engineer, Fellow of the Institution of Radio and Electronics Engineers Australia, Member of the Institution of Engineers Australia and Associate Fellow of the Australian Institute of Management. He is the author of six books dealing with the history of telecommunications.

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