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"To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering."

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Research, Reliability and Communications

By

ADMIRAL OF THE FLEET THE EARL MOUNTBATTEN OF BURMA, K.G.†

Considerable interest has been centred on an Address given by the President of the Institution to the Radio and Electronics Industry Councils at the Industry Dinner held in London on 29th November 1961. The following is a complete reproduction of the President's speech.

Your President, Lord Brabazon, has been most generous in his kind remarks and I thank him and your Council for the warm welcome and splendid hospitality. In 1947 I accepted the invitation to open the Radio Exhibition but before the opening took place I was sent to India. I therefore recorded my opening speech, which was broadcast at the Exhibition, although I was actually in Delhi. When your Council subsequently invited me to open the 1951 Festival of Britain Radio Show, I was by then back in London serving at the Admiralty, and was able to open it in person. I am glad this was possible as I found it a rewarding experience to see how the industry was already developing new techniques and applying new ideas in radio and electronic science engineering. The industry had, in fact, seized its post-war opportunities and was becoming one of the major and most important industries in our country.

You have built up an excellent export record not only in Europe and the Commonwealth, but throughout the world. We cannot, however, live on past achievements. I know that the events of the past 10 years have made more difficult your task of increasing the export turnover; not only are more countries establishing their own radio industries for defence and other purposes, but overall international competition has become keener.

The future offers as great a challenge as the industry faced at the outset of the last war, and with perhaps about the same time in which to marshal its forces: not only for extending our export trade, but also for satisfying the needs of the home market—and please remember that in this respect your biggest customers are the Defence Forces!

A Research Association for the Radio and Electronics Industry

We are entering a new era in electronic developments; but, just as we did in the days of the discovery and development of Radar, we start to-day with many assets—for example, our experience in ionospheric probing, and long-distance communication technique.

In my recent presidential address to the British Institution of Radio Engineers,‡ I expressed my belief that communication via satellites opens a tremendous field of opportunity which may well revolutionize our whole conception of communication both internationally and in the domestic field.

Industrial successes in this and other electronic fields will demand, however, that research be on a scale not hitherto contemplated in peace-time. The Government has already sponsored space research by its grants to the Post Office and other agencies in-

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‡ *J. Brit.I.R.E.*, **21**, No. 6, pp. 473–6, June 1961.

cluding the Department of Scientific and Industrial Research and the Royal Society. This Government contribution to our radio and electronic research programme is additional to the very considerable effort made by your own industry. But in this coming era an even greater effort in research and development is clearly called for. So I suggest that the Radio and Electronics Industry Councils should investigate the desirability of promoting a radio and electronic industries research association.

This should enable you to achieve greater strength by more co-operation and to avoid the failure which may attend separate individual efforts. It is moreover a fact that fundamental research is impossible of completion—and often even of initiation—when it is contingent upon immediate financial result. Continuous research is essential to industrial prosperity and must not be subject to spasmodic effort caused by trade fluctuations. A scheme of this kind will not affect the need for continuing the research and development activity already undertaken by some of the larger segments of the radio and electronic industry. Indeed, such enterprise can stimulate the development of projects most suited to the individual company.

The need to increase our research effort however makes it essential to introduce planned research in order to make the best use of our available resources, both in finances and manpower; it would also help us to compete successfully with the rest of the world.

The assets of this country consist not only of our natural, material resources, but predominantly in the creative and inventive capacity with which we have been endowed; but if we fail to work together these assets will not be used to their fullest advantage.

We certainly cannot afford to fall behind other nations in our research programme; and if we are to hold, and even improve, our position in international trade, we must take full advantage of the ability of our scientists and engineers and of the intelligence and craftsmanship of our workers. Testimony to their ability is shown by the eagerness with which other countries offer attractive employment to our scientists and engineers. Such exports are not, however, entirely to our advantage!

I hope that your Councils may quickly examine the proposal to establish a Research Association. There is danger in delay; for once established markets are allowed to lapse, or the opportunity to establish new ones is missed, it is not easy to regain lost ground. I hope that a research organization of the kind suggested will not only offer increased opportunities to keep us in the vanguard of progress and engineering development, but will also enable us to give assistance to the newly emergent countries to develop their electronic industries along British lines. For the introduction of British ideas and "know how" in these countries will obviously not only open up new markets for our skills—with all the prestige that that implies—but will also help us to keep these markets for our exports.

Manufacturers' associations such as yours perform a most valuable function in co-relating the opinion of all parts of your industry on such matters as I have mentioned. I am, of course, well aware that you have disagreements and sometimes even publish minority reports! I can also appreciate that the growth of the whole industry has developed through separate channels. In my present and past jobs, I have been faced with having to reconcile various—and sometimes even conflicting—interests; and I believe the answer for you also lies in some form of "Combined Operations".

From the Services viewpoint—as well, I am sure, as that of other Government Departments—the Radio and Electronics Industry Councils should be regarded and used as a Combined Operations Headquarters for the whole of this nationally important industry. In wartime you operated in this way in representing and co-ordinating the several but interdependent interests of your constituent bodies.

I know that the top men in many companies are considering how best to work together in the country's interests as well as their own. You may, therefore, agree that in such a vitally important matter as a research association you will wish to act together.

Another important aspect of combined industrial operations is the provision of adequate maintenance facilities for export equipment, and this is a question which your Councils might well take up with the Board of Trade and other Government agencies. Whilst the industry is now better placed to overcome the criticism of late deliveries, there is still criticism on reliability and the availability of servicing. Whatever the real situation may be, nothing but good can result from consultation within your industry. Co-operation between firms exporting to the same country might, for instance, be worth exploring. Certainly, an industry report would interest Government departments, who are as anxious as yourselves to maintain the prestige of British goods *after* they have been delivered, so that the foreign countries concerned will wish to continue to buy British.

Reliability of Electronic Equipment

In attacking this problem, I hope the industry will also aid inquiry, and perhaps instigate research into the whole question of reliability. This is a subject of tremendous importance to the Defence Services and to the whole of our space research programme. Any increase in the complexity of equipment must be accompanied by at least a corresponding improvement in reliability and maintainability; the competition of the export market places increasing emphasis on these aspects.

A recent inquiry into the reliability, or perhaps I should say the unreliability, of present electronic equipment, revealed the staggering fact that the present equipment costs from about 10 to 100 times as much money to maintain throughout its lifetime as its original capital cost.

On Friday I addressed the Ministry of Aviation Scientists Annual Conference, and in stressing the importance of establishing reliability definitions I showed them an American book called "Reliability Factors for Ground Electronic Equipment". I also referred to the Americans setting up their Advisory Group on Reliability in Electronic Equipment, with the delightful short title of AGREE. On Saturday one of the audience sent me a copy of an English book published last year by two scientists of the Royal Radar Establishment, called "Electronic Equipment Reliability".

I must admit I had not heard of this before, and I hasten to make amends by drawing your attention to it. I was pleased to see that such a book had been produced over here though it was a private venture, whereas the American publication was a combined effort between the Defence Services and the manufacturers. I hope that we shall continue to make progress and finally have an all-British AGREE.

A far higher degree of reliability could be the means of saving many maintenance technicians. In the Services, in particular, this is the type of man we are most likely to be short of.

To make such equipment really reliable will cost a lot of effort and money in the future but if a guarantee of reliability backed if possible by free maintenance were given surely customers would soon appreciate that the extra reliability was well worth the extra cost.

The industry is already being helped by the work being pursued in Government establishments, and I would particularly mention the work in the Royal Radar Establishment at Malvern. The results obtained at Malvern and in the U.S.A. indicate that the production of reliable components may well involve new ideas in test equipment, apart from the fundamental question of design.

Circuit reliability introduces new thinking in terms of module construction, by which equipment is designed in the form of a number of sub-assemblies. This principle has two advantages:

Firstly, maintenance is carried out by replacing an unserviceable module by another:

And, secondly, the function of the equipment can be changed by the replacement of one or more modules by those of a different type, but of the same size.

Continuous research is also necessary into the new materials used in components. For example, today nearly all our crystals are man-made. Those of you who are concerned with transistor production will know that the basic problem has been that of understanding the electrical behaviour of the new materials. Incidentally, it recalls the earlier days of your industry when similar problems were faced in the use of natural quartz crystal.

Component and circuit reliability will greatly affect the future prosperity of your industry; and I think it of the utmost importance that you should share in, and contribute to, a Government programme of investigation into reliability and materials.

Communications Development

Perhaps you will allow me to return for a moment to defence communications—which is the only really direct concern of mine that impinges on your industry—and to repeat briefly from what I said last June at the British Institution of Radio Engineers dinner.

Each of the three Defence Services at present operates its own long distance world-wide communications network; and I am one of those who believe it would be better to combine these three separate networks, thereby saving both money and manpower, but this is a development which can only be economically introduced as the next generation of equipment comes to be designed and put into service. In any case, the Services have their own economic problems caused by changes in the design of communications equipment which are, of course, a continuing process.

So it seems essential that communications users should get together and pool their resources; since not one of them will be able to "go it alone" in the face of the technological developments which are with us now, and which are growing at an ever increasing rate. I am glad to tell you that all interests, both Service and civilian, are represented at the top official level, in investigations into the possibility of all governmental communications sharing in future expensive developments, such as the use of communications satellites.

The great increase in the importance of electronics to the Defence Services is perhaps best illustrated by the startling rise, over the last few years, in the expenditure on communication, radar and navigational aid equipment for use by the armed services. As a potent illustration of this increase, the cost of the electronic equipment which is being fitted in a single *Hampshire* class guided missile ship is more than the total annual expenditure on electronic equipment for the whole fleet in each of the postwar years up to 1951.

It is most important that this vast increase in electronic expenditure shall be along lines that not only enable our own three Services to work together with complete efficiency, but also with those of the other Commonwealth countries and our allies. In the old days we surmounted our language difficulties by the provision of common signal manuals; but now we are faced with the more difficult problem of the language of machines—therefore compatibility of equipment is a vital factor. How are we going to achieve this essential compatibility? I would suggest that the foundations for compatibility must be laid at the design stage, and that we need a greater exchange of ideas between the development organizations of our three Services and of industry.

I have already spoken of the importance of reliability from a commercial point of view: I now wish to stress the vital need for reliability in the communications equipment provided for the Defence Services. For instance, with high performance aircraft there is an increasing need for accurate navigation; and navigation and flying rely more and more on the continuous and accurate functioning of the electronic devices in the air and on the ground.

I would also like to say a word about the problem of congestion, for the congestion of the available radio frequency spectrum—particularly in the h.f. band—becomes daily more chaotic; but I believe there is one method of alleviating the problem which has not yet been fully explored. I refer of course to the use of minimum bandwidth transmissions. The services are becoming increasingly interested in the use of radio telephony, and it is in this field that the greatest benefits could be expected to accrue. The use of bandwidth compression techniques could reduce the bandwidth required while still providing speech of adequate intelligibility, although of reduced quality.

The problem of congestion in the frequency spectrum leads me naturally to the question of the use of satellites for communications purposes. The use of satellites for communications and navigational purposes has a tremendous potential, and we want to press forward with development in this important new field. Quite apart from the possibilities which are opened up for more reliable methods to meet the tactical needs of individual Services, I shall be most surprised if satellite communications do not form an essential part of a future integrated military world-wide strategic communications system.

The use of satellites emphasizes the need for even more miniaturization. Transistors, printed circuits and other devices of this nature have already made a great reduction in the space required for electronic components. However, continuous effort for further miniaturization is still needed; and together with this goes the development of equipment on the module principle.

The Importance of Training

And now what about the personnel? I would suggest that the need for co-ordination of technical training schemes between the Services and industry is greater now than it ever has been—particularly in the field of electronics.

As I have stated we must, as a nation, make the best possible use of our available material and this especially applies to men and brain power. We are concerned with this problem in the Services and I believe that in the future industry will be able to make even better use of men who have been trained and had practical electronic experience in the Services. To facilitate the best use of these men it is important to correlate the technical qualifications obtained by men in the Services with those in industry. I do not think that either the Services or industry do this as well as they might.

All that I have said is based on my own continuing interest in your industry; and I am glad to have had this opportunity of giving my thoughts on your problems. Perhaps it would have been easier for me—and, I suspect, more popular with you—if I had recited figures showing the astonishing growth of the industry and its valuable contribution to our export trade. All of us here, however, are well aware of this, and I feel that the facts can be much better publicized by your own organization.

In my capacity as Charter President of the British Institution of Radio Engineers I have specially appreciated your invitation to attend and speak at this year's dinner. I have been associated with the Institution almost from its inception, and I know that its future is bound up with the future of the British Electronics industry. It is, therefore, with particular pleasure that I propose the toast of the British Radio and Electronics Industry.

35th Annual Report of the Council of the Institution

The Council has pleasure in presenting the 35th Annual Report of the Institution which reviews the proceedings for the twelve months ended 31st March, 1961. The Annual General Meeting will be held on 24th January, 1962, at the London School of Hygiene and Tropical Medicine, Gower Street, London, W.C.1, commencing at 6 p.m. (Notice of the meeting and the Agenda was published in the December 1961 Journal.)

INTRODUCTION

POSITIVE achievement is more noteworthy than details of the work undertaken to secure it, and for this reason the present Report does not include a section dealing with the work of the Professional Purposes Committee.

During the year under review, the activities of this Committee were almost wholly concerned with preparing and submitting, in July 1960, a Petition to the Privy Council for the grant of a Royal Charter of Incorporation, and subsequently with the responsibility for preparing a reply to some observations which had been made to the Privy Council on the Petition. Much of this detail will no doubt be recorded in a future history of the Institution. The membership, throughout the world, has expressed great satisfaction with the final achievement announced in August 1961—a few months after the ending of the year reviewed in this Report.

The first Professional Purposes Committee of the Institution was appointed in 1938. It has ever since been the senior Committee of the Institution, with an overall responsibility for all Institution activity and policy consistent with the ultimate aim of securing a grant of a Royal Charter of Incorporation.

Achievement of this purpose does not mean dissolution of the Committee. Under its future title, the Executive Committee of the General Council, it will still be responsible for the writing of the Bye-Laws of the Institution and drafting future policy and development of Institution activity, particularly in the Commonwealth.

The terms of the Charter granted the Institution will be published in the 1962 edition of the *List of Members.* This includes the members appointed as officers and members of Council as indicated in the January 1962 *Journal.* The proposed Bye-Laws will be submitted to Corporate Members for approval at a Special Meeting of the Institution to be held in March 1962.

During the twelve months ended 31st March 1961, there were 108 meetings of the various standing committees of the Institution in addition to six meetings of the General Council.

Considerable preparation was also made during the year for the Institution's Convention on "Radio Techniques and Space Research" held in the University of Oxford in July 1961.

This Report reviews the principal activities of the main Committees, and the Council is especially anxious this year to express its appreciation to all members who have contributed so much to the work of these Committees by giving so generously of their time and labour in serving the Institution. Whilst these comments apply particularly to work done in the past year, it is also an expression of thanks to all members who have found time to serve the Institution during its life of thirty-six years. Some measure of the value of these endeavours is perhaps best summarized by recording that when in August 1932 the Institution secured incorporation under the 1929 Companies Act, the Institution had fewer than 400 members. The Institution entered its first year as a Chartered body with nearly 8000 members and a record of achievement in every field covered by the work of its Standing Committees.

MEMBERSHIP COMMITTEE

At the time of preparing this report for publication, the Council was discussing the desirability of forming two separate Committees; one dealing with proposals for corporate membership, and the other being responsible for proposals for the non-corporate grades. The reason for this way of easing the work of the Membership Committee will be seen from the tables included in this report, and the comments under the heading "Future membership".

Table 1 shows the total membership during the past five years and the net increase during each of those years. Including registered students, the net gain of 735 for the year ended 31st March, 1961 was the highest in the Institution's history.

Table 1

Total membership as at 31st March		*Net increase during the year*
1961	7067	735
1960	6332	419
1959	5913	291
1958	5622	54
1957	5568	176

The following Table 2 analyses the elections and transfers considered and approved during the year under review, *excluding* Studentship Registrations. A comparison of this table with that published in the last Annual Report shows an increase of nearly 200 proposals considered by the Committee. The number of elections and transfers to corporate membership shows an encouraging increase and whilst elections to Associate are down this may be a reflection of the desire of applicants to seek election to those grades of membership which bear testimony to their academic ability.

Elections or transfers to the grade of Graduate show the largest percentage increase—approximately 35% over the previous year. This is an encouraging feature since nearly every Graduate accepted for direct election eventually qualified for transfer to Associate Member. The increase in the number of Graduates should, therefore, lead to a proportionate increase in the number of corporate members as the Graduates gain the necessary professional engineering experience and responsibility to meet the qualifications for corporate membership.

Studentship Registrations. The last Annual Report referred to the higher academic qualifications held by applicants for Studentship Registration and suggested that this would lead to a greater percentage qualifying for transfer to Graduateship or higher grade. This assumption is borne out by the comments in the preceding paragraph; the membership records show that 160 Students qualified for transfer to higher grades of membership compared with 134 for the preceding year.

A total of 636 applications for Studentship Registration was approved during the year. Losses by resignation or inability to comply with the examination requirements within the 5-year period amounted to 238. This figure, added to the 160 who transferred to a higher grade, accounted for a net gain in the Studentship grade of 238.

The decease of a number of members was recorded in the *Journal* during the year; the Council was especially sorry to announce the death of an Honorary Member, Professor George William Howe, B.Sc.,

Table 2

	Considered	Honorary Member	Member	Associate Member	Companion	Associate	Graduate	Total
Direct election	632	—	7	88	—	62	280	437
Reinstatements	18	—	1	4	—	1	7	13
Transfers from other grades	495	—	31	147	—	7	139	324
	1145	—	39	239	—	70	426	774
Losses by resignation, expulsion, decease and transfer		1	6	58	1	45	166	277
Net gain in Membership		—	33	181	—	25	260	497

Ll.D., who delivered the first of the Clerk Maxwell Memorial Lectures at the Institution's 1951 Convention in Cambridge.

Future membership. During the year under review the London office dealt with 2,958 enquiries regarding membership—600 more than for the previous year. All the Local Sections in the United Kingdom and Commonwealth countries handled an increased number of enquiries. The next report of the Committee will show an even larger increase in enquiries and subsequent proposals for membership and this is a further reason why the Council is discussing the division of the Membership Committee's work.

Honours. The work of several members of the Institution was recognized by their inclusion in Her Majesty's Birthday and New Year's Honours Lists and details appeared in the June 1960 and January 1961 *Brit.I.R.E. Journals.*

Appointments Register. There has not been any increase in the number of members seeking assistance from the Register during the year, only 31 members applied for assistance and 156 introductions to prospective employers were made.

TECHNICAL COMMITTEE

The work of the Technical Committee can be divided into three parts: (1) to prepare technical reports; (2) to co-operate with other bodies, such as the British Standards Institution, on matters of standards and specifications; (3) to advise the Council and other Committees of the Institution on technical matters.

Under the first heading the Committee prepared a further report in the series "Recommended Methods of Expressing Electronic Measuring Instrument Characteristics". This was the seventh of this series and was concerned with Wave and Distortion Analysers. It will be published early in 1962. The previous recommendation in the series was concerned with Stabilized Power Supplies and was published in the February 1961 issue of the *Journal*. This series of recommendations has proved most useful and the Committee has been encouraged by the excellent co-operation received from manufacturers and users of electronic instruments who have supplied information and commented on drafts.

The British Standards Institution adopted the first report in this series as the basis of the United Kingdom submission on Signal Generators to the International Electro-technical Commission.† The Committee considering the international standardization of signal generators is still at the drafting stage.

The Technical Committee has also given a great deal of thought to the subject of reliability. Probably more has been written on the subject of reliability in recent years than on any other aspect of radio and electronic engineering and there is ample technical information available on the means by which reliability can be improved in individual components and circuits.

The Committee has therefore tried to find the best way in which the philosophy of reliability can be conveyed to radio and electronic engineers and particularly to the younger engineer entering the field of design and development. It has been decided to prepare a bibliography listing the most important papers on this subject and to preface this bibliography with a clear and concise statement of the problem and the general philosophy with which reliability should be approached.

The British Productivity Council invited the Institution to join in preliminary discussions on the subject of Quality Control and Reliability and the Chairman of the Technical Committee represented the Institution at these discussions. Subsequently a National Council for Quality Control and Reliability was formed under the aegis of the B.P.C. and the Institution is a constituent member of the National Council.

Standards. The Technical Committee maintains constant liaison with members of the Institution appointed to Committees of the British Standards Institution.

The Institution's representative on Committee TLE/5, Electronic Tubes and Valves, was invited to join the United Kingdom delegation to the International Electro-technical Commission. The Institution assisted in sponsoring this delegate and is always anxious to help in the promotion of international standards.‡

It will be appreciated that in the field of international standardization it takes longer to secure agreement than is the case with national standards. At present all drafts submitted to the I.E.C. Committees are confidential but it is the opinion of the Technical Committee that some means should be found of circulating information at the draft stage in order that the engineers may be aware of the trends and have opportunity of presenting their views.

Another matter of concern to the Technical Com-

† See *J.Brit.I.R.E.*, **19**, p. 603, October 1959.

‡ "I.E.C. Interlaken 1961", *J.Brit.I.R.E.*, **22**, p. 375, November 1961.

mittee is the absence in Great Britain of any national standards of measurement at radio frequencies. It is considered that this lack of standardization facilities could be very serious, and an editorial on the subject was published in the *Journal* during the year.† The information subsequently received by the Committee seems to indicate that the Institution, through the Technical Committee, must do more to stimulate the interest of the British radio and electronics industry in the necessity for introducing standards.

Technical Advice. The Committee has been particularly active this year in giving technical advice to Council and other Committees, largely because of the submission of evidence by the Institution to the Pilkington Committee. The main burden of this work fell on the Television Group Committee who are to be congratulated on their work in the preparation of this evidence.‡

EXAMINATIONS COMMITTEE

The policy laid down by the Education Committee is implemented by the Examinations Committee which is responsible to the Council for the holding of examinations, and the assessment of exempting qualifications. A significant development in the assessment of exempting qualifications has been the increasing number of applications for approval of courses submitted by technical colleges in Great Britain for exemption from the Graduateship Examination. Almost all colleges providing courses at an advanced level in radio and electronic engineering have submitted applications for the approval of their courses and, moreover, have consulted the Examinations Committee in advance of the introduction of any new scheme. During the year thirty-seven such applications were received, the majority being Higher National Certificate courses or endorsement subjects operated on a part-time day or evening basis. In view of the recommendations of the Crowther Committee, which were fully supported by the Institution in its report on "The Education and Training of the Professional Radio and Electronic Engineer", the fact that the applications also included four full-time diploma courses is a welcome development.

Assessment of Examination Papers. One result of the work of the Committee in the approval of courses has been the introduction by technical colleges of courses and examinations specifically designed to cover a particular part of the Institutions Graduateship Examination—usually the specialist subject. As stated in the last Annual Report, assessment of courses by the Institution started some four years ago and there are now fourteen colleges responsible for setting twenty-one question papers between them. The total number of candidates who attempted these papers in 1961 was 277. The Examinations Committee visualizes a further increase in this work, particularly if more full-time diploma courses are introduced in which the final examinations are assessed by the Institution.

The Graduateship Examination. It was to be expected that with a rising number of candidates qualifying for membership of the Institution by exempting qualifications or success in examinations conducted by technical colleges and assessed by the Institution, there would be a drop in the number of candidates entering directly for the Graduateship Examination. In fact the entries have remained virtually constant and the table opposite shows the number of entries and the results for the May and November 1960 examinations. The 1959 figures are given in brackets for comparison.

Recently there has been editorial comment in *British Communications and Electronics* and other technical journals on the small number of candidates passing professional examinations in general and the Graduateship Examination in particular. This criticism is directed at the fact that only 10% of the total number of candidates sitting the examination actually complete the examination requirements and qualify for election or transfer to Graduate membership. This poor performance is not a new experience for the Institution and successive annual reports show that the percentage of candidates fulfilling the examination requirements each year has changed very little.

The Institution has been far from satisfied with the examination results and has introduced measures from time to time to try to ensure that candidates are better prepared. However, rising standards of examination and new syllabuses tend to defeat these measures.

One difficulty is that more than half the candidates are educated and trained overseas often in countries which have very few establishments offering training of an appropriate standard. Many of the candidates have therefore not been able to attend a satisfactory course of study.

In these circumstances the number of successful candidates in *both* sections of the examination, 134 out of 408 in May 1960, was not as unsatisfactory as the comment has suggested.

† "Radio frequency standards", *J.Brit.I.R.E.*, **21**, p. 105, February 1961.

‡ "Radio and television broadcasting in Great Britain", *J.Brit.I.R.E.*, **21**, p. 379, May 1961.

Graduateship Examination Entries and Results for 1960

	May 1960	*November* 1960
Entries received	408 (435)	399 (342)
Candidates appeared	306 (346)	297 (252)
Candidates who succeeded in Section A	88 (118)	69 (52)
Candidates who succeeded in Section B	46 (118)	36 (38)
Number of candidates who by their success completed the examination requirements	49 (35)	40 (40)

The number of examination centres used throughout the world is increasing annually and, in 1960, 76 centres were established in 28 different countries. The increase is mainly due to the candidates wishing to sit the examination in isolated parts of the world and many of these centres operate for one or two candidates. The additional expense is borne by the candidates in these cases.

Exemptions. As the report of the Membership Committee shows, there has been a very large increase in the number of applications for membership, particularly for Graduate and Associate Member, and these usually involve an application for exemption from the examination. The Examinations Committee is, of course, mainly concerned with those applicants submitting qualifications which are not included in the published regulations, and these applications often involve long and detailed consideration. Nevertheless during the year 606 applications were considered, of which 247 were granted exemption from the entire examination and 297 were granted exemption from part of the examination.

Examination Prize Winners. There has been comment on the number of examination prizes that are withheld each year. During the year under review the Audio Frequency Engineering Prize, the Electronic Measurements Prize, and the Mountbatten medal could not be awarded. The terms of reference of these prizes stipulate that the award must be made to the most outstanding candidate, and the Committee has quite rightly insisted that a mere pass in an examination is not sufficient to gain a prize. Awards are only made to candidates of outstanding merit. The Council has, however, been pleased to approve the following.

PRESIDENT'S PRIZE:

Oded Smikt (*Graduate*), Israel (winner of the S.R. Walker Prize for 1959).

S. R. WALKER PRIZE:

Sushil Kumar Takkar (*Student*), India.

ASSOCIATED TELEVISION PRIZE

Wilfred Bennett (*Graduate*), United Kingdom.

Acknowledgments. The work of the Examinations Committee is aided by a large number of members of the Institution who act as examiners, assessors and visit technical colleges on behalf of the Committee. This assistance and support is greatly appreciated.

The Graduate Examination could not be held without the co-operation of the many universities, technical colleges and education authorities throughout the world who provide accommodation and arrange for invigilation. The Committee is particularly grateful to the authorities who made arrangements for small numbers of candidates in remote parts and captains of vessels at sea who provide similar facilities.

EDUCATION AND TRAINING COMMITTEE

The terms of reference of the Education Committee† are perhaps the most comprehensive of any of the Standing Committees. The Education Committee has always had the responsibility of reporting to Council on education standards and the Institution's policy in regard to improvements. These discussions and recommendations have formed the basis of several reports. The latest recommendations were contained in an Institution report published in September 1960‡. Since the publication of the report the Committee has been concerned with two main projects, the revision of the Graduateship Examination syllabus and the preparation of further reports on practical training for the professional engineer and for the technician. In order that these projects could proceed simultaneously the Council agreed to the division of the Committee into two separate panels, the Education Panel which is concerned with the academic training of the radio and

† *List of Members 1961*, p. xi.

‡ "The Education and Training of the Professional Radio and Electronic Engineer", *J. Brit.I.R.E.*, **20**, pp. 643–56, September 1960.

electronic engineer and the Training Panel which is concerned with practical training for professional status.

The Training Panel has now completed its first report on "The Practical Training of the Professional Radio and Electronic Engineer" and this will be published early in 1962. The Training Panel gratefully acknowledges the help which it received from industry and trainees, which provided the factual information on which the report was based. A second report on training, devoted to practical training for the technician, will be prepared during the coming year.

The Graduateship Examination. Previous annual reports have referred to impending changes in the syllabus of the Graduateship Examination. The new syllabuses have now been published and are the result of many meetings of the Education Panel during the year. These new syllabuses are incorporated in the twenty-eighth edition of the regulations.

A comparison of the scheme of examinations is given below showing the subjects in each of Sections A and B.

The changes in Section A will operate from May 1963 and those in Section B from November 1963.

Exempting Qualifications. The introduction of a new examination syllabus involving two new papers will have an effect on the acceptance of the present exempting qualifications. University Degrees and Diplomas in Technology with an adequate treatment of radio and electronic engineering will still carry entire exemption. However, qualifications which only just meet the present requirements such as the Higher National Certificate and endorsements and the Higher National Diploma will in many cases need amendment if they are to continue to secure the same recognition for exemption. When assessing Higher National Certificate schemes the Institution will require a greater emphasis on radio and electronic engineering subjects or additional endorsements.

The changes have been outlined in a publication entitled "The new syllabus of the Graduateship Examination and the effect on exempting qualifications" which was prepared in co-operation with the Examinations Committee.

Reference was made in the last annual report to the Telecommunications Technicians examinations of the City and Guilds of London Institute, and under the new regulations candidates are not encouraged to follow these courses if they intend to satisfy the Institution's examination requirement.

Careers Guidance. Commonwealth Technical Training Week was held in May 1961 and part of the Institution's contribution was the preparation of a booklet "Careers in Radio and Electronic Engineering" and a

Graduateship Examination

PRESENT SCHEME	NEW SCHEME
Section A	**Section A**
4 *compulsory papers to be completed in one sitting.*	5 *compulsory papers to be completed in one sitting.*
Physics I—Mechanics, Heat, Sound.	Physics I—Heat, Light, Sound
Physics II—Light, Electricity, Magnetism.	Physics II—Mechanics
Principles of Radio and Electronics	Principles of Radio and Electronics I
	Principles of Radio and Electronics II
Mathematics I	Mathematics I
Section B	**Section B**
3 *papers to be completed at one sitting.*	4 *papers to be completed at one sitting.*
Mathematics II	Mathematics II
Advanced Radio and Electronic Engineering	Communication Engineering
	Electronic Engineering
ONE *of the following specialist subjects*	ONE *of the following specialist subjects*
Applied Electronics	Industrial Electronics
Audio Frequency Engineering	Electro-Acoustic Engineering
Electronic Measurements	Electronic Measurements
Radar Engineering and Microwave Techniques	Radar Engineering
	Microwave Engineering
Radio Reception	Radio Reception
Radio Transmission	Radio Transmission
Television	Television
Valve Technology and Manufacture	Computer Engineering
	Control Engineering

wall chart showing career routes via the various qualifications. These were prepared by the Education and Training Committee and copies were distributed to the many exhibitions featuring radio and electronic engineering throughout the country.

Careers guidance is a growing part of the Institution's routine work. Enquiries are received from Youth Employment Officers, careers masters and boys, apart from organizers of exhibitions, careers forums and similar events at which the Institution is often represented. As far as possible, every request for a representative of the Institution to attend a careers meeting is met either by the Education Officer or a member of the Education or Examinations Committees. In all this work the booklet and wall charts have proved most valuable.

Co-operation with Colleges of Technology and Technical Colleges. Without the assistance and active co-operation of Technical Colleges and Colleges of Technology, the Institution's efforts in the field of education and training would be of little consequence. The Institution has always been fortunate in its good relations with technical colleges, and since the beginning of the Institution's activities there have been colleges which prepared students for the Graduateship Examinations or ensured that their courses met the Institutions requirements for whole or part exemption.

The Future of Higher Education. The appointment of a Government Committee, "to review the pattern of full-time higher education" and advise on its long-term development is a matter of great interest to engineering Institutions. Although the Committee has been specifically asked to cover universities and colleges of advanced technology, enquiries will also cover other advanced work in technical education. The Chairman of the Committee is the Rt. Hon. Lord Robbins, C.B., Professor of Economics at London University.

The Education Committee has given preliminary consideration to the evidence which the Institution might submit and further details will be given in the next Annual Report.

Meetings on Education. Programmes of meetings in London and the Sections have often included papers and discussions on the various aspects of the education of the radio and electronic engineer. There has, however, been no regular arrangement of this nature. The Council has decided that this situation should now be rectified and has agreed to the establishment of an Education Group.

The Education Committee has as one of its terms of reference the holding of meetings and the encouragement of papers on education and training and the Council has agreed that the Committee should undertake the duties of the Education Group Committee.

LIBRARY COMMITTEE

During the year there were accessions to the Library of 173 new textbooks and 62 bound volumes of periodicals. In addition, members made donations of a number of back issues of periodicals. Some of this material is of historical value and is included in the recently formed historical section of the Library.

Once again it must be reported that the accessions are being limited because of present pressure on available Library space, even though during the past five years the shelf space has been doubled.

Apart from adding new books and replacing old volumes, 225 different periodicals are now taken regularly, many of which are bound. The stock now stands at some 2,600 catalogued books of which 800 are bound volumes of periodicals. Unfortunately it is difficult to display Government publications and reports, reprints of papers, B.S.I. specifications, etc., so that they are easily accessible for quick reference but as soon as more space becomes available, a suitable system will be adopted.

With such a continually expanding subject as radio and electronics engineering it is important that new editions of existing volumes should be purchased, together with as many newly published books as possible. This is a matter which is regularly considered by those responsible.

Among the new periodicals now taken in the Library are the *Journal of Scientific Instruments*, *British Journal of Applied Physics*, *Journal of the Acoustical Society of America*, *Communications and Electronics* (*Trans. AIEE*), the *I.R.E. Convention Record*, and the *IRE Wescon Convention Record.* All these periodicals have been in demand for some time now and have previously had to be borrowed from other libraries.

Library Handbook. Present stocks of the Library Handbook are now almost exhausted and work has commenced on a revised edition of this useful publication.

Loans. A total of 1,397 items were loaned from the Library during the year. Of these 346 were sent through the post, and the remainder were borrowed by personal callers. A request is made that members who borrow by post should refund postal expenses. Periodicals form about one-third of the items loaned each month, and in some cases the demand for these is stimulated by the regular publication of abstracts from papers of interest appearing in foreign periodicals and published in the Institution's *Journal* under the heading "Radio Engineering Overseas".

Technical Information and Bibliographies. Quite apart from the requests for the loan of books, numerous enquiries are received for information on particular subjects. These inquiries invariably require a search through the literature to find appropriate papers and other references. This type of research occupies a good deal of the time of the library staff. More detailed inquiries call for the preparation of a bibliography, and an example of this is the assistance given to the Technical Committee in its work on Reliability. Several letters expressing appreciation of the service given by the library staff have been received from members and other inquirers.

Co-operation with other Bodies. In the last Report mention was made of the intention of the National Foundation for Educational Research to publish a quarterly bibliography of articles on technical and commercial education. The Institution is a contributing organization and regularly scans periodicals for papers which are suitable for inclusion in the bibliography. The first number of "Technical Education Abstracts", covering September–December 1960, has now been published and will be followed by regular quarterly issues.

There is a great deal of co-operation with other libraries and the Institution's Library provides assistance to many other technical libraries. In return, Institution requests for loans and information have been most helpfully met by such organizations as the G.P.O., Ministry of Aviation, Science Library, Aslib, and other technical libraries not omitting libraries in industry.

PROGRAMME AND PAPERS COMMITTEE

(including the Specialized Group Committees)

The last year has seen still further extension of Institution activity in arranging meetings and publishing technical papers, responsibility for which forms the main task of the Programme and Papers Committee.

The planning of the 1961 Convention on "Radio Techniques and Space Research" took place during the latter half of the year and during this period the Programme and Papers Committee and the Specialized Group Committees assisted the separate Convention Committee. The report on the Convention will appear in full in next year's Annual Report, but interim information on the four-day meeting has appeared in the August and September 1961 *Journals.*

Institution Meetings in London. In achieving a record number of meetings held during the 1960–61 session the Programme and Papers Committee has been greatly aided by the Committees of the five Specialized Groups whose contributions to the Institution's proceedings have now given a completely different "look" to the Programme Booklet. Throughout the session there was, on average, an Institution meeting in London every week from the end of September to the middle of May.

During the year the Council authorized the establishment of the Electro-Acoustics and Television Groups who held their inaugural meetings in October 1960 and March 1961 respectively. The organization of ten meetings by these two Groups, together with meetings sponsored by the Medical and Biological Electronics Group, the Radar and Navigational Aids Group and Computer Group, and those meetings covering a wider field arranged by the Programme and Papers Committee, gave a total of 32 individual meetings. This figure includes several symposia which consisted of more than one session, so that 46 meetings gives a more realistic idea of the magnitude of the year's activity. Attendances at the evening meetings during the session averaged nearly 80, while the six major symposia attracted average audiences of over 230.

The most ambitious meeting during the year was that on "New Components" which lasted for two days and attracted over 400 engineers—a small convention in fact. Comparable success was achieved with the half-day symposia which dealt with, for instance, Alpha-Numeric Display Devices and Computer Control of Air Traffic; two other meetings describing the application of electronic instruments to two widely different fields—"Nuclear Power Stations" and "Cardiac Surgery"—gave ample evidence of the value of Institution meetings in providing a forum for discussion with workers in other fields. The Symposium on "Electronic Instruments for Cardiac Surgery" is worthy of special mention as it was arranged jointly by the Medical and Biological Electronics Group and the Post-Graduate Medical Federation of the University of London and took place at the Post-Graduate Medical School, Hammersmith. This was the first meeting of its kind at which members of the medical and engineering professions met in a hospital in this country, and the attendance of 400 is a measure of its success.

Another joint meeting was that arranged in collaboration with the Electronics Group of the Institute of Physics and the Physical Society on "Tunnel Diodes". The interest shown both by the physicists and radio engineers in this new device was demonstrated in the attendance of over 300 members of both bodies.

Section Meeting in Great Britain. The session saw the establishment of the ninth local section in Great Britain—the Southern Section which meets in Southampton, Farnborough and Portsmouth. This Section made a very successful start and during its first year held eight meetings.

In October 1960 the South Western Section held a well-attended one-and-a-half day Convention on "Aviation Electronics and its Industrial Applications". Meetings on a similar scale have been held in the past by other Sections but the South Western Section is to be congratulated on arranging a function of this magnitude so early in its life—the Section was founded in 1958.

The other Sections have all held more meetings during the session compared with the previous year and the total of over 75 meetings shows how active the Local Section Committees have been. On numerous occasions assistance in obtaining papers on particular subjects has been given by the Specialized Group Committees. Section programmes demonstrate that the aim of their Committees is to cater both for local interests in the radio and electronic industry and to provide more general papers in other fields; in this latter respect the assistance of the Groups has been especially valuable.

Sections Overseas. Institution Sections now operate in four continents outside Europe and local chairmen all report steady progress during the year. The growth of the radio and electronics industry in India, New Zealand, Pakistan and South Africa has facilitated the planning of programmes of papers and discussions to meet local requirements. The co-operation of engineers from the United Kingdom in making contributions at short notice when visiting these countries is always appreciated.

The Montreal and Toronto Sections have continued to consolidate their work. Several useful meetings have been held and it is expected that the next Annual Report will record further progress in Canada.

Plans for increasing Institution activity in India have been the subject of discussions with the Chairman of the Indian Advisory Committee, Major General B. D. Kapur, the Council and the Programme and Papers Committee, and it is hoped to arrange a Convention in Delhi or Bangalore in the early part of 1963.

Other discussions have taken place at Institution headquarters with members from other parts of the world regarding the setting-up of additional local sections. In considering such proposals the Council has to be quite sure that the number of corporate members in the proposed section area is sufficient to provide a strong committee.

Consideration of Papers. Arising out of their considerable contribution to the programme of meetings, the Specialized Group Committees have been able to assist the Programme and Papers Committee in procuring a greater number of papers for consideration for publication in the *Journal* than has been previously recorded. During the year 110 papers were considered by the Committee, and out of this total 77 were accepted either as submitted or with comparatively minor amendments. Two-thirds of the remaining papers were returned to the authors requesting revision, and a number of these have been re-submitted and subsequently published. Only about ten per cent of papers received by the Institution were judged to be completely unsuitable. The total number of papers does not include any papers intended for the 1961 Convention. The Papers Committee is considerably encouraged by the fact that the standard of papers submitted for publication has been maintained and indeed increased.

The Journal. In the latter part of 1960 the Council took the decision to enlarge the format of the *Journal* with effect from the January 1961 issue and to divide the year's issues into two volumes. That this was a step which had become due may be seen from the size of Volume 20 for 1960, namely 952 pages plus index. The change from a page size of $10\frac{1}{4}''$ by $7\frac{1}{2}''$ to $11''$ by $8\frac{1}{2}''$ brings a number of advantages, for instance, an increase of one-fifth in editorial content per page and better opportunities for presenting large and complicated circuit diagrams. At the same time several changes were made to the general layout including the adoption of a more distinctive cover. The appearance of the new *Journal* has drawn many appreciative comments from both members and subscribers.

One of the *Journal*'s most important functions is to keep members in touch with Institution affairs and this has been emphasized during 1960 and the first half of 1961 by the publication of more "News from the Sections". News items on matters of engineering, scientific and educational interest have appeared regularly.

Advertising revenue which plays an important part in supporting the heavy and always increasing costs of printing, paper and distribution has shown a small but encouraging rise. One of the advantages which was gained by adopting the larger format has been to enable advertisers to use the standard size advertisement blocks and a feature of the *Journal* in its new form has been an increase in the use of colour.

The History of the Institution. In support of the Institution's Petition for a Royal Charter of Incorporation, the history of the Institution was published under the title of "*A Twentieth Century*

Professional Institution—The Story of the Brit.I.R.E.". This work appeared in June 1960 and in describing the growth of the Brit. I.R.E. it throws an interesting light on the parallel growth of the radio and electronics industry.

Institution Premiums. Following the generous endowment of new Institution Premiums last year and the establishment of three additional Institution awards, the Council had available 15 Premiums and Awards for outstanding papers for 1960. Seven of these are to be awarded and full details were given in the September 1961 *Journal.*

Co-operation with the Australian I.R.E. The friendly relations with the Institution of Radio Engineers of Australia have continued during the year. Under the mutual agreement for the reprinting of outstanding papers from each other's proceedings, the Fourth Clerk Maxwell Memorial Lecture, "The Human Aspect of Engineering Progress" by Dr. Vladimir K. Zworykin (first published in the *Brit. I.R.E. Journal* for September 1959) has appeared in the *Proceedings* of the Australian Institution.

In 1960 it fell to the Brit.I.R.E. to adjudicate on the award of the Australian Institution's Norman W. V. Hayes Memorial Medal for 1959. This pleasant task is undertaken in alternate years with the I.R.E. (America), and the Brit.I.R.E.'s recommendation was that A. J. Seyler and C. R. Wilhelm, authors of the paper "A Video Transmission Test Set for Steady State and Time Response Measurements," published in *Proc.I.R.E. Aust.* for February 1959, be awarded the Medal.

Acknowledgments. Until the Institution acquires its new building with lecture theatre, London meetings will continue to be held in the lecture theatres of London University. The co-operation which has been given by the London School of Hygiene and Tropical Medicine, where Institution meetings have been held for some fifteen years, and by University College, London, The School of Pharmacy and Birkbeck College is greatly appreciated by the Council.

Local Sections in Great Britain and Overseas hold meetings in many lecture theatres, most of them associated with educational establishments. The Council wishes to thank the authorities of those organizations who make such helpful contributions to the Institution's activities.

Finally, the Council thanks the editors of many technical and scientific journals for co-operating during the year by including in their publications notices and reports of Institution meetings and other activities.

FINANCE COMMITTEE

The auditors' report covering the revenue account and Balance Sheet for the year ended 31st March 1961 was reproduced and commented upon in *J.Brit.I.R.E.* December 1961 (pp. 450 *et seq.*).

Arising out of the last Annual Report,† an Extraordinary General Meeting of the Institution was held on 7th June 1961, but the full effect of the resolutions taken at that meeting will not be felt until the year 1962–63. Stringent economy has therefore been essential in the Finance Committee's efforts to balance expenditure with income.

The revenue shewn in the present accounts reflects continued Institution expansion. Whilst it must be expected that such growth necessarily involves increased expenditure, the Committee again comment upon the very considerably enhanced costs of materials and external services, particularly printing. It is hoped that there will in future be a reduction in the *rate* of increase in the basic costs of supplies and services, thus making it easier to budget. Notwithstanding difficulties caused by these heavy increases in necessary expenditure, the accounts show that it was possible to make a small addition to the Reserve Account.

The retiring Finance Committee recommend the adoption of the accounts—the last to be prepared under the provisions of incorporation under the Companies Acts 1929 and 1948.

† *J. Brit.I.R.E.*, 20, Page 901, December 1960.

U.D.C. 621.039: 621.311: 621.317

Instrumentation at Berkeley Nuclear Power Station

By

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AND

M. W. JERVIS, M.Sc.Tech.†

Presented at the Symposium on "Electronic Instrumentation for Nuclear Power Stations" in London on 29th March 1961.

Summary: From the shut-down power of about 10 watts upwards neutron flux instrumentation is used for reactor power measurement and to operate safety trips. At high powers, control and protection is based on temperature measurements (fuel element, channel gas, graphite etc.). Selected fuel element temperatures can shut down the reactor, others being recorded by multi-point recorders and automatic loggers. The shut-down initiating devices shut down the reactor only if at least two out of the three give a trip signal. The system of faulty fuel element detection employs an automatic logger which computes averages, giving discrimination between random and significant rises in CO_2 gas activity. Equipment is also provided for the detection of leaks between steam and CO_2 circuits; in addition radiation activity in and around the station is monitored. Gas and steam flows are measured and the data transmitted by a pneumatic system. The display equipment for the major instrumentation is centralized in or near the station control room.

1. Introduction

The control of nuclear reactors both manual and automatic is achieved by means of a system of instrumentation, the general principles of which have been discussed in many publications.[1-3] The following paper is restricted to a more specific account of the equipment installed at the Berkeley Power Station, which is being constructed for the Central Electricity Generating Board.

A general description of the design of the station has been given by Ghalib and Southwood[4] and the safety aspects considered by French and Yellowlees.[5] However, in order to assist in providing a background to the instrumentation, the following are some relevant details of the station:

Number of reactors	2
Number of boilers per reactor	8
Nett heat output per reactor	555 MW
Gross electrical output per reactor	160 MW
Fuel element temperature (maximum)	475°C
Fuel element temperature (design)	427° C
Reactor gas inlet temperature	160° C
Reactor gas outlet temperature	345° C
Mass flow through core	6000 lb/second
Coolant gas working pressure (inlet)	125 lb/in^2
H.P. steam pressure (at turbine)	310 lb/in^2
H.P. steam temperature (at turbine)	319° C
L.P. steam pressure (at turbine)	72 lb/in^2
L.P. steam temperature (at turbine)	315° C

† The Nuclear Power Group, Knutsford, Cheshire.

The control of the station is effected from a central control room common to the two reactors and illustrated in Figs. 1 and 2. This control room contains the control desk which is fitted with instruments and controls required for minute to minute operation. The desk is surrounded by vertical panels which contain instrumentation for longer term recordings and major control operations. The arrangement of the desk is illustrated in Fig. 3.

Instruments associated with the safety circuits and certain other equipment, such as temperature loggers, are mounted in the apparatus room which is adjacent to the control room as shown in Fig. 2. This room is air conditioned, maintaining a dust-free temperature controlled atmosphere to give good operating conditions for the equipment.

In the design stage, it was decided that where possible, equipment and techniques would follow U.K.A.E.A. experience suitably modified for industrial use. In the case of the nuclear channels, instruments designed and manufactured to U.K.A.E.A. standards are used, modifications being kept to a minimum, so that they closely resemble equipment having previous field experience. In other cases, for example, automatic data loggers and temperature trip units, no suitable equipment was available and new instruments had to be developed.

Many of the techniques are based on Calder Hall experience, modifications being incorporated where appropriate to allow operations to be performed with fewer staff than is usual in the case of U.K.A.E.A. reactors.

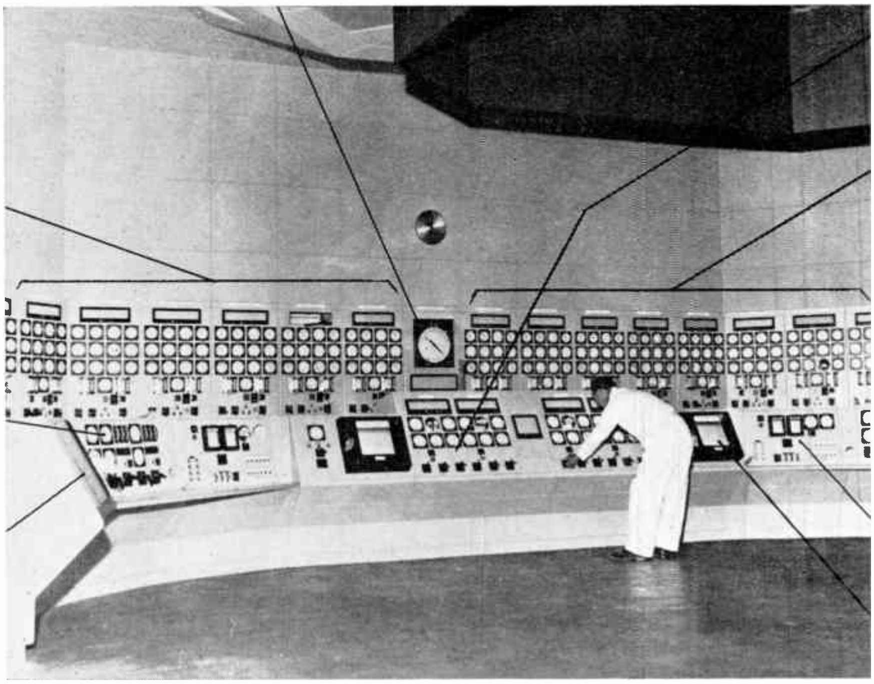

Fig. 1. View of the central control room.

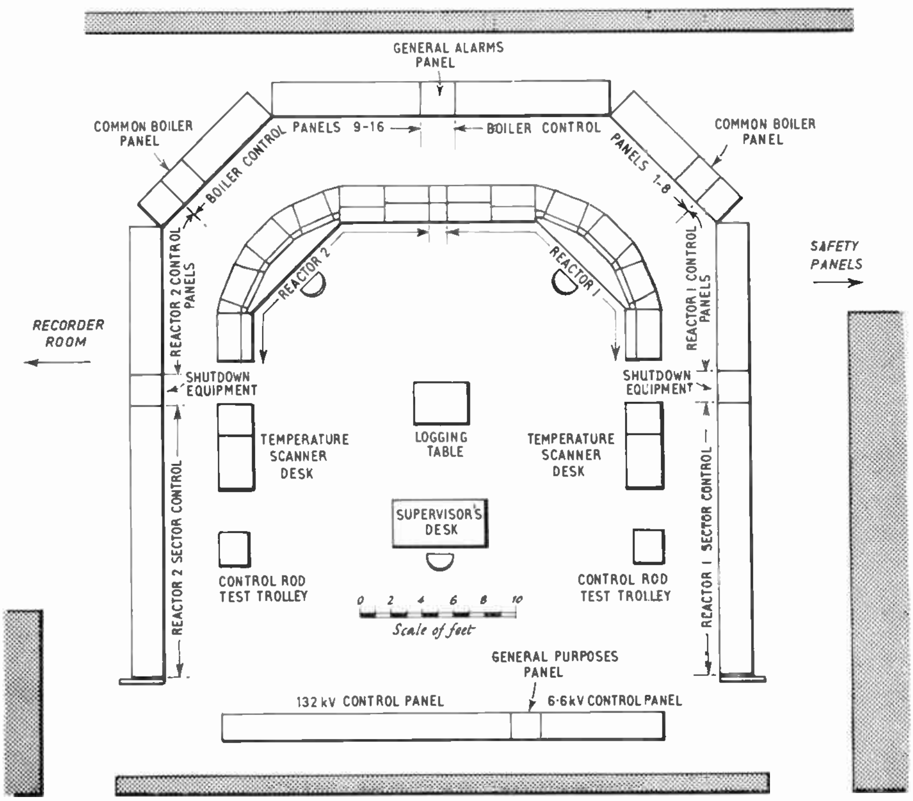

Fig. 2. Layout of central control room.

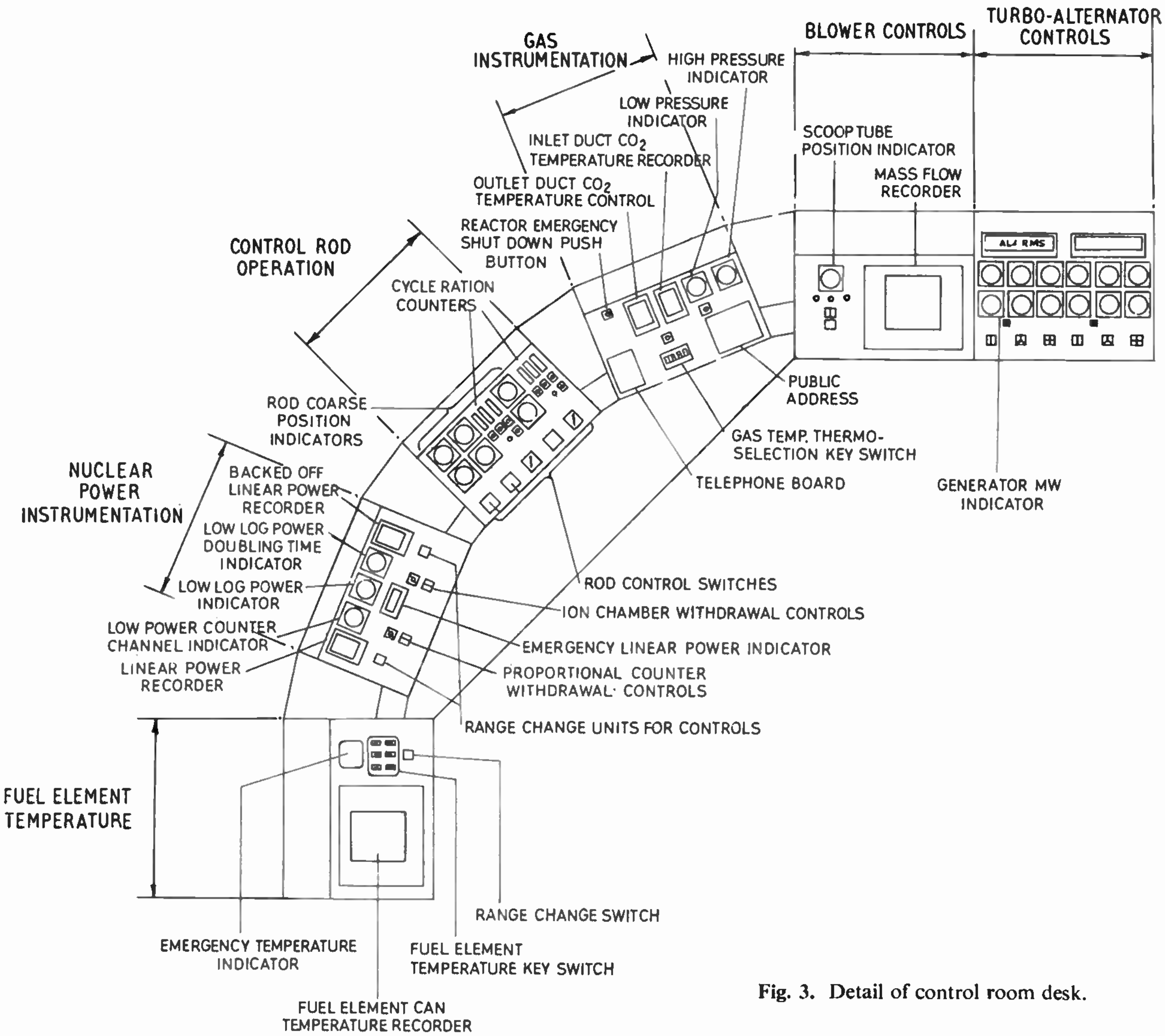

Fig. 3. Detail of control room desk.

2. Nuclear Instrumentation

2.1. *The Measurement Problem*

A notable characteristic of nuclear power plants is the large range of powers which must be monitored between full power and shut-down. For example, a power plant might have a full power rating of hundreds of megawatts but when shut down, its power would be a few watts. This amount of power might be considered completely negligible but facilities must be provided for monitoring it since even 10 watts represents a large number of neutrons. If a fault occurred in which these numbers were allowed to multiply, the power might increase and damage the reactor if no monitoring system were present to give automatic protection.[1–3]

We therefore have the fundamental concept that neutron levels must be monitored at all times and at all powers. Near full power the reactor is controlled from signals derived from temperature measurements but this method is clearly not applicable at shut-down power levels of the order of watts.

In general, the fission rate is the most useful indication of reactor power for indication and protection purposes. The fission rate is proportional to the neutron flux in the reactor and this is deduced from measurement of neutron flux leaking from the side of the core. Since this flux has a large fast component to which the neutron detectors are relatively insensitive, a block of graphite known as a thermal column is used to reduce the neutron energy to thermal levels. For a centre core thermal neutron flux of 2×10^{13}n/cm^2/s at full power, a thermal column flux of the order of $10^9 - 10^{10}$n/cm^2/s is expected.

At Berkeley one main column and two auxiliary columns are used, spaced at angles of approximately

120 deg. By measurement of the neutron fluxes in them, an indication of non-uniform distribution of flux can be obtained, and automatic safety action taken if necessary.

In the absence of artificial neutron sources, the reactor flux at shut-down originates from spontaneous fission and cosmic ray effects. These represent a power of the order of milliwatts, a level which cannot conveniently or reliably be measured by the thermal column instrumentation.

This power level can be raised to one which enables the equipment to give satisfactory results by installing an artificial neutron source. At Berkeley this is of the antimony beryllium type in which the antimony is activated by the neutrons in the reactor during previous operation and at shut-down continues to emit gamma rays with a half life of 60 days. The gamma rays interact with the beryllium to give neutrons corresponding to a power level of a few watts.

The full power rating of the reactor is 550 MW thermal and it can be seen that, for a source power of 5 watts, a range of about 10^8 must be covered between shut-down and full power.

In the thermal column there is a 3 : 1 ratio between the flux at front and back of the instrument holes and the position of the detector can be chosen to give a flux to suit the calibration of the measuring channel. Typically the position of the ionization chambers is chosen to give a current of 50 μA for full reactor power.

Two types of detectors are used.[1, 3] At the higher power levels and with the wide range channels the flux is measured by boron-type ionization chambers and at lower powers, boron trifluoride (BF_3) proportional counters are used. Details of the components of the channels are given in Table 1.

2.2. *Linear Power Measurements*

Two single-point 10-in. potentiometer recorders are fitted in the central control room and record the reactor power on linear scales. The information is retransmitted to 3-in. recorders mounted on the reactor control desk and is printed out by the low speed temperature scanners to be described in Section 3.4.

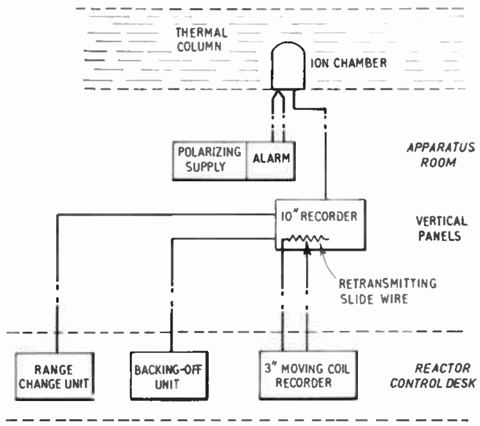

Fig. 4. Block diagram of backed off linear power channel.

One recorder has ranges 0–7, 0–70, and 0–700 MW. The other has a backing-off supply so that small deviations from a pre-set power level are indicated and recorded. The backing-off supply has a range corresponding to 0–699 in 1 MW steps and the instrument has three ranges, 5–0–5, 50–0–50, 500–0–500 MW. The scheme is illustrated in Fig. 4.

Table 1

Nuclear Power Measurements

Channel	Detector (Basic A.E.R.E. Design Ref. No.)	Thermal Column		Instrument Basic A.E.R.E. Design Ref. No.	Display		Trip Action
		Main	Aux.		Panels	Desk	
Linear power	RC7	1	—	—	10″ recorder; logger	3″ recorder	
Backed-off linear power	RC7	1	—	—	10″ recorder	3″ recorder	
Low log power	RC7	3	—	1389	10″ recorder (power)	Indicator (power doubling time)	Short doubling time; intermediate power
Main log power	RC7	1	2	1389	10″ recorder (power)		Short doubling time
Excess flux	RC7	3	6	1520	Trip margin		Excess flux
Pulse counter	12EB40	2	—	1515 & 1508	10″ recorder	Indicator	High count rate Low count rate

The ionization chambers are fitted in the main thermal column. The chambers are similar to the A.E.R.E. RC7 type and are polarized by transistorized power units, having stabilized d.c. outputs of 600 V. The presence of the polarizing voltage is checked by a "tell-tale" lead and an alarm and trip is initiated if the correct voltage does not reach the chamber.

A moving coil indicator is connected in the linear power circuit which gives an indication of reactor power range 0–700 MW, even in the event of failure of mains power supplies to all the equipment.

2.3. *Logarithmic D.C. Channel and Periodmeter*

Logarithmic d.c. channels are fitted to provide, over a range of power which overlaps the pulse counter channel, measurements of power, intermediate power trips and doubling time protection.

Three of these, known as the low log channels are intended to cover the lower end of the power scale. These are arranged to give a lower operating current limit at a power level which is below the upper limit of the pulse counting channel (Section 2.5).

Each channel has a mean current ionization chamber followed by a logarithmic d.c. amplifier of the type described by Gillespie,[2] the components being detailed in Table 1. The ionization chamber is polarized by a stabilized transistorized d.c. power unit.

The range covered by mean current ionization chambers is limited by ionization currents due to gamma irradiation and to activity induced in the chamber materials. The effect of gamma irradiation is reduced by lead shielding thimbles in the thermal column and the chamber activity is minimized by withdrawing the chambers into the biological shield at powers above the range 10–20 MW.

The output of the amplifiers is displayed on indicators and also on a 10-in. single pen recorder which can be switched to the output of any amplifier. In addition to this, the signal from the logarithmic amplifier passes into a differentiating circuit, the output of which gives a signal inversely proportional to reactor doubling time with a range -80 to ∞ to 20 seconds. This is used to initiate trips and alarms and an indicator can be switched to each channel. A trip unit is also fitted providing a power trip function.

A further three channels known as the main log channels are arranged to cover the power range from full power downwards. These are similar to the low log channels except that they are not withdrawn or provided with lead shielding.

The ionization chambers of the three low log channels are fitted in the main thermal column and initiate intermediate power and period trips on a 2-out-of-3 basis. One chamber for each of the three main log channels is fitted to each thermal column. These also give protection on a 2-out-of-3 basis. (See Section 5.)

2.4. *Excess Flux Shut-down Amplifier Channel*

Protection against the reactor power reaching an abnormally high level is provided by excess flux shut-down channels. Ionization chambers and polarizing units are of the same type as described in Section 2.2 and the output of the chambers feed shut-down amplifiers which are basically similar to the A.E.R.E. 1520 type. These operate on the a.c. principle described by Gillespie[2] and have indicators displaying the trip level over the range 0–750 MW and trip margin (range 0–50 MW). The trip level is adjustable from the central control room and alarms are given for low or high trip margin and excess flux. Thus any failure or maloperation of the equipment is drawn to the attention of the operator.

The total of nine ionization chambers and amplifiers provided are distributed three to each thermal column. The trip contacts are connected into the safety system described in Section 5 so that a reactor trip is initiated on a 2-out-of-3 basis for a rise in neutron flux at two of three ionization chambers in any thermal column. This gives protection against a localized rise in flux associated with one thermal column.

2.5. *Pulse Counting Channel*

As pointed out in Section 2.1, the reactor power must be measured at all times including shut-down. Under these conditions the fission power of the reactor is in the region of watts and about 10^{-8} of the full power. At such power levels the neutron flux in the thermal column is too small to be accurately measured by ionization chambers, due to the difficulty of measuring small currents and interfering effects due to gamma rays. These originate from isotopes of long half life and so persist after the reactor is shut-down. It then becomes more appropriate to use neutron sensitive counters which have a higher sensitivity and to which pulse height discrimination can be applied to reduce the effects of gamma rays.

The counter channels employ the components listed in Table 1. Two detectors of the BF_3 proportional counter type are fitted on carriages in the main thermal column and are withdrawn into the biological shield at powers above 10 kW to prevent unnecessary irradiation, which if excessive, causes deterioration in performance.

The counter is followed by a pulse amplifier, amplitude discriminator and logarithmic ratemeter feeding output recorders and indicators, scaled logarithmically. Alarms and trips are provided. Alarms indicate abnormally high or low count rates and the trip is arranged to initiate a reactor shut-down. This shut-down action operates on a 1-out-of-2 basis.

A trolley-mounted pulse generator and oscilloscope test system is supplied and can be used to check all parts of the system with the exception of the counter itself.

3. Reactor Temperature Measurements

3.1. *General*

Some parts of the reactor have a maximum safe operating temperature and rate of rise in temperature. A particularly important case is the fuel element sheath, the life of which is a function of temperature, and a representative sample of these must be measured. A summary of the temperatures measured at Berkeley are given in Table 2. It will be seen that the temperatures are displayed and recorded on a system of automatic data loggers, recorders and indicators. This information is used for control purposes and in certain cases excessive temperature is arranged to initiate a reactor shut-down.

The temperature of components of the reactor unit are measured by chromel-alumel and iron-constantan thermocouples. Inside the reactor vessel $\frac{1}{8}$ in. and $\frac{1}{16}$ in. diameter stainless steel sheathed mineral insulated thermocouples are used with chromel-alumel cores. Outside the vessel the sheath is of galvanized mild steel or cupro-nickel with chromel-alumel or iron-constantan cores.

The internal reactor thermocouple cables leave the vessel by pressure seals and after passing through cold junction boxes the signals emerge on copper leads and are collected in marshalling boxes in the thermocouple room. External thermocouples are treated in a similar way and are marshalled in the same room.

Cold junction compensation for the chromel-alumel copper joints is obtained by maintaining them to within $\pm 0{\cdot}1°$ C at 45° C $\pm$ 0·2° C by small thermostatically controlled ovens (9 thermocouples per oven) which incorporate suitable alarms.

The thermocouple voltage then appears on copper pairs and can be passed through a jumper field using conventional telephone terminations with a minimum of error due to stray thermal e.m.f's.

To ensure that the thermostats operate correctly their action is checked by monitor thermocouples. Departure of temperature of any oven in either direction initiates an alarm. Maximum continuity of power supply to the ovens is ensured by using the station 260 V battery supply. The jumper field gives a large measure of flexibility in routing thermocouples to measuring equipment, so ensuring the most efficient utilization of the equipment provided.

The copper wires between the marshalling boxes and central control room are in the form of twisted and shielded cable, so that the possibility of a.c. pick-up is minimized.

Table 2

Distribution of Temperature Measuring Equipment

Thermocouples		Display/Trip		
Location	Number (Total)	Number (Selected)	Type	Location
Fuel element	354	54	10″ recorders	C.c.r. annexe
		6	10″ recorder	C.c.r. desk
		48	Indicated	Reactor local panel
		36	Trip	Safety panels
		66	High-speed scanner	C.c.r.
		75	Low-speed scanner	C.c.r.
Fuel channel outlet gas	312	16	10″ recorders	C.c.r. annexe
		54	High-speed scanner	C.c.r.
		134	Low-speed scanner	C.c.r.
		108	Auto control	Temperature regulating panels
Graphite moderator	243	48	10″ recorders	C.c.r. annexe
		195	Low-speed scanner	C.c.r.
Carbon dioxide at reactor outlet	72	9	10″ recorders	C.c.r.
		16	Trip	C.c.r.
Carbon dioxide at reactor inlet	40	9	10″ recorders	C.c.r.
Reactor support grid	14		Selected number recorded	C.c.r. annexe
Test specimen containers	10		Selected number recorded	C.c.r. annexe
Graphite samples	20		Selected number recorded	C.c.r. annexe

C.c.r. = Central Control Room. N.B. Spares not indicated

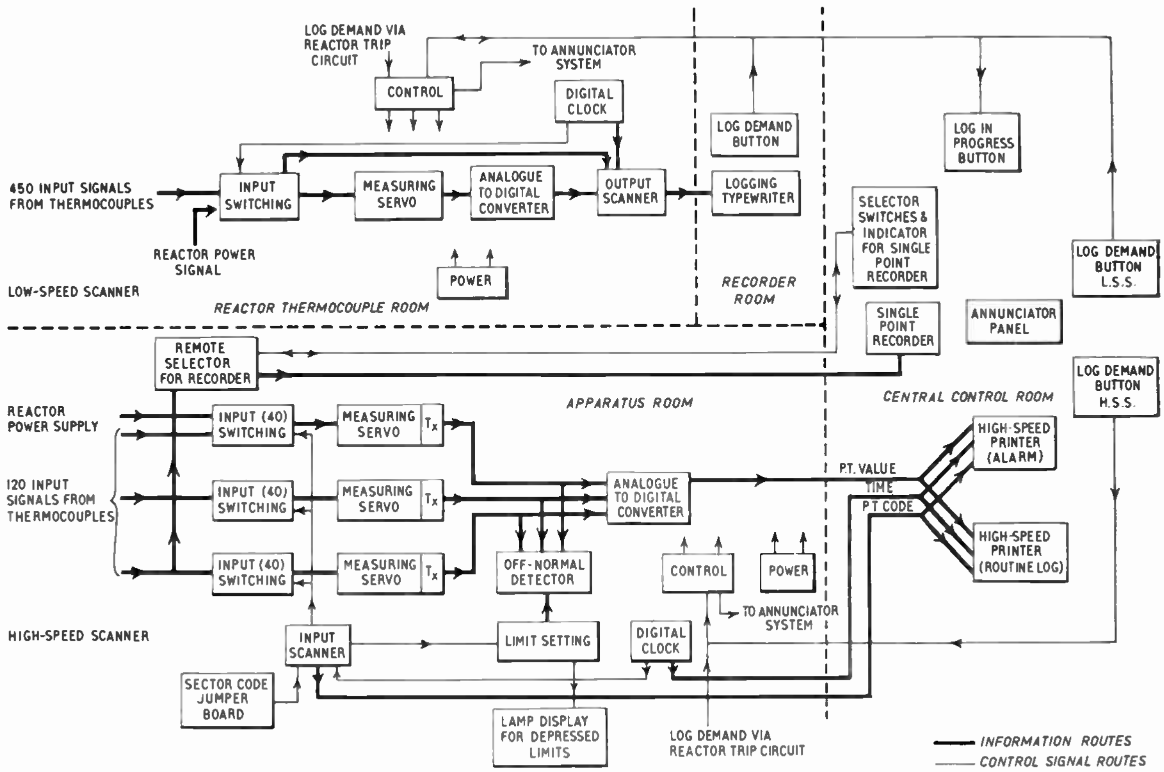

Fig. 5. Block diagram of temperature logger.

3.2. *Measuring Points*

A total of 1065 thermocouples is provided for measurements in and around each reactor and these are tabulated in Table 2.

On the fuel elements, the hot junctions of the thermocouples are formed from $\frac{1}{16}$ in. cable and fitted to the fuel element can. The majority of these thermocouples have contact assemblies which permit fuel elements to be replaced complete with new thermocouples. Two thermocouples are provided on each of these fuel elements and the cable runs through the graphite and leaves the pressure vessel via sealing plates.

Nine fuel elements are equipped with continuous (trailing) lead thermocouples which are normally used to feed the excess temperature trip units.

Measurements are taken on the fuel elements at the plane of highest temperature (2nd fuel element from top), that of maximum Wigner energy storage† and in six channels where nine of the thirteen fuel elements have thermocouples. The latter give an indication of the axial distribution of temperature.

The temperature of the gas leaving some fuel element channels is measured by fixed thermocouples, some being used for record purposes and others in the overall automatic reactor control system. Temperature measurements of graphite moderator are made by similar thermocouples. Outside the pressure vessel other types are used as detailed in Table 2.

3.3. *Temperature Recorders*

Recording and indication of thermocouple temperatures are provided by single and multi-point 10-in. scale potentiometric recorders mounted on the control room desk or vertical panels in the central control room.

The multi-point recorders are mostly of the 8-point type with a scanning time of 5 seconds per point; the single point recorders have a response time of about 1 second full scale. Both types employ stable mains driven slide wire supplies so that standardizing is required only at intervals of about 1000 hours. The recorders have slightly non-linear slide wires to correct for thermocouple non-linearity and in some cases contacts are provided for alarm initiation.

† Wigner energy storage: After nuclear irradiation, the crystal lattice of graphite suffers dislocations which have the effect of energy storage. This energy can be released by a relatively small rise in temperature and if the energy stored is large the subsequent rise in temperature may be high. The maximum energy storage occurs in graphite operating at temperatures and neutron fluxes existing near the bottom of the reactor.

On the control desk a single point recorder can be switched to measure any one of a group of six fuel element temperatures which are normally the hottest. A galvanometer type indicator which operates independently of mains supply is also fitted.

3.4. *Automatic Temperature Loggers*

In addition to the recorders, one low-speed and one high-speed logger are provided per reactor.[3] The high-speed logger gives print-out facilities in the central control room and the low-speed logger has its printer in the recorder room.

The low-speed logger is installed in the thermocouple room near the reactor and has an input capacity of 450 points. The temperature of this number of thermocouples is printed out "on demand" or at preset intervals, the speed of scan being 2·5 seconds per point.

Since the recorders do not provide alarms with individually set alarm levels, high temperature alarms on selected thermocouples are initiated by a high-speed logger which scans 120 points in 2 minutes and compares the temperatures of each point with preset limits, as illustrated in Fig. 5. When a point is off normal an alarm and print-out is initiated in the control room. Routine or "on demand" print out of the 120 points is given on another printer. The high-speed logger is fitted in a room adjacent to the control room.

A typical allocation of thermocouples to high- and low-speed loggers is given in Table 2. Both high- and low-speed loggers employ relay type scanning systems. The thermocouple output is amplified by a servo balance unit with a re-transmitting slide wire. The output of this slide wire is then digitized by a transistor analogue-digital converter using the voltage balance principle.

3.5. *Temperature Trip Units*

Certain fuel element thermocouples are required to initiate a reactor shut-down if their temperature rises above a pre-set value. The signals from these thermocouples, after passing through the cold junction and marshalling boxes, are connected by copper leads to trip units.

In the trip unit, the thermocouple signal is compared with a trip level adjustable over the range 0–750° C. The difference between this pre-set voltage and the thermocouple voltage is amplified by a d.c. amplifier using a transistor d.c.–a.c. modulator. The amplifier output feeds indicator and trip circuits, the indicator reading trip margin having a range of 0–50° C. The units operate an alarm for low trip margin, adjustable over the range 5–50° C. For zero trip margin, relay contacts operate into the reactor safety system.

The trip unit has a high degree of failure-to-safety, an alarm or trip being given for internal faults. It also is sufficiently insensitive to common mode or series a.c. pick-up to render negligible the probability of spurious trips or loss of accuracy from this cause.

4. Telemetering

As in conventional power stations, it is necessary to transmit measurements of the more important plant pressures and flows to the central control room. In the case of nuclear power stations it is also necessary to monitor coolant gas conditions in addition to steam and water.

Two transmission systems are available, using pneumatic or electric transmission, the characteristics of the two being discussed elsewhere.[3, 6]

4.1. *Pneumatic System*

Two independent air supplies, one for each reactor, are provided, each having main and standby compressors driven by 30 h.p. motors. These compressors feed reservoirs capable of storing sufficient air to give 20 minutes operation. The output of the transmitters is 3–15 lb/in^2 and is fed to the central control room by $\frac{1}{4}$ in. copper pipes combined into a multi-channel pipe, in a p.c.p. sheath. This piping runs in the cable tunnel with the electrical cables and is treated as normal cabling.

The pneumatic system is used for the transmission of plant pressures and flows with the exception of the main duct flow. The system is detailed in Table 3. Where an electrical alarm is required to be initiated, a simple pressure switch is used on the 3–15 lb/in^2 air line. A reactor trip facility is required for rate of fall of reactor pressure. This signal is obtained from a differential pressure transmitter connected across a restrictor between the reactor and a gas reservoir.[7] The air output from the transmitter operates a pressure switch connected in the safety system, the system being triplicated to enable it to be used in a 2-out-of-3 system. Each transmitter is backed up by a fast-operating differential pressure switch connected directly into the gas circuit. This pressure switch has contacts which are also connected in the safety system.

4.2. *Electrical Telemetering System*

In some cases electrical transmission is considered more suitable, e.g. the use of thermocouples or resistance thermometers provides a simple electrical system.

Electric transmission is also used for the duct mass flow, as a flexible method of flow summation and recording and of individual flow indication is required. Electric force-balance differential pressure transducers are used to measure the pressure drop across the outlet nozzle where the ducts leave the reactor pressure vessel. This pressure drop is proportional to the square of the gas flow. The transducer is operated with the balance electromagnet in series with the balance coil[3, 6] so that the current is proportional to the square root of the differential pressure, i.e. gas flow.

The transducer output current is available for individual flow indication and for initiation of alarm and safety action in the event of the flow falling below a pre-set value. A signal proportional to summated flow is obtained by a resistor mixing network and this

Table 3

Gas and Steam Circuit Instrumentation (Excluding non-transmitted quantities)

Pressure Measurements

Quantity	Transmitted	Indication and Recording			Number per Reactor
		Tapping point	Local panel	Central control room	
Pressure vessel (dome)	PN.P	PG	—	ER	1
Pressure vessel (boiler outlet)	PN.P	PG	PG	PG	8
Feed water main	PN.P	PG	PG	PG	2
L.p. drum	PN.P	PG	PG	PG	8
H.p. drum	PN.P	PG	PG	PG	8
L.p. outlet steam	PN.P	PG	PG	—	8
H.p. outlet steam	PN.P	PG	PG	—	8
Distilled cooling water	PN.P	PG	PG	—	2
Distilled cooling water booster	PN.P	PG	PG	—	2

Differential Pressure Measurements

Across gas circulator	PN.DP	DPG	PG	—	8
Across gas circulator seal	PN.DP	DPG	PG	—	8

Flow Measurements

L.p. water	OP + PN.DP		PG	PG	8
L.p. circulator pump	OP + PN.DP		PG	—	8
H.p. water	OP + PN.DP		PG	PG	8
H.p. circulator pump	OP + PN.DP		PG	—	8
CO_2 mass flow	Nozzle + EDP	M	EI	ER, EI (1 only)	8

Level Measurements

L.p. drum	PN.DP	M	PG	PG	8
H.p. drum	PN.DP	M	PG	PG	8
Blower seal drain	Capacitor	—	EI	—	8

Rate of Change of Pressure

Pressure vessel	PN.DP	PG	PG	—	3

Abbreviations: PN = pneumatic, OP = orifice plate, M = manometer, DP = differential pressure, R = recorder, P = pressure, E = electrical, PG = pressure gauge, I = indicator is fed to a common 10-in. potentiometric recorder mounted on the control desk. The outlet nozzle is calibrated during commissioning of the plant by means of a standard orifice which is afterwards removed.

5. Safety Systems

5.1. *General*

The reactor is protected by a combination of mechanical and electrical systems which ensure that if a condition arises which might damage the plant, the reactor is shut down.[3] Only the electrical features will be mentioned here, the complete problem having been discussed elsewhere.[5]

Table 4 indicates reactor trip parameters, any one of which must initiate a reactor shut-down. The outputs of the detectors and their associated equipment are fed into a common network known as the safety system. The output of this network feeds into the control and safety rod system and when required allows all rods to drop in to the reactor core and shut it down.

The safety circuit and the equipment feeding it is designed to fulfil two basic requirements:

(a) initiate an alarm or reactor shut-down if any one part of the system develops a fault, i.e. fail safe,

(b) prevent spurious reactor shut-down due to failure of one piece of equipment, e.g. the failure of a thermionic valve. This is essential because of the financial penalty resulting from spurious shut-downs. It is considered acceptable that the occurrence of two or more simultaneous equipment faults may give a reactor shut-down, since the probability of this is very small.

All the equipment associated with the safety system is fitted with alarms so that the origin of the alarm or trip signal can be identified.

Table 4
Reactor Shutdown Initiation

Trip condition	Number of Initiators per Safety Line	Trip Arrangement†	Initiating Device	Setting or Range of Setting
Fuel element—excess temperature	12	2/3	Thermocouple and transistor trip unit (Sect. 3.5)	0–1000° C
Duct gas—excess temperature	—	2/3	Thermocouple and transistor trip units (Sect. 3.5)	0–1000° C
Blower trips	—	2/4 blowers	Motor current transformer and relay	18% full load current
Excess flux main column	3	2/3 on	Ion chambers	0–750 MW
Auxiliary column	3	any one	and amplifiers	0–750 MW
Auxiliary column	3	column	(Sect. 2.4)	0–750 MW
Short doubling time			Ion chamber	
Main log	1	2/3	and amplifiers	20–60 seconds
Low log	1	2/3	(Sect. 2.3)	20–60 seconds
Counter channel power trip (shut-down only)	2 for 3 lines	1/2	Counter etc. (Sect. 2.5)	
Intermediate power trip	1	2/3	Ion chamber etc. (Sect. 2.3)	
High rate of fall of gas pressure	1	2/3	See Sect. 4.1	10 lb in^{-2} min^{-1}
Manual shut-down	1	—	Press button on control desk	

†2/3 = 2-out-of-3

5.2. *Reduction of Spurious Trips*

The probability of spurious reactor shut-downs due to equipment faults is reduced by the use of the well known 2-out-of-3 scheme. This action is achieved by providing three sets of detectors and instruments for each reactor condition as listed in Table 4. The output relay contacts of these are connected in each of three safety lines as shown in Fig. 6. If the conditions are normal all the relay contacts are closed and the six safety contactors SC1a and SC1b, etc., are all held closed by the 110 V a.c. supplies. The choice of a.c. and 110 V was made on the basis of giving short drop-out times, reliable operation with a large number of series contacts, and minimum contact welding problems. In order to reduce the number of series contacts, those associated with temperature and blower failure trips are connected in auxiliary lines as shown in Fig. 6.

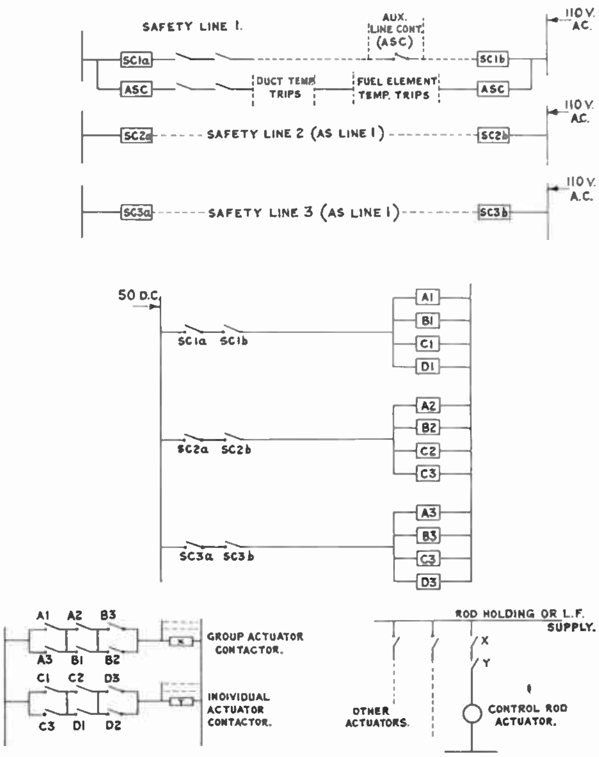

Fig. 6. Safety circuit diagram.

The contacts of the six safety line contacts SC1a, etc., control a further set of contactor coils A1, B1, C1, D1, etc., and these are held closed during normal conditions. The contacts of these contactors are connected in a hammock-type system, which gives the 2-out-of-3 operation and initiates dropping of the rods. The rod actuators are connected either to a holding supply or to a low frequency supply. The latter is required for raising or lowering the rods and is obtained from a frequency changer system. De-energizing of relays A1, B1, etc., results in the interruption of the current supplied both to the individual rod actuator contactors and to the rod holding rectifier contactors, i.e. the holding supply is broken in two places.

It will be seen that the opening of the contacts of one initiating relay contact (e.g. one in line 1) breaks one safety line only so that only relays A1, B1, C1, D1 are de-energized. This opens the contacts of A1, B1, C1, D1 but this does not break the rod holding circuits. Thus operation of one initiating relay does not cause a reactor shut down.

If, however, the operation of one initiating device is confirmed by the operation of another, so that a further safety line is broken, then one section of the hammock is completely opened and the reactor is shut down.

Three a.c. power supplies are provided, one feeding each safety line and the instruments associated with that line. Thus failure of one supply does not cause a reactor shut-down. The cables and equipment associated with the three safety lines are also segregated to avoid common effects.

5.3. *Fail-safe Features*

It will be seen that open circuit faults or faults involving the short circuiting of relay coils in the safety coils will be equivalent to one line being tripped, i.e. it will not prevent the reactor being shut down. The situation with a fault on a power supply has the same effect.

The dropping of the safety and control rods is initiated by breaking of the circuit in two ways, by individual and by group circuits. Thus failure of one will not prevent the reactor being shut down.

The instruments feeding into the safety circuits are arranged, where possible, to have fail-safe properties. If a fault develops in an instrument, it is made to behave either as though a high signal has been received or an alarm is initiated. Thus no fault which might prevent the reactor being shut down is allowed to pass unnoticed.

One safety line could be prevented from operating by a welded contact. This possibility is reduced by a.c. operation and choice of suitable ratings. In any case such a situation would not prevent reactor shutdown as the other two lines would trip the rods.

6. Control Rod Instrumentation

The reactivity of the reactor is controlled by movement of neutron absorbing rods vertically within the core.[1] The effectiveness of these rods is related to their insertion into the core and so by indicating and recording their position, information on the reactivity state of the core can be indicated to the operator and permanent records produced of all control rod movements.

6.1. *Control Road Allocation*

A total of 132 control rods are used on the reactor. These are divided into groups as follows:

Safety group	20 rods
Bulk groups (A, B and C)	94 rods
Sector control (1 rod per sector)	9 rods
Sector trim (1 rod per sector)	9 rods

The safety group is distributed over the reactor core and is held out of the core for all normal and shut-down conditions. The rods drop into the core for an automatic reactor trip condition, but are immediately withdrawn again and held in reserve.

The bulk groups A and B are also distributed over the core and consist of rods which will be manually withdrawn from the core under maximum power operating conditions (poisoned state).

The group C rods are left inserted in the reactor for purposes of flux shaping. They will be manually withdrawn by approximately 15% of their lift and will also be used if required for trimming of sector rods.

The "sector control" and "trim" rods are used in the automatic control system as described under Section 6.5.

6.2. *Bulk Rod Control*

The rods connected to each group are operated in a "quasi" bulk manner, i.e. each rod on the group is lifted by $\frac{1}{16}$th of a full lift at a time and all the rods in the group similarly raised sequentially. The power signal is routed to the appropriate actuator by means of a rotary selector switch. Two selector switches, total capacity of 55 on each, are provided for all bulk rods. Each of the "bulk" groups have equal numbers of rods connected to each selector switch, so that failure of one switch does not result in a loss of control.

This system gives the effect of a bulk lift as at no time is there more than $\frac{1}{16}$th of a lift between rods in any one "bulk group". The rods are pre-selected to their appropriate duty in the control rod sub-station but once this has been done, all "group" control is carried out from a desk in the central control room.

6.3. *Control Rod Actuator Supply*

The control rod actuator motor is a six-pole two-phase permanent magnet machine which requires a d.c. supply on one phase to hold the rod in position and a low frequency two-phase supply to raise or lower the rod.

The d.c. supply is obtained from a holding rectifier in the supply cubicle. Each rectifier normally supplies d.c. to four rods but is designed to hold eight rods at 75% voltage.

The low frequency a.c. supply for rod movement is obtained from a frequency changer machine. This consists of a three-phase induction motor driving a four-pole power selsyn through a gearbox. The rotor of the selsyn is excited at 50 c/s single-phase and causes the two-phase stator output to be modulated at 2 cycles per revolution. After demodulation an l.f. two-phase supply is available for the actuator motor.

Two speeds are possible and are selected by electro-magnetic clutches in the gearbox. This selection gives the following speeds to the rods:

(1) Insertion	Fast speed
	Slow speed
(2) Withdrawal	Slow speed

6.4. *Control Rod Position Indication and Recording*

Control rod positions are measured by a selsyn transmitter coupled, via gearing, to the actuator drive shaft. The output of the rotor of this selsyn is rectified and gives a direct current which is related to rod position. This current operates 0–5 mA moving-coil edgewise instruments, one for each rod, mounted in the central control room and the control rod sub-station. The current also passes through a resistor giving a voltage signal for operation of the nine control rod position recorders, one for each reactor control section.

The recorders are of the 16-point 10-in. chart type with the 10-in. chart divided into three narrower sections; one third of the points are recorded in each section. Thus, at the expense of some resolution, superimposition of the records, which are identified by numbers, is avoided. Each control rod position is recorded every 80 seconds.

The indicators and recorders are fitted with non-linear scales and charts to compensate for non-linearity introduced by the selsyn and the relation between angle turned through and distance moved by the rod. The latter is caused by the " pancake" winding system used in which the winding diameter increases as the wire rope is wound on. The overall accuracy of indication is $\pm$ 1 ft, the total travel being 30 ft.

In addition to the multi-point recording of all rod positions the "regulating" and "trim" rods of each of the nine zones have 3-in. moving-coil position recorders. The "regulating" rod is part of the automatic control system while the "trim" rod is under manual control and is used to keep the control loop on range.

6.5. *Automatic Control System*

A full discussion of the automatic station control system is outside the scope of this paper, details being given by French and Yellowlees[5] and Belsey.[10] However, the following are some aspects of the system.

For control purposes the reactor is divided into nine zones, one central and eight radial sectors. Each zone has an automatic controller which receives signals from one of two groups of thermocouples and transmits impulses to the particular control rod ("regulating rod") in its sector.

The two groups of four thermocouples measure the channel gas outlet temperature in the different parts of the zone and the average output of each group is compared with a reference voltage. The two different signals are fed to a low level magnetic d.c. amplifier and to an "auctioneering circuit". This selects the signal corresponding to the higher reactor temperature and this is fed to a control unit in which integral and derivative terms are incorporated to modify the loop transfer function to give optimum performance. Variations in the controller output are converted to pulses which feed the regulating rod actuator and adjust its position.

The overall effect of this closed loop system is to maintain the average channel gas outlet temperature at a value corresponding to that set by the reference voltage. Each reactor zone has an independent system but the reference settings can be ganged together with a common setting control.

The whole system is duplicated up to the output of the d.c. amplifier at which point the outputs of the two amplifiers associated with one zone are "auctioneered" and the highest passed to the controller. The outputs of the two amplifiers are also compared and any unbalance is taken as an indication of an equipment fault and an alarm is initiated. Alarms are also given for thermocouple earth faults. It will be seen that a highly reliable and safe system is obtained by combination of intrinsically reliable equipment, redundancy techniques and fault monitoring.

The performance of each complete zone system is checked by a further group of four thermocouples feeding a d.c. amplifier and recorder with backing-off arrangements giving ranges 0–420 and 320–380° C.

7. Burst Cartridge Detection (B.C.D.)

The uranium fuel is provided with a can which prevents oxidation of the uranium by the carbon dioxide and contains the products of fission so that they are not dispersed into the coolant. The can is also used to provide an extended surface to improve heat transfer. In view of the importance of its function, it is necessary to keep a check on the integrity of the cans and to locate defective elements so that they can be removed from the reactor.

Defective cans are detected by the release of gaseous fission products from the can. The concentration of isotopes in the gas stream is measured by an electrostatic precipitation and counting technique and works on the same principle as that used at Calder Hall.

The Berkeley installation, design details of which have been described by Harlen,[8] differs in some respects, the most important being as follows:

(a) The numbers of precipitators and valves is greater to match the larger number of fuel element channels.

(b) The rotary selection valves have combined single sample selection cocks, so greatly reducing the bulk of the equipment.

(c) The rotary selection valves and fission product detecting precipitators are synchronized by a common drive shaft. This enables display equipment for the detectors to be synchronized.

(d) The inclusion of a data logger print-out system.

The signals from the precipitator and scintillation counter comprise a series of counts corresponding to the fission product concentration of the group of channels being sampled.

The relevant parameters of the main channel scan system are as follows:

Total number of channels sampled	3275
Number of channels grouped during normal scanning	4
Number of groups scanned by each rotary valve	49 (50 positions)
Number of rotary valves	17
Number of precipitators (scanning)	17
Number of precipitators (spares and single channel monitoring)	4
Counting period	30 seconds
Total cycle time	36 seconds
Total scan period	30 minutes
Approximate number of pulses in a count per group of channels, assuming external can contamination only	1000 pulses

It will be seen that the main scan alarm and display system has to accept a set of 17 counts occurring every 36 seconds, the whole cycle being repeated every 30 minutes. This amounts to over 40 000 sets of counts to be recorded each day.

7.1. *Recorder System*[3]

The outputs of the scintillation counters are amplified to a level where amplitude discrimination can be applied and the pulses are then fed to integrating ratemeters basically similar to A.E.R.E. type 1161B. This has the property of storing the counts as a d.c. voltage and at the end of the counting period giving an output proportional to the counts accumulated.

This d.c. output is measured by means of a 54-point recorder the pen carriage position and pen firing selection circuit being synchronized to the rotary valve movement. Thus each recording area on the chart corresponds to one channel group. The valve has 50 ways, only 49 being used in most cases, and the information is transmitted as tens and units. At the recorder end these signals are converted to six-by-nine information for the 54-point recorder by means of a rectifier matrix.

One 54-point recorder is provided for each of the 17 channel group precipitators the chart speed being 1 inch in 24 hours.

In addition to recorders for the main reactor scan, four conventional single point recorders per reactor are fitted for following the counts from channels suspected of containing defective fuel element cartridges. Four special precipitators are provided for this purpose; they are fed via the selection cocks fitted to the rotary selector valves. This facility does not interfere with the remaining normal programme in any way, all remaining fuel channels still being monitored.

7.2. *Duct Scan System*

In addition to the main scan system a back-up scanning system which uses samples taken from each of the main outlet gas ducts on the reactor is installed. This uses a valve and precipitator similar to the main scan but the display takes place on a modified 8-point recorder of the conventional potentiometric type. The total scan time of this circuit is approximately 5 minutes so that should a fuel element in a channel which has just been scanned by the main system develop a significant burst, this can be detected in an appreciably shorter time than may be possible on the main system.

7.3. *Automatic Data Logger*[9]

An automatic data logging system is installed in addition to the recorder system described in Section 7.1, as the latter suffers from the following shortcomings:

(a) The records require continuous observation if trends in the count rate are to be noticed and alarms given if the rate of change is high.

(b) The records are small (1 in. × 1 in.) with poor resolution owing to the large spot size so that accurate observation is difficult and accurate records are not available.

(c) It is difficult to provide an alarm level which is individual to each channel group.

Automatic data logging techniques can provide a display which is superior in these respects.[8] The equipment can be arranged to print out significant

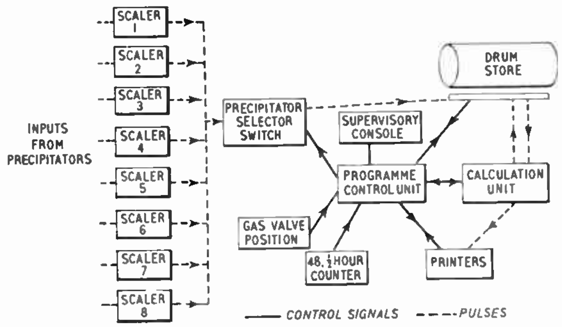

Fig. 7. Block diagram of burst cartridge detection computer.

changes only so that the operators are not distracted by normal information. Furthermore, by incorporating a storage system, simple arithmetic operations such as computing of averages can be performed. This is of particular advantage since, due to the statistical nature of radioactive decay, the information from the scintillation counter is a series of random spaced counts.

Operation of the logger is illustrated in Fig. 7, the input being pulses from the pulse amplifier fitted in the ratemeter previously mentioned. The information is retained in digital form and is handled by simple transistor units similar to those used in digital computers. The store is of the rotating magnetic drum type, the speed of rotation being chosen to give long life.

A brief specification of the logger is as follows:[8]

The print-out includes a statement of time, channel group number and counts.

Logging print-out given on demand, or at pre-set intervals, of current values or readings for past 24 hours.

Alarm initiated and alarm print-out given for the following:

(a) Current reading exceeding pre-set absolute limit.

(b) Current reading exceeding by a pre-set amount either—
the last reading,
or the reading five ago,
or the reading ten ago,
or the average of the last ten readings.

(c) Current reading very low, indicating equipment fault.

The alarm levels associated with both absolute and differential alarms are variable and can be different for all channel groups. Thus the alarm settings can be set as close to the count as is permitted by the statistical spread of the count rate. By judicial choice of the type of alarm and settings, a suitable compromise can be achieved between sensitivity and rate of spurious alarms.

8. Gas Analysis

8.1. *Requirements*

Measurements on the carbon dioxide coolant are required as follows:

(a) Steam in carbon dioxide.

In the event of a fault in the h.p. section of a boiler, steam will leak into the carbon dioxide stream. Such leaks are detected by measurement of the moisture content, a range of 0–1000 parts in 10^6 being suitable.

(b) Carbon dioxide in steam.

Similarly a leak in the l.p. section of a boiler will allow carbon dioxide into the steam circuit, and this can be detected by a measurement of carbon dioxide in steam concentration. A range of 0–1000 parts in 10^6 is again suitable.

(c) CO in carbon dioxide

In order to have an indication of the state of the carbon dioxide reduction reaction $CO_2 + C \rightleftharpoons 2CO$ it is necessary to monitor the CO concentration; a range of 0–1% is convenient.

8.2. *Gas Analysis Instruments*

All three of these measurements are made by means of infra-red gas analysers.[7] In the case of H_2O in carbon dioxide and CO in carbon dioxide a relatively simple gas-handling system and analyser is used.

However, for the measurement of carbon dioxide in steam, the steam is first condensed. Any carbon dioxide in it is then stripped off by a flow of air which is free of carbon dioxide. The concentration of carbon dioxide in this air is then measured by an infra-red gas analyser. The scheme is similar to that used at Calder Hall.[7]

Both carbon dioxide in steam and moisture in carbon dioxide measuring systems are provided per heat exchanger and the measurements are recorded on multi-point 10-in. recorders. A lock-out alarm system is also provided which indicates which heat exchanger is first associated with the change in gas components.

9. Flux Scanning

The neutron flux within the reactor is measured by the activation technique using a tungsten wire.[3]

Twenty winches for the wire are fitted in assemblies capable of withstanding the reactor pressure. The winch assemblies are fitted to the reactor standpipes and after purging and pressurizing to reactor pressure, valves are opened which allow communication between winch and reactor. The winches are motor operated and the wires are lowered into the reactor core and are irradiated for 30 minutes. The wires are then withdrawn and the winch assemblies sealed off and depressurized.

For the peak flux the wire acquires an activity of 1·25 mc/cm due to the isotope W^{187} which is a gamma emitter with a half life of 24 hours. After the irradiation procedure the winches are moved in turn to a pair of measurement wells. At the well, the wire is lowered through a hollow ionization chamber and then raised.

The wire activity is measured by the ionization chamber and a capacitance modulator type electrometer. The chamber (the A.E.R.E. type 1544A) has a polarizing voltage of 100 and a sensitivity of $8{\cdot}6 \times 10^{-9}$ amps/mc/cm, i.e. about $1{\cdot}1 \times 10^{-8}$ amps for the peak flux.

The output of the d.c. amplifier is fed to a 10-in. potentiometric recorder, the chart being driven by a selsyn receiver which is coupled to a selsyn transmitter fitted to the winch. Thus the chart and wire movement are related and as the wire is raised through the ionization chamber, a graph of the distribution of activity of the wire is automatically plotted. A simple manually operated attenuator system is used to correct for decay of wire activity between irradiation and measurement, the correction being about 3% per hour.

10. Health Physics Instruments

Most of the measurement of levels of radioactivity and toxic gases in and around the station is performed with the aid of portable instruments which are supplied by and are the responsibility of the C.E.G.B. A discussion of these instruments is, therefore, outside the scope of this paper. However, in a few special cases, fixed equipment is installed, the following being the more important instances.

10.1. *Gamma Monitors*

The gamma monitors give indication of level in the range 0·1 mr/h to 100 r/h with an alarm if the level exceeds a pre-set figure. The monitor comprises an ionization chamber and a logarithmic d.c. amplifier with trip circuit similar to that described in Section 2.3. The alarms are given in the central control room.

Four monitors of this type are fitted on the charge face of each reactor to check that no hazardous condition arises during the movement or the use of equipment associated with fuel charge and discharge, flux scanning, and similar operations. The monitors are intended to pick up a general increase in radiation background rather than detect beams of radiation. A similar monitor is positioned in one chamber of each thermal shield cooling system filter room to determine the rate of build-up of particulate activity on the filter roll.

Gamma monitors are also used for interlock applications on irradiated fuel element handling machinery. In these cases the monitor gives a check on the correct positioning of radioactive components with respect to shielding and is used to initiate alarms and in some cases automatically stop the sequence if this would lead to a hazardous situation.

The main difficulty associated with installed gamma monitors is that of obtaining good stability and reasonable time constants at the normal working level, i.e. below 1·25 mr/h, together with a wide range. A range of some decades is necessary to cover the high levels which might occur with the hazard concerned. Multi-range linear instruments are unsuitable in these applications since the range would then have to be recorded and an instrument where the indicator goes off scale is disturbing to the operator.

10.2. *Gaseous Effluent*

Estimates have to be made of the total particulate and gaseous activity discharged from the stacks under normal operation and blow-down. Arrangements are provided for obtaining representative samples from the thermal shield cooling air, carbon dioxide circuit gas, carbon dioxide discharged at blow-down and during intermittent discharge.

The facilities provided for particulate activity consist of a pump or Venturi system for obtaining the sample, a flowmeter and a filter paper holder. This paper is removed after use and the activity measured in the laboratory.

The gaseous activity measurement technique is similar except that the gaseous activity is measured in a known volume of gas by a scintillation counter.

10.3. *Liquid Effluent*

The activity of liquid effluent is made either by a dip counter or by removing a sample and measuring it in the laboratory.

10.4. *Carbon Dioxide in Air*

Monitors of carbon dioxide in the air are provided to safeguard personnel against the toxic hazard of carbon dioxide which may result from leakage into the atmosphere from glands, flanges, etc., in the carbon dioxide circuit.

The carbon dioxide concentration is measured by katharometers with ranges 0–3%. Air from the sampling points is drawn through a pipe by an aspirator to the katharometer cell, the circuitry associated with it being arranged to give indication and an alarm if the normal carbon dioxide level is exceeded.

The following points on the station are covered by the equipment:

(a) Burst cartridge detection rooms, one per room. This room houses the valves and precipitators mentioned in Section 7.

(b) Blower house and blower control room. This area contains blower running seals and lubrication pits in which carbon dioxide might possibly accumulate.

(c) Stack gas.

(d) Fan rooms associated with the shield cooling air.

The stack gas instruments give indication of any leakage into the air circuit.

11. Instrument Power Supplies

To ensure continuation of the power supply to the instrumentation and particularly to the safety circuit instruments, it is necessary to provide a special "guaranteed" supply. This is achieved by an arrangement of reliable equipment with flexible facilities for routing of supplies from alternative sources, during maintenance periods.

Most of the instruments are fed from 110 V 50 c/s power supplies obtained from four motor alternator sets energized from two 260 V reactor batteries. These are kept charged via rectifiers from the station a.c. supply. In the event of failure of the a.c. supply the battery capacity is sufficient to maintain full emergency supplies to the station for a time adequate to enable manual starting of diesel generator sets.

Two of the four motor alternator sets feed two distribution boards, one for each reactor, for the majority of the instrumentation not concerned directly with safety.

Automatic changeover gear is provided so that failure of one alternator gives only a momentary break in the supply. These alternator sets have closed-loop control keeping the voltage and frequency constant to $\pm 1\%$. The constant voltage ensures accurate valve heater voltage which is desirable for long valve life and instrument stability. The supply is also time controlled so that the charts fitted in recorders connected to the supply run in synchronism with station time to within $\pm$ 3 minutes.

In the case of a situation arising where two sets are out of action, a supply to the instrument distribution boards can be provided from the control rod motor alternator sets. These have stabilization to $\pm 2\frac{1}{2}\%$. As a further alternative, the supply can be derived from the station a.c. supply. This is not stabilized but the instruments are designed to operate with voltage fluctuations of $+8\%$ to -20% and $\pm 10\%$ frequency changes.

The instruments which are associated with the safety system and can initiate a reactor shut-down are fed from three of the alternators, one safety line of each reactor being connected to one machine. Thus the safety lines of each reactor have an independent supply. As the safety system works on a 2-out-of-3 basis, simultaneous faults on two of the supplies are necessary before a spurious reactor trip would result from this cause.

12. Conclusions

It is recognized that the technology of reactor instrumentation owes a great debt to the pioneering efforts of the U.K.A.E.A. at Calder Hall and elsewhere. However at Berkeley Power Station notable advances have been made on Calder Hall practice, particularly in the cases of the safety circuit equipment and of temperature and b.c.d. data handling. The safety system has been improved to meet the requirements of reducing the probability of spurious shutdowns without prejudice to safety and the b.c.d. and temperature display system reduce the recording of redundant information while giving improved alarm facilities in the case of abnormal conditions.

The concentration of running controls of the two reactors and turbine hall plant in one area also provides increased efficiency of employment of operational staff, this concept following the modern C.E.G.B. practice in conventional power stations.

13. Acknowledgments

Acknowledgment is due to the Central Electricity Generating Board for permission to publish the information contained in the paper.

The authors acknowledge permission granted by The Nuclear Power Group to submit this paper for publication, and thank their colleagues for supplying information on various aspects of the station.

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APPLICANTS FOR ELECTION AND TRANSFER

As a result of its meeting on 14th December the Membership Committee recommended to the Council the following elections and transfers.

In accordance with a resolution of Council, and in the absence of any objections, the election and transfer of the candidates to the class indicated will be confirmed fourteen days after the date of circulation of this list. Any objections or communications concerning these elections should be addressed to the General Secretary for submission to the Council.

Direct Election to Member

BUTTOLO, Romeo Leonida. *Cape Town, South Africa.*
DREYER, Captain Raymond Garnier, M.B.E., R.N. *Beaconsfield, Canada.*
JONES, Francis Edgar, Ph.D., B.Sc. *London, W.C.1.*

Transfer from Associate Member to Member

GREAVES, Charles Alfred. *Adelaide, South Australia.*

Direct Election to Associate Member

ANDERSON, Captain Irene, W.R.A.C. *Irvine, Ayrshire.*
ANDREWS, William Douglas. *Cardiff, Glamorgan.*
ASHER, Leonard. *Stevenage, Hertfordshire.*
BISHOP, Kenneth George Thomas. *Petts Wood, Kent.*
BUTCHER, Jack Leslie. *Hayes, Middlesex.*
CHILD, Herbert George Frederick. *Wallingford, Berkshire.*
CRIPPS, George Alfred. *Potters Bar, Middlesex.*
HEATH, Frederick John. *Dar es Salaam, Tanganyika.*
HOWE, Frank. *London, E.C.2.*
HUNT, Cyril. *Woking, Surrey.*
McMURRAY, Wilfred Rodney. *Reading, Berkshire.*
VAUGHAN, Harold James. *Southminster, Essex.*
WARD, Edward Vernon. *Malvern, Worcestershire.*
YEATES, Brian Leonard Edward. *Bexleyheath, Kent.*

Transfer from Associate to Associate Member

BONNER, Trevor Frank Kirkpatrick. *Bushey, Hertfordshire.*
MORRIS, Stanley Withnell. *Manchester.*

Transfer from Graduate to Associate Member

COLE, Horace Albert George. *Reading, Berkshire.*
DUNCAN, Malcolm John. *London, N.13.*
EDIRISINGHE, Don Francis. *Enfield, Middlesex.*
KLIMEK, Georges Eugene. *Mitcham, Surrey.*
MESSENGER, Michael Charles, B.Sc.(Hons.) *Lagos, Nigeria.*
MILLBURN, John Richard, B.Sc. *Aylesbury, Bucks.*
OSSELTON, John Walkinshaw, B.Sc. *Newcastle-upon-Tyne.*
PAWLING, John Francis, B.Sc. *Old Coulsdon, Surrey.*
READ, Squadron Leader Ian Stuart, R.A.F. *East Sheen, Surrey.*
SARDAR SINGH, Captain, I. Sigs. *New Delhi.*
SHORT, Allan. *Oakington, Cambridgeshire.*
SIDERAS, Christokis Stavros. *Hounslow, Middlesex.*
WOODS, John Joseph. *Dublin, Eire.*

Transfer from Student to Associate Member

DUNN, Alan George. *Hull, Yorkshire.*
FIRTH, Peter Thomas. *Huddersfield, Yorkshire.*
HYATT, James Leonard. *Potters Bar, Middlesex.*
LANGFORD, Richard Godwin. *Basra, Iraq.*
STRAY, Ian George. *Cippenham, Buckinghamshire.*

Direct Election to Associate

ALLEN, Norman Leonard. *Hockley, Essex.*
BENJAMIN, Ronald Ivor Alfred. *Rickmansworth, Hertfordshire.*
HAWTHORNE, Squadron Leader James Francis, R.A.F. *Wallington, Surrey.*
LITTLE, John. *Thurso, Caithness.*
SMITH, Howard, B.Sc. *Harlow, Essex.*
VENUGOPALAN NAIR, T., Captain I. Sigs. *Mhow (M.P.), India.*

Direct Election to Graduate

ABIGAIL, James Trevor. *Hornchurch, Essex.*
ADAMS, Brian James. *Hertford.*
ALLEN, Frank Peter. *Sutton, Surrey.*
ASHWORTH, John Robert. *Isleworth, Middlesex.*
BALFOUR, George Leitch. *Inveruerie, Aberdeenshire.*
BELLAMY, Howard John. *Bristol.*
BENNETT, Derek Peter. *Kingston-upon-Thames, Surrey.*
BOFF, Malcolm George. *Manchester.*
BRAMALL, Alan Desmond. *Doncaster, Yorkshire.*
CHAPPELL, Terence Roy. *Wotton-under-Edge, Gloucestershire.*
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McARDLE, Darragh Peter, B.E. *London, S.E.26.*
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SMITH, Colin Leslie. *Cardiff.*
WILLCOCKS, Michael William. *Windsor, Berkshire.*
WISEMAN, Edward Elliott. *London, S.W.11.*

STUDENTSHIP REGISTRATIONS

The following students were registered at the 26th October and 21st November meetings of the Committee. The names of a further 71 students registered at the November meeting together with 43 students registered at the 14th December meeting will be published later.

PADMANABHAN, V., B.Sc. *Cachin, S. India.*
PARKER, Hubert C. *Macclesfield, Cheshire.*
PARKINSON, Lionel V. *London, S.W.13.*
PATEL, Ebrahim Mohamed M. *London, S.E.9.*
PIASTUNOVICH, Theodore. *London, N.W.3.*
PORTER, William. *Newington Annan, Dums.*
POSTLETHWAITE, Peter. *Bristol.*
POTTER, Malcolm Richard. *Chatham.*
POWELL, David Keene. *Hereford.*
POWER, Frederick John. *Darlington.*
RAFIQ, Mohammad. *London, S.W.19.*
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SHOLANKE, Patrick A. *Kaduna, Nigeria.*
SQUIRE, Robert S. *Winchester, Hampshire.*
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CHAI HENG KAM. *Singapore, Malaya.*
CHANCHLANI, Anand R. *Maharashtrya, India.*
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DAVID, Samuel. *Bangalore, India.*
*DESAI, Ramesh C. *Brienen, West Germany.*
DOHERTY, Gordon R. *Dublin, Eire.*
EVANS, Walter D. *R.A.F. Valley, Anglesey.*
GOODAY, John Hamilton. *Colchester, Essex.*
GOPALKRISHNAN, Rangaswami. *Bangalore.*

* Reinstatement.

U.D.C. 621.375.4: 621.362: 621.039

A Transistor Thermocouple Trip Amplifier

By

G. G. BALLARD†

Presented at a Symposium on Electronic Instrumentation for Nuclear Power Stations, held in London on 29th March 1961.

Summary: The problem of protecting a nuclear reactor against excess temperature operation is reviewed and design requirements applicable to thermocouple trip amplifiers are discussed. Particular mention is made of features which render the unit fail-safe. It is concluded that a unit possessing the necessary fail-to-safety features may be manufactured using transistor techniques. The equipment may be made both reliable and compact and these features, supported by robust construction, fulfil the needs of first-line temperature protection on a nuclear power reactor.

1. Introduction

The advent of the nuclear power reactor has led to the development of many first-line safety instruments which are intended to govern directly the safe working of the reactor. Such instruments normally function from pressure, neutron flux, or temperature signals. It is the intention of this paper to cover in detail the design of a unit to provide surveillance of reactor temperature and to emphasize the manner in which a fail-safe unit may be constructed.

The present trend in nuclear power station design is such that every effort is being made to increase the efficiency of the plant. In order to obtain the highest thermodynamic efficiency, temperatures are kept as high as possible consistent with an acceptable fuel element failure rate.

It has thus become essential to safeguard the reactor against excess temperature operation. The fine limits set between the normal operating temperature and the fuel-cladding failure temperature make it essential to obtain a reliable and fail-safe unit.

The range of temperature between operating limits depends on the type of reactor. Reactors built in 1948 had a fuel-can operating temperature of 250° C, while the present power reactors of the gas-cooled type functioning on natural uranium fuel with "Magnox" cladding operate at a can temperature of approximately 450° C. The Advanced Gas-cooled Reactor (A.G.R.) using enriched uranium fuel will operate with a can temperature using beryllium cladding of 600° C. From these values of temperature it becomes obvious that the thermocouple trip unit, in order to be universal, must cover a large operating range. Using conventional thermocouple transducers the above temperature range would correspond to a voltage range from 10 millivolts to 50 millivolts.

The thermocouple trip unit receives an input from a thermocouple located in the reactor core and is provided with some convenient form of "backing-off" or set trip level. For reactor operating temperatures lower than the set trip level the unit indicates a safe condition. However, if the reactor temperature equals or exceeds the set trip an alarm is given and trip or shut-down action is taken.

It follows that since these units constitute the main reactor temperature safeguard they must be both reliable and fail-safe. For the purpose of this paper the definition of fail-safe is that the unit must either operate correctly or produce a trip in the event of any component or combination of components failing to a short or open circuit. In achieving this condition the reliability of the unit must not be impaired.

Since an inadvertent reactor shut-down may result in a loss of power to domestic consumers of electricity and a corresponding possible cost of many hundreds of pounds it follows that the failure of a single component in the trip amplifier should not cause a spurious shut-down. In order to combat these conflicting requirements it is usual to connect trip units in a two-out-of-three system. In this manner a reactor shut-down cannot be caused by one component failure and may only result from the simultaneous tripping of two units in one group of three.

The availability of transistors has now made it possible to comply with all the above requirements in a reliable and compact manner and at the same time has produced a great saving in power consumption. In general the transistor circuit consumes about one hundredth the power of its valve counterpart and occupies about one tenth of the space. Thus the heat per unit volume is reduced by a factor of ten, making for more reliable operation.

2. General Conception

The general conception must be such that the unit complies with the fail-to-safety requirements specified above, it is thus essential to examine the manner in which a fail-safe unit may be constructed, bearing in

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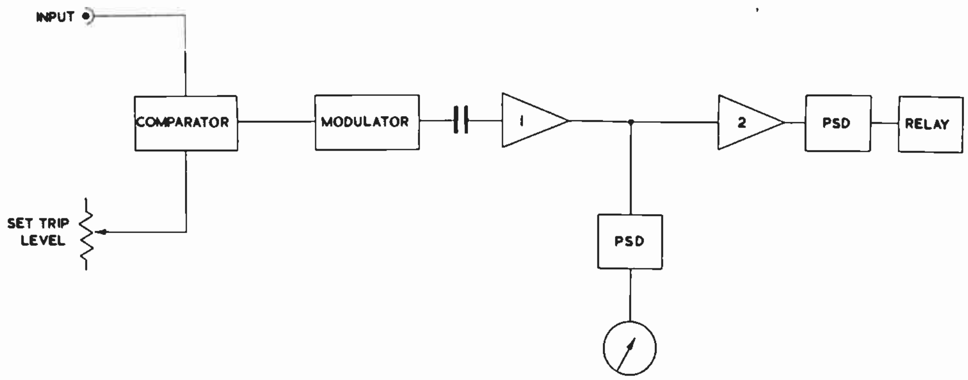

Fig. 1. Basic schematic of the trip amplifier.

mind the type of input from which the unit has to function. Since the input at a minimum may be only ten millivolts full scale deflection the drift of the unit must not exceed 100 μV for an accuracy of 1% full scale deflection, corresponding to an error of approximately 2·5 deg C.

Using transistor circuits this low drift may readily be achieved providing the input impedance of the unit is maintained at a low value, say 500 ohms. If the input impedance of the unit is retained at this low value it follows that changes in the resistance of the thermocouple compensating cable may have an appreciable effect on the scaling of the instrument. In general this would result in an excess trip level due to the effective reduction in signal at the input to the amplifier. This effect may be avoided if the system is made a null balance type, so that at the trip point the input is zero and no current flows; increases in compensating cable resistance having no appreciable effect.

Trip indication is generally given by a relay releasing and a pair of contacts opening, the relay being connected to the output of an amplifier.

If the amplifier is a d.c. type, failure of a component could result in the permanent energizing of the relay so preventing trip operation. To overcome this difficulty an a.c. carrier technique is normally employed, utilizing some form of a.c. modulator, so that by using the correct design, failure of a component will result in loss of the carrier frequency and the relay will release.

From the foregoing it may be seen that there are two basic requirements to achieve fail-safe operation, namely

(1) a null balance system must be employed,

(2) the system must employ an a.c. carrier technique.

The manner in which these two basic requirements are fulfilled is detailed later together with other advantages introduced by their use.

3. Basic Design

A basic design which complies with these requirements is shown in Fig. 1. From this basic schematic it will be seen that the unit employs an input comparator which compares the incoming signal corresponding to reactor temperature with a pre-set demanded trip level. The resulting d.c. error signal is converted into an a.c. waveform by use of the modulator illustrated. The a.c. waveform derived from the modulator has a peak-to-peak value equal to the magnitude of the d.c. error while the phase is dependent on both the modulator a.c. reference and the polarity of the error signal. The resulting error signal corresponding to the difference between the reactor temperature and the demanded trip level is amplified by the first-stage amplifier shown. The output of this section thus provides a signal proportional to the margin from shut-down. A phase-sensitive rectifier is employed to demodulate the amplified error signal and provide a d.c. current to feed a meter. A display of percentage or degrees Celsius from trip is provided by the meter which is normally referred to as the trip margin indicator.

A second amplifier stage is provided to amplify further the a.c. error signal obtained from the first amplifier. The resultant signal is demodulated in a phase-sensitive rectifier and fed to a polarized relay. For all operating conditions where the independent variable input corresponding to reactor temperature is lower than the pre-set trip level, the relay is held in. For conditions of equality between the input and pre-set trip, the relay receives no volts, and thus releases. If the input exceeds the reference, the relay is provided with reverse polarity d.c. and, being polarized, remains released.

4. Design Refinements

In order to render this basic design fail-safe several design features have to be incorporated. As described previously the basic design has one major disadvantage in that an open circuit, caused by a dry joint or fracture, in the wiring between the pre-set trip potentiometer and the signal earth line would result in a high trip level and fail-to-danger state.

This effect may be overcome by utilizing the system shown in Fig. 2 whereby the two basic amplifier units, though being used to amplify a.c., are in fact directly-coupled stages. The first amplifier stage is set to the correct d.c. operating point by a degree of bias obtained from the pre-set trip line. Should any short- or open-circuit condition arise in the trip reference line, the d.c. bias will change, causing the amplifier to either "saturate" or "cut-off". In either event the result will be to prohibit the amplification of the a.c. carrier which will in turn cause the relay to release, or at worst, will result in a low trip level.

This type of protection affords a safeguard against all possible failures of the reference trip supply, including an open- or short-circuit condition of the Zener diode used as the voltage reference.

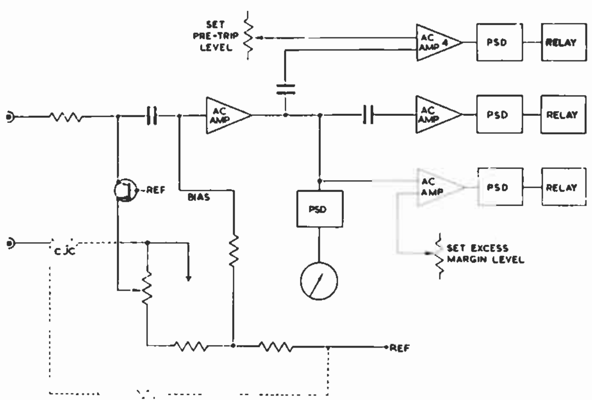

Fig. 2. Detailed schematic of the trip amplifier.

The use of direct-coupled stages implies that any component or combination of components failing to short- or open-circuit will cause the amplifier to either saturate or cut off resulting in a trip condition.

Since a null balance system is employed, the gain of the amplifiers is of secondary importance, serving only to produce a small on/off differential. The differential is defined as the difference between the input voltage and the preset trip level required to energize the relay. Thus if the gain of the amplifiers decreases, due to ageing of components or any other reason, the effect will only be to increase the on/off differential and effectively cause a low trip level to result. However, this effect is very small. Should the gain of the amplifiers increase, the effect is to reduce the on/off differential resulting in a more accurate trip level.

By careful design the unit may be made to monitor external component failure, for example, open-circuited and short-circuited thermocouples or compensating cable. The former condition is readily detected by the unit described since an open-circuit input renders the input modulator inoperative as there is no d.c. chopping path. In this manner the a.c. waveform from the modulator reduces to zero and the relay releases.

The short-circuited thermocouple is not so readily defined for the resulting voltage presented to the amplifier under short-circuit conditions is rather dependent on the relative position of the short. Some degree of safeguard against this occurrence may be achieved by employing an additional amplifier to provide an excess margin warning. Such an amplifier will give a warning should the input voltage to the unit represent a temperature which is too far below the trip level to be realistic.

Protection against inadvertent hum pick-up must be provided and can normally be achieved in two ways. The first method, being the simpler and thus more reliable of the two, employs a simple CR filter at the input to the unit which serves to eliminate any hum pick-up. One disadvantage of this scheme is the inherent time lag which results on receipt of a true trip signal. A typical unit may well employ a 0·2 second time-constant which will attenuate pick-up. A hum signal injected in series with the thermocouple compensating cable of peak-to-peak value ten times that of the instrument input full scale deflection, will then only cause a 1% change in trip level. Pick-up between the compensating cable and earth does not generally affect the unit as the entire instrument may be isolated from earth.

The second method which may be adopted to protect the instrument against hum "pick-up" is to use a modulation frequency in excess of the normal mains supply, for example 2 kc/s. This technique involves the use of a built-in oscillator and although the elimination of hum effects is almost complete, the circuits are more complicated with a consequent reduction in reliability.

A further refinement is normally incorporated to aid the reactor operator. This involves the provision of a pre-trip warning and serves to remind the operator that the trip margin has reduced to a point where care should be exercised. An additional amplifier circuit may be used to meet this requirement as represented by amplifier 4 in Fig. 2.

5. Detailed Design

The foregoing sections have dealt with the basic design features required to render the unit fail-safe; however, much care is needed in the detailed designs to maintain the standards of safety and reliability laid down.

5.1. *The Modulator*

In order to comply with the fail-to-safety requirement prescribing the use of an a.c. carrier technique, some form of modulator must be used. This requirement may readily be met by use of a transistor acting as a chopper. The transistor is connected with the collector joined to the trip signal line, the input being fed to the emitter. An a.c. waveform is applied to the base electrode in such a manner that negative half-cycles of the applied reference cause the transistor to conduct and provide a low impedance between the input and set trip level. Positive half-cycles cause the transistor to be cut off thus releasing the input from the reference. The output from the modulator thus constitutes a square waveform of amplitude equal to the error between the impressed d.c. and the trip reference, and of phase determined by the error polarity.

With refinements, this and similar circuits[1, 2] have been found to provide reliable modulators.

When the major refinements have been applied to the circuit, for example stabilization of the reference amplitude by use of a Zener diode, very low drift figures may be achieved as may be seen from Table 1.

Table 1

Type	Configuration	Drift
Germanium transistor:	single-sided	150 μV
	balanced	20 μV
	temperature stabilized	10 μV
Silicon transistor:	single-sided	100 μV
	balanced	15 μV
	temperature stabilized	5–10 μV

These values of drift have been determined using a 1000-ohm source impedance and a temperature range of 20° to 50° C. From the Table it may be seen that drift values well below 100 μV may be achieved by use of either temperature control or by employing a balanced modulator. Although both these techniques are in constant use they are not suited to a first-line safety instrument as there is no reliable way of determining that they are functioning. In the case of temperature stabilization some form of oven has to be employed which may readily fail to a hot state, giving rise to a drift in excess of that achieved without temperature control.

For these reasons it is normal to employ a single-sided chopper transistor without any form of temperature stabilizing. The resultant drift is limited to 100 μV in the case of the silicon transistor.

5.2. *Amplifier Sections*

Each amplifier section comprises a ring-of-three transistor circuit which is direct-coupled throughout. The direct coupling in conjunction with bias received from the reference line renders the unit fail-safe as described earlier. Overall d.c. feedback is applied as shown in Fig. 3 by use of R1, this resistor being subdivided and decoupled to earth at its centre point. This enables a large degree of d.c. negative feedback to be applied and serves to stabilize adequately the operating point of the amplifier with ambient temperature variations. The a.c. gain of the amplifier section is determined by the feedback resistor R2 and input resistor R3.

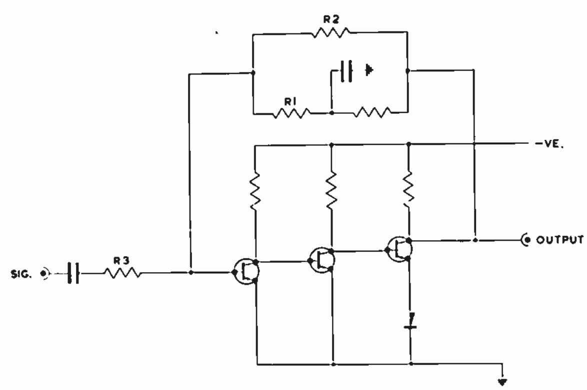

Fig. 3. Amplifier sections.

A high loop-gain and consequent stable overall gain is achieved by operating the first transistor of the ring-of-three at a lower current than the second. In this way the bias voltage of the second transistor is adequate for the collector of the first transistor. Thus no emitter bias resistors are employed and the full transistor gain is realized. The third transistor is biased by use of a Zener diode coupled in the emitter circuit which, having a low resistance, does not greatly reduce the gain. Direct interstage coupling is employed without any potentiometer networks with a resultant effect that the loop gain of the ring-of-three is approximately 150 while the overall gain is in the region of 200.

5.3. *Phase Sensitive Detector*

Two phase-sensitive rectifiers are employed, one for the trip margin indicator and the other for the polarized relay feed. Each detector employs a transistor acting as a d.c. restorer, the action being similar to that of the input modulator. The a.c. waveform to be rectified is coupled to the collector of the transistor and the emitter is earthed. A reference waveform is applied to the base electrode.

On negative half-cycles of the base waveform, the a.c. on the collector is restored to earth while positive half-cycles of the reference release the collector waveform. The resulting restored a.c. waveform is thus positive or negative with respect to earth depending on the relative phase of the collector and the base waveforms. A d.c. signal, the polarity of which is dependent on the phase of the applied a.c., is thus obtained, while the magnitude is a function of the peak-to-peak value.

This type of detector may be said to be fail-safe in that any short or open circuit on the transistor can either cause no output or, at worst, an output which is of the wrong phase to energize the relay.

6. Overall Circuit

The overall circuit is illustrated in Fig. 4 in which the combination of each of the above sections is shown. Some extra detailed design features now become obvious. The polarized relay is connected to the output phase-sensitive detector so that it is energized when the d.c. output voltage is positive with respect to earth. This configuration is necessary if the unit is to remain fail-safe since a short circuit of the coupling capacitor from the second-stage amplifier output could give rise to the relay being coupled to the negative supply line. In this event the relay must release.

Some extra features are essential if the unit is to become a practicable working proposition. For example, cold junction compensation must be provided to suit the particular type of thermocouple in use. This requirement may be fulfilled by use of a copper bobbin mounted adjacent to the unit input terminals so that it is subjected to the same ambient temperature variations as the cold junction. Provision must be made to pre-set the current via the bobbin to enable correct backing off to be obtained. In order to reduce drifts in the reference circuit which also powers the cold junction compensation, two Zener diodes are employed back to back.

In practice one power pack is provided for each trip amplifier since the failure of one unit supply must not render all three instruments in one group faulty. As the unit operates from low voltage supply lines it is practicable to power the unit from ± 24 volt batteries. If this requirement is essential, a separate oscillator to provide the modulator and de-modulator references must be provided as described earlier.

Under these operating conditions it is usual to couple the battery input via diodes. In this way the unit will function from either mains or battery inputs whichever is the higher. Temporary interruption of the supplies for a short duration need not cause trip operation if large reservoir capacitors are provided on the supply lines.

As discussed earlier pre-trip warning and excess margin warnings may be provided. These warnings may be pre-set relative to the actual trip level and operate at any point of the trip margin indicator scale. Once set the warnings will act at a fixed number of degrees from the trip setting, even if this level is changed.

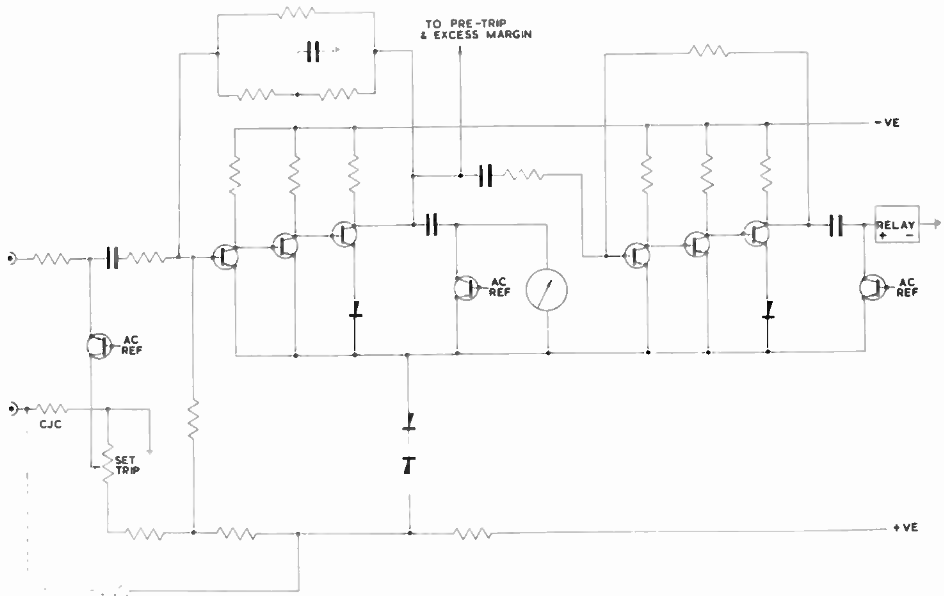

Fig. 4. Overall circuit.

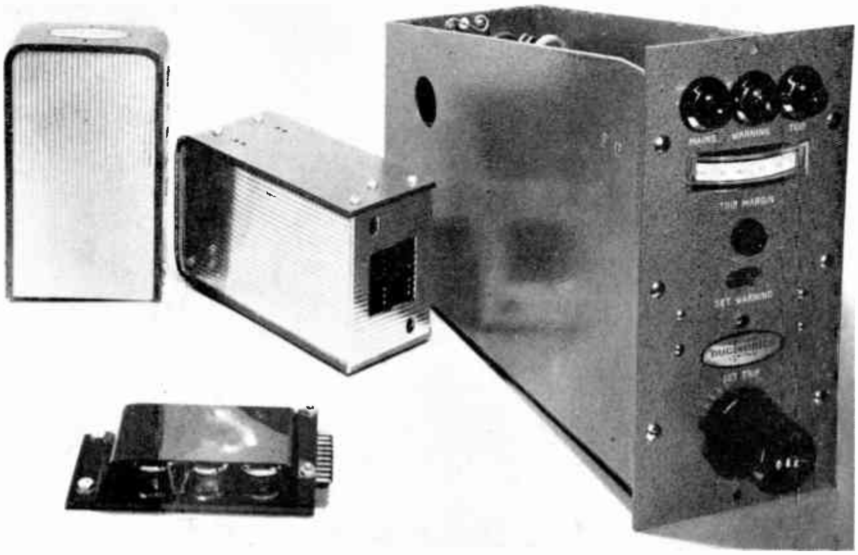

Fig. 5. The trip amplifier.

In practice the thermocouple output voltage is not exactly a linear function of temperature, thus the trip-setting potentiometer must be loaded if the dial provided is to read directly in terms of degrees Celsius. This technique is not generally recommended since the loading resistor can become open-circuited and give rise to a high trip level and consequent fail-to-danger state. To overcome this disadvantage the dial may be calibrated in a linear manner and a conversion chart provided. This is usually fully acceptable since the trip setting does not normally require frequent adjustment.

7. Construction

The unit discussed is constructed in individual plug-in sub-unit form. Two plug-in units contained in one case form the complete instrument. The power supply is contained in one unit while the amplifier is housed in the second sub-unit. The range of the instrument is determined by use of a plug-in bobbin card. The front panel houses the necessary meter display, alarm lights and pre-set controls. The instrument is illustrated in Fig. 5.

8. Performance

The type of unit described may provide a stability referred to the input of 100 μV corresponding to 2·5 degC over an ambient temperature range of 30 deg C. The on/off differential may be made less than 200 μV. With the possible exception of a mechanical failure in the relay the unit is fail-safe. Common mode rejection of a hum signal injected in series with the thermocouple compensating cable is in excess of 1000 to 1. A slave relay may be operated from the polarized relay to provide a large number and variety of contacts for external use.

9. Acknowledgments

Acknowledgments are due to the engineers of Elliott Nucleonics Ltd., who carried out much of the experimental work and made the satisfactory development of this unit possible.

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Nerve Impulses from a Stretch Receptor in Muscle

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Summary: The principles of nerve activity are discussed with special reference to electrical properties. The mechanism of the nerve ending as a transducer is described and the phenomenon of biasing is dealt with. The techniques of recording from a sensory nerve and several features of these recordings are explained, in particular the frequency, temperature and noise characteristics.

1. Introduction

Muscular movement in man and in animals is controlled by nerve impulses which travel outwards from the nervous system: however, the precision, co-ordination and smoothness of movement depend on an uninterrupted flow of information from muscles to the nervous system. This information does not normally reach consciousness but acts at the level of the spinal cord, continually modifying the outgoing motor nerve impulses. This paper describes some of the "circuitry" which controls muscular contraction and one component which is of particular interest: a transducer in muscle, which is sensitive to stretch and generates nerve impulses.

There are two main problems concerning this transducer: (i) what part does it play in regulating muscular contraction? (ii) by what mechanism does the energy of stretch give rise to nerve impulses? The first problem is essentially that of trying to determine the characteristics of the transducer and to find out how it is connected in the circuit; the second problem is more biophysical and requires some knowledge of how nerve cells generate electricity.

2. The General Principles of Nerve Activity

The transducer is a specialized nerve ending and it is important to stress that nerve trunks which conduct impulses to and from the central nervous system are not mechano-electrical transducers. Stretching a nerve trunk like the sciatic does not give rise to impulses. Although modified, the transducer is nevertheless part of a nerve cell, sharing many of its properties, and the basic properties of nerve fibres will therefore be summarized before the transducer itself is discussed.

A nerve can be considered as a tube of protoplasm of relatively high conductivity separated from the tissue fluid bathing it by a high resistance membrane. This is a double layer of material with a resistance of about 2000 Ω.cm^2 and a capacitance of about 1 μF/cm^2. At rest there is a potential across the membrane of 60–90 mV, the outside being positive with respect to the inside. This "resting potential" is caused by inequalities in the concentrations of ions on the two sides of the membrane according to a Donnan equilibrium, which in turn arises from the selective permeability of the membrane. If the cell is poisoned or damaged the selective permeability barrier breaks down and the potential falls to zero; the composition of the intracellular contents is also maintained at a constant level by active transport of ions, notably sodium.

A simple way of observing the "resting potential" is to push a fine electrode into the cell by means of a micromanipulator and measure the voltage directly with respect to an indifferent electrode in the bathing fluid. The micro-electrode is a glass tube drawn out to a tip of less than one micron diameter. It is filled with a fluid of high conductivity (3 molar potassium chloride) into which dips a non-polarizable silver-silver chloride electrode. Since the resistance is still very high (10–50 MΩ) a cathode follower is used to convey signals to the amplifier; valves are chosen in which the grid current is less than 10^{-11} A, as 10^{-10} A or more can damage the cell. The recording circuit is otherwise quite conventional and consists of a d.c. amplifier and oscilloscope.

During a nerve impulse the polarity of the membrane is reversed so that the outside becomes temporarily negative to the inside by about 30 mV; thus the size of an impulse can be up to 120 mV. Known as the "action potential", the impulse lasts for about 1 ms and is initiated by any electrical or chemical disturbance which reduces the resting potential by about 20 mV. It is propagated along the fibre, without decreasing in size, at a constant velocity of 10–100 metres/second, which in any one fibre

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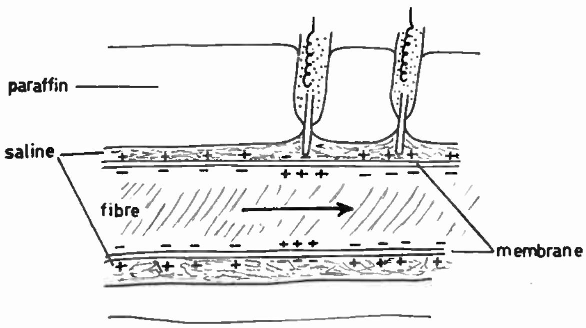

Fig. 1. Diagram of longitudinal section of a nerve fibre. The resting membrane is charged with the outside positive to the inside. The impulse is shown as a wave of external negativity travelling from left to right and passing under one electrode. The layer of saline and connective tissue which cannot be removed has a high conductivity and acts as a short circuit between the two electrodes. Liquid paraffin prevents the nerve from drying.

depends mainly on the diameter. Stronger currents do not produce larger or faster action potentials.

It is possible to make direct measurements of resting and action potentials only in relatively large structures. Nerve fibres less than about 10 microns in diameter and nearly all nerve endings are too small for impalement by a micro-electrode and indirect methods of measurement have to be used. If two electrodes are placed on the surface of a fibre changes in potential can be recorded, but the absolute magnitude of the potential cannot be measured accurately, because connective tissue and fluid act as a short circuit of variable amount between the electrodes.

Using the arrangement shown in Fig. 1 one can stimulate the nerve with a brief pulse and record the propagated impulse as it travels under each electrode; the recorded action potentials will be reduced to considerably less than 120 mV by inter-electrode shunting, even if the preparation is very carefully stripped of inert connective tissue by microscopic dissection.

Stimulating currents which are too small to initiate action potentials give rise to local potentials. These, unlike the propagated impulses, decrease in size exponentially with distance from the source and their size is proportional to the current. Hence, for small currents, the membrane behaves like a leaky cable, while with currents large enough to initiate impulses a regenerative process depending on complex ionic movements is set up. There is now much evidence that sensory nerve endings can only respond to stimuli by producing local potentials graded in size and decreasing with distance. This local potential then stimulates the nerve fibre to which the ending is connected and gives rise to propagated non-decrementing impulses.

3. The Role of the Transducer

The basic circuit which regulates muscular contraction is a loop of negative feedback. When a muscle is stretched it actively contracts back to its original length; this reaction is known as the "stretch reflex" and it was described before the time when electrical recordings could be made. It is now known that during a stretch a specialized structure in the muscle (called the "muscle spindle") generates nerve impulses (Fig. 2); the impulses travel along the sensory nerves to the spinal cord, where motor nerves to the muscle are stimulated; as a result the muscle shortens to its original length, if it can overcome the external tension on it. When it shortens the load is taken off the transducer and the generation of impulses stops.

The cessation of impulses from the transducer during shortening of a muscle would mean however that the flow of information to the nervous system would stop when it was most needed. For example, it is difficult to see how movements as precise and intricate as playing the piano could be performed if the transducers became silent and the frequency of sensory nerve impulses fell to zero whenever a muscle contracted. In the body this is prevented from happening by a special group of motor nerves from the nervous system. Impulses from these nerves alter the "bias" on the transducer so that it is always working on the most sensitive part of its characteristic, even if there is no external load on the muscle. Hence, except for very brief periods, the transducer is never silent.

To understand how the "bias" and the sensitivity are altered it is necessary to describe the appearance of the muscle spindle (Fig. 3). The structure which is sensitive to stretch is the last millimetre or so of the sensory nerve which divides into a large number of

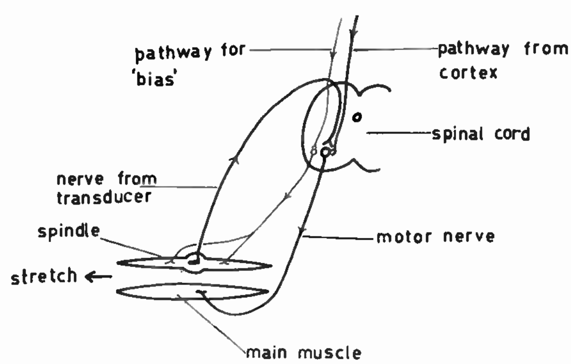

Fig. 2. Diagram of connections involved in the "stretch reflex". Arrows indicate the direction normally taken by nerve impulses. The muscle spindle lies in the main mass of the muscle but is shown separately for convenience; similarly the motor and sensory fibres all run in one nerve trunk, except at their point of entry to the spinal cord.

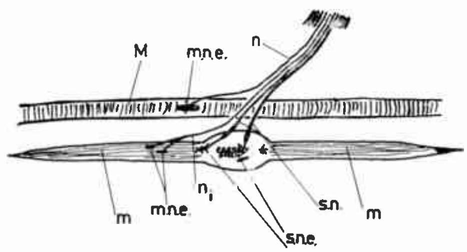

Fig. 3. Diagram of a muscle spindle lying alongside a muscle fibre (M): s.n.e.—sensory nerve endings connected to nerve fibres (s.n.); m—modified muscle fibres within the spindle, innervated by nerve fibre (n_i) from biasing system; m.n.e.—motor nerve ending; main muscle fibre innervated by nerve fibre n. When the spindle muscle fibres (m) contract, the sensory nerve endings which constitute the transducer are stretched. When the main muscle contracts the sensory nerve endings are relaxed.

very fine filaments each with a diameter of less than one micron. The ending usually looks like a spiral coil, but may take many forms. It is embedded in jelly-like material in the central region of a group of small, modified muscle fibres. This whole structure, which is about 2 cm by 30 microns in size, is surrounded by a capsule.

The muscle spindles are arranged longitudinally within the main mass of the ordinary muscle fibres, so that when the muscle is stretched the spindle is stretched and when it contracts the spindle is relaxed. The small modified muscle fibres within the spindle are however "in series" with the nerve ending which constitutes the transducer; when these fibres contract the nerve ending is stretched and impulses are initiated. The amount of bias which is applied to a transducer at any time is controlled by the nervous system on the basis of information obtained from many sense organs, particularly from the muscle spindles in other muscles, from the skin and eyes and from structures in the ear concerned with balance and position sense. The bias is altered during movement of the main muscle and ensures smoothness and accuracy.

One might expect that even voluntary movements could be initiated by this biasing system rather than by the direct motor pathway from the cerebral cortex to muscle. Thus the first event in contraction would be shortening of the spindle muscle fibres, increasing the sensory discharge and initiating a "reflex" contraction. It has not been proved that the brain actually does initiate movement by this pathway, but evidence for this view is growing, especially as some very fast pathways from the brain to the spindle muscle fibres have recently been demonstrated. Many forms of spasticity and tremor are probably due to disorders of this circuit rather than of the direct pathway from the cerebral cortex to muscle.

4. Recording from the Transducer

If one stretches a muscle and records the sensory impulses with two electrodes placed on the undissected nerve trunk the signals will be only a few microvolts. The potentials propagated in the sensory nerve fibres are still about 120 mV, but the motor fibres to the muscle which are inactive short the input and reduce the signal size. Consequently, to record satisfactorily from a spindle one has to dissect the nerve trunk until there is only a single sensory fibre left with one or two motor fibres beside it. There is a convenient muscle called the "tenuissimus" in the hind-leg of the cat which can be used for this; the cat is anaesthetized and the muscle removed, after which the animal is killed without ever recovering consciousness or having felt pain. The muscle is long (10 cm), narrow and only a few millimetres thick. It contains about 12 muscle spindles arranged longitudinally among the several thousand muscle fibres. If placed in oxygenated fluid

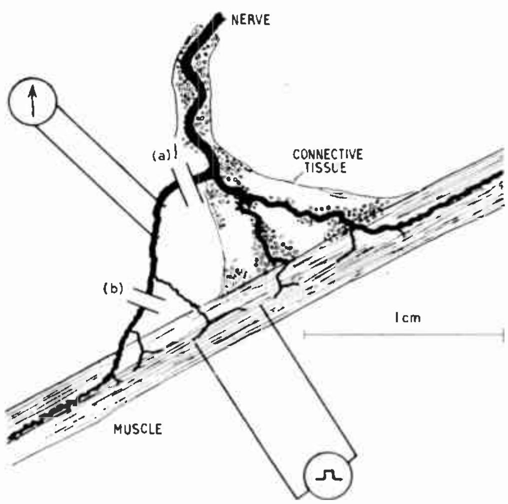

Fig. 4. Diagram of tenuissimus muscle from a cat. The nerve has been cut at a and b and the branch on the electrodes is connected to a single spindle. As much connective tissue as possible has been dissected off. Lower electrodes are for passing current through the spindle (see section on "adaptation").

whose ionic composition is similar to the animal's blood, the muscle can survive for 24 hours or more at room or body temperature. No reflexes can occur outside the body but the muscle will twitch if the nerve is stimulated and the spindles will send impulses up the nerve if the ending is stretched.

The nerve is dissected under a microscope and when a single sensory fibre has been teased out it is held up into liquid paraffin which has a low conductivity (Fig. 4). This reduces shorting between the electrodes and prevents the nerve from drying up, as a thin film of the bathing fluid remains on it. Silver-silver chloride electrodes make contact with the nerve through saline agar bridges.

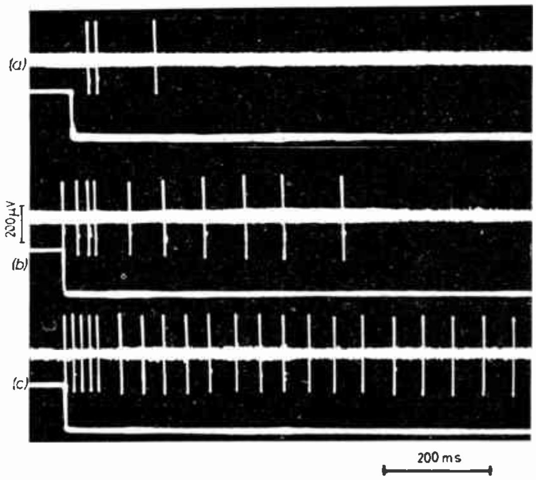

Fig. 5. Photographs of action potentials initiated by a muscle spindle recorded with moving film; upper beam—action potentials, lower beam—stretch monitored by RCA 5734 transducer. Stretch increased in (*b*) and again in (*c*) by 5%.

Recording is through a cathode follower, d.c. amplifier and oscilloscope, and pictures are taken with a stationary spot and moving film in the camera. The preparation is mounted in such a way that it can be stretched at one end by a relay operating from a 9 V battery. Any oscillations are damped by a vane dipping into a silicone solution. The stretch is monitored either by a transducer (RCA 5734) or by a photocell, connected through an amplifier to one beam of the oscilloscope.

Figure 5 shows impulses generated by a single spindle in a tenuissimus muscle; as the muscle is stretched a burst of impulses occurs and the discharge continues throughout the stretch, if sufficient tension is applied. The frequency of impulses is related to the magnitude of the stretch, and this relationship is demonstrated in Fig. 6 where the frequency of impulses is plotted against the stretch. Intensity of stimulus is therefore signalled to the central nervous system by a frequency code (since all the signals in the nerve fibre from one spindle are the same size and are propagated with the same velocity).

Other characteristics of the transducer are illustrated in Fig. 7(*a*). When the muscle is made to twitch, by stimulating motor nerve fibres during a stretch, the discharge stops. This is because the twitch of the main muscle relaxes the strain on the transducer which temporarily stops generating impulses. However, as mentioned earlier, there is a mechanism for altering the bias on the transducer so that it will fire even when the muscle is not under tension. This is shown in Fig. 7(*b*) where a strong stimulus to the muscle makes not only the main muscle; but also the small muscle fibres within the spindle, twitch. These stretch the transducer and cause a burst of impulses.

5. Mechanism of the Transducer

Since the nerve fibre can only propagate signals of fixed size, the question arises: how does a stimulus of variable intensity (stretch) give rise to discrete impulses of proportionate frequency? The intermediary step in this conversion is a local d.c. potential in the sensory nerve endings. The duration and magnitude of this potential depend on the stretch and its sign is negative; that is to say, the resting potential in the nerve ending is decreased. The potential spreads passively into the nerve fibre where it acts as a stimulus by reducing the resting potential. Impulses are then generated in the usual manner; the frequency of the impulses will depend mainly on the rate at which the membrane becomes depolarized after each action potential is over and this in turn will depend on the time-constant of the membrane and the size of the stimulus. Hence, the larger the local potential in the transducer the greater the depolarization of the nerve fibre and the higher the frequency; the maximum frequency possible is fixed at about 500 c/s by the shortest interval required for recovery after each action potential.

We have seen that to record the action potentials in the nerve trunk is fairly easy; but to record from the transducer nerve endings is much more difficult. They

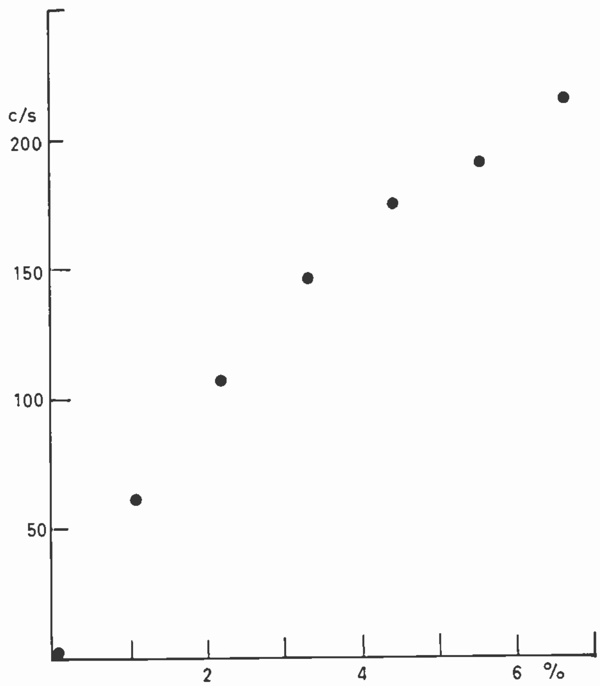

Fig. 6. Relation between frequency of impulses in a single sensory nerve fibre (ordinates, c/s) and stretch applied to the muscle (abscissae, expressed as % increase in original length).

(*a*)

(*b*)

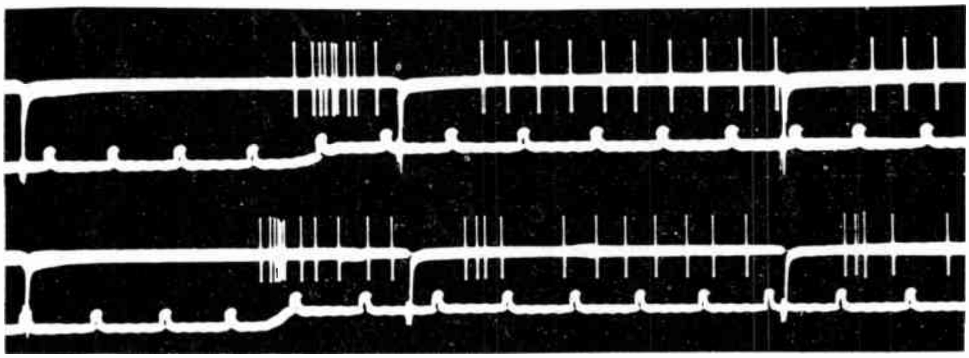

Fig. 7. (*a*) Stimulation of the muscle (indicated by large downwards deflections of upper beam) causes twitching which interrupts the discharge by relaxing the spindle.
(*b*) Stronger stimulation of the muscle causes twitching of the spindle muscle fibres as well as the main mass of the muscle, and this results in a burst of impulses from the spindle in the middle of the pause. 100 ms pulses on lower beam upwards deflection of which indicates stretch of muscle.

are too small to be penetrated by a micro-electrode (even if one knew exactly where to put it) and they are embedded in a large mass of inactive tissue which one cannot dissect off. Consequently even an external electrode cannot be placed accurately on the nerve terminals. However, the cable-like properties of nerve enable one to use the fibre as an electrode in

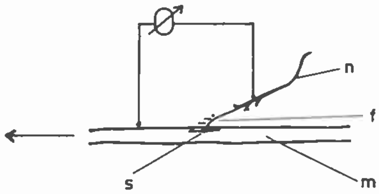

Fig. 8. Diagram to illustrate method of recording local potentials from the nerve ending. Electrodes are placed on the nerve (n) and the muscle (m). Local negativity of the spindle nerve endings (s) is passively conducted into the single fibre (f). The whole preparation is in paraffin after removal of as much saline and connective tissue as possible.

continuity with the ending. Figure 8 shows how this is done. The nerve is dissected to a point as near to the ending as possible without causing damage. One electrode is placed on the nerve trunk, the other on the main mass of the muscle and the whole preparation lifted into paraffin. One is now recording between a point on the nerve and the interface where the high resistance nerve filament leaves the mass of the muscle. If this latter point is near enough to the nerve ending, local potentials can be recorded, although they will exponentially decrease in size with the distance from the source. A d.c. shift in the baseline is recorded when one stretches the muscle. This shift is caused by negativity of the nerve ending and is known as the "receptor" or "generator" potential. Such potentials are observed more clearly in the presence of a drug like procaine which temporarily prevents the initiation of action potentials. Receptor potentials recorded in this way from the

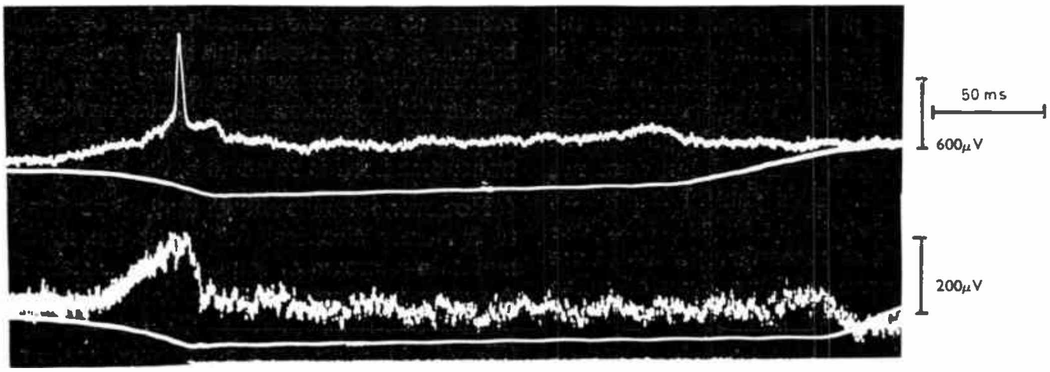

Fig. 9. Receptor potentials recorded from a tenuissimus muscle. Stretch (downward deflection of lower beam monitored by RCA 5734) causes negativity of the nerve endings. Action potentials have been practically abolished by bathing the muscle in procaine—a local anaesthetic which in small concentrations does not affect the receptor potential but prevents the initiation of impulses. There is a single action potential in the upper record; gain increased three times in lower record.

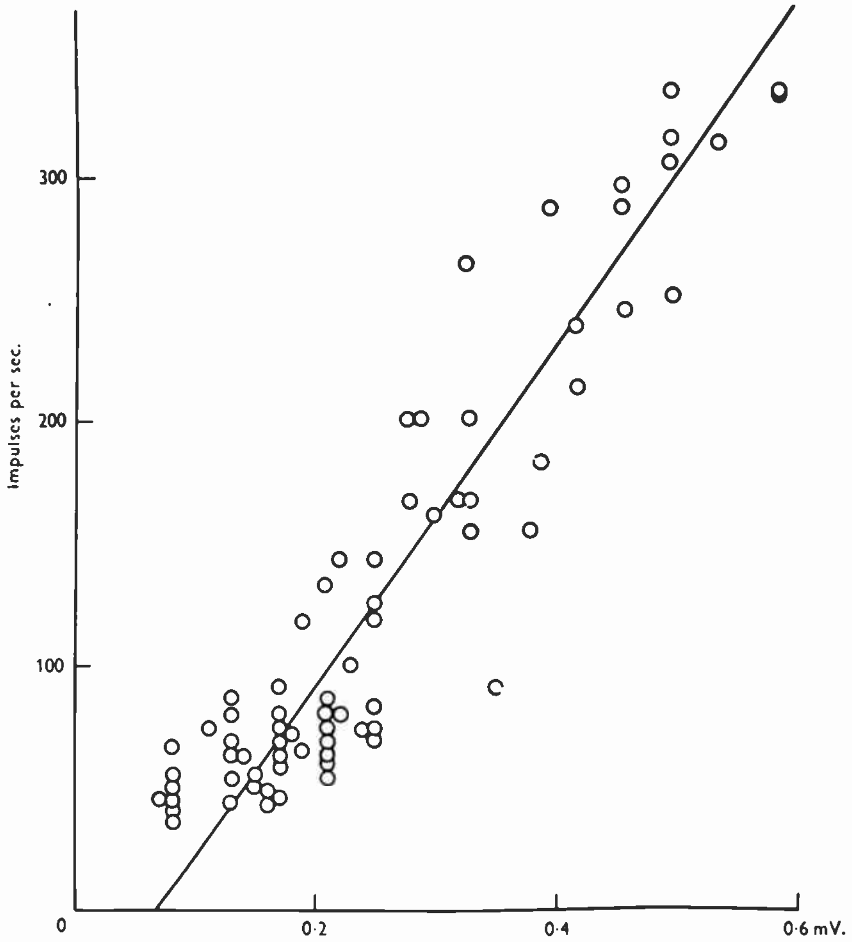

Fig. 10. Relation between local depolarization of the nerve endings (abscissae) and frequency of impulses (ordinates). (After B. Katz.[3])

tenuissimus muscle of a cat are shown in Fig. 9. The relationship between depolarization and the frequency of propagated nerve impulses is linear and is shown in Fig. 10 (from a paper by Katz who first observed receptor potentials). The absolute magnitude of the potential in the ending is not known; owing to the decrease in size through passive spread through the nerve membrane the signal actually recorded is usually less than 1 mV and it is important to distinguish this from artifacts caused by movement. The simplest control is to kill the nerve fibre by pinching it, which abolishes the receptor potential but does not affect movement artifacts. This control is applied, inadvertently, only too often during and after dissection. Other methods of recognizing artifacts are to short the receptor potential by a drop of saline between the electrodes or by letting the nerve lie against the muscle.

6. Peculiarities of the Transducer

6.1. *Phasic Sensitivity*

It can be seen from the previous figures that the frequency of discharge is greatest at the beginning of a stretch. Later, even though the stretch remains constant the impulse frequency decreases or may even stop. This fall in frequency is known as adaptation. There is more than one mechanism by which adaptation might possibly occur. For example a square-wave stretch may be distorted in the centre of the muscle so that the transducer is deformed at the beginning of a stretch but then relaxes with time; alternatively there may be some capacitive coupling within the transducer mechanism itself. It has not been possible to resolve this question since the transducer itself is so small and inaccessible.

However, it can be shown that adaptation is not due to a purely electrical failure of the nerve fibre to maintain a stream of impulses at constant frequency. A square-wave receptor potential can be simulated by passing d.c. from a battery through the nerve ending (Fig. 4). Impulses are then initiated in the nerve fibre if the direction of current flow is such that the nerve endings become depolarized (Fig. 11(*b*)). If the current is reversed so that the resting potential in the nerve is increased, the excitability is reduced and no impulses are initiated. The impulses produced by depolariza-

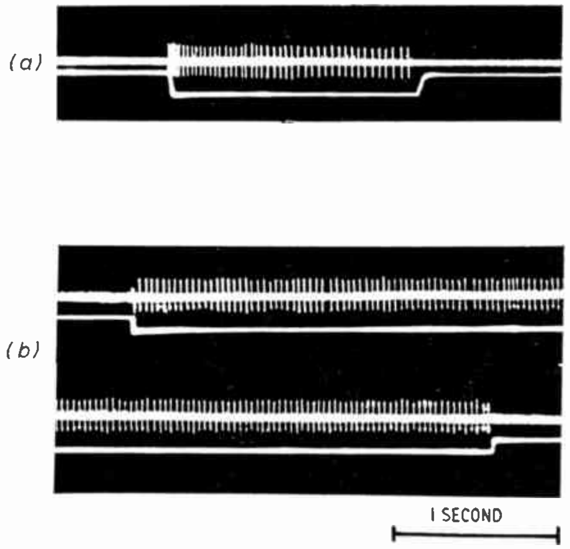

Fig. 11. (*a*) Response to stretch of a single spindle; note the initial high frequency which declines with time; lower beam stretch monitored by RCA 5734 transducer.

(*b*) Response of the same nerve ending to d.c. Lower beam is the current monitored across a resistance. Downwards deflection indicates that current flow is depolarizing the nerve terminals. The frequency of impulses does not decline with time.

tion, unlike those produced by stretch, do not decline in frequency while the current is maintained (Fig. 11(*a*)). One can conclude from this that adaptation is due to distortions in the receptor potential and not to any electrical failure in impulse generation.

6.2. *Temperature Characteristics*

Another characteristic of the muscle spindle is its ability to respond to cold. At 37° C the spindles in an isolated, relaxed muscle are silent; when cooled to 32° C a regular discharge at 10 c/s begins abruptly. This is probably not due to mechanical deformation of the transducer and it may be caused by a fall in the resting potential of the nerve endings. Once again this cannot be proved directly and only indirect experimental evidence could be obtained for this hypothesis.

6.3. *Noise*

The transducer mechanism in mammals is remarkably free of noise. After adaptation the discharge is so regular that it can be synchronized on the oscilloscope for many minutes. In the frog, however, the impulse frequency is never regular and it can be shown by laboriously counting thousands of intervals that the irregularity is constant at about 2·5 c/s at all frequencies. This suggests that there may be some constant electrical disturbance in the finest nerve terminals, possibly caused by random ionic movements.

7. Conclusions

Some of the difficulties which occur when one tries to study a small fragile transducer buried in inactive tissue have been described. In doing so considerable oversimplifications have been made regarding the complex biasing system and the variations between different types of spindle. There are still many gaps in our knowledge; the transducer's fuel is not known but is possibly glucose; it probably maintains a resting potential of about 90 mV by separating sodium and potassium ions but no matter how often it is stretched it does not fatigue; as yet there is still little or no evidence about the energy transformations which occur in the nerve endings during stretch, and even less information about the circuits within the nervous system which control muscular movements.

8. Acknowledgment

I would like to thank Mr. K. Copeland (Associate Member) for suggesting the subject of this paper, Drs. O. C. J. Lippold and J. W. T. Redfearn for permission to reproduce Figs. 4, 5, 6, 7, 9 and 11, and Professor B. Katz for Fig. 10.[3]

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The Diamond Jubilee of Transatlantic Radio

Sixty years ago—on 12th December 1901—Guglielmo Marconi became the first to send a wireless signal across the Atlantic. This remarkable achievement with such primitive equipment marked the birth of world-wide communication.

During the early 1890s many leading physicists were closely interested in the properties of "Hertzian waves", but none expressed a thought that these waves would be of the slightest value for the purpose of communication. In 1895, Guglielmo Marconi, working in Italy, discovered the great increase in range which could be obtained by the use of an elevated aerial. It was this discovery which paved the way for the use of Hertzian waves in a practicable system of wireless telegraphy.

Early in the following year Marconi came to England and applied for the world's first patent for wireless telegraphy. He spent the next few years in an almost continual round of experiment, development and demonstration, his object being continually to improve the reliability and range of his apparatus. At first he only covered a mile or so on Salisbury Plain; in 1900 he set up reliable communication from the Isle of Wight to The Lizard in Cornwall, a distance of 186 miles.

The shipping companies had shown mild interest but very little enthusiasm to install wireless equipment on their ships. Scientists were sure that really long ranges were impossible, believing that wireless waves, like light waves, should not follow the curvature of the earth. However, Marconi's experiments had led him to believe that the key to longer ranges lay in the employment of larger aerials and higher transmitter powers. He therefore determined to build super-power transmitting stations, one on each side of the Atlantic, and to attempt two-way communication. Accordingly sites were selected at Poldhu in Cornwall and at Cape Cod in Massachusetts.

It is difficult to visualize the stupendous problems which confronted him. The aerial systems were of a size and complexity which had never been attempted before, consisting of twenty 200-ft masts in a circle with an inverted cone of about 400 wires leading down to the transmitter. The transmitter itself was to be 100 times more powerful than any hitherto built. Marconi delegated the responsibility for this to his scientific adviser, Professor J. A. (later, Sir Ambrose) Fleming.

Some details of the transmitter may be of interest. The prime mover for the generation of power was an oil engine which drove a 2000 V 50 c/s alternator, capable of delivering 25 kW. The transmitter employed two 20 kW transformers parallel-connected to step up the input voltage to 20 000 volts. This was fed through r.f. chokes to a closed oscillatory circuit in which a capacitor discharged across a spark gap via the primary of a "jigger" or r.f. transformer. The secondary of this transformer connected to a second spark gap and capacitor and the primary of a second r.f. transformer, the secondary winding of this transformer being in series with the aerial. Keying was effected by short circuiting the chokes in the alternator output.

Both the Poldhu and Cape Cod stations were all but ready when severe gales wrecked the aerial arrays and masts at both stations almost simultaneously. A new aerial system was therefore erected at Poldhu, consisting of 54 copper wires arranged in a fan-shape and upheld by a triatic slung between two 150 ft masts. The current into the bottom of this aerial is stated by Fleming to have been 17 amperes and the radiated frequency is thought to have been between 100–150 kc/s.

With the encouraging news that Poldhu's signals were being strongly received at Crookhaven in Ireland, 225 miles away, Marconi went to St. John's, Newfoundland, the nearest landfall in the New World, taking large canvas kites and several small balloons with which to raise the aerial on Signal Hill. On 9th December a cable was sent to Poldhu instructing the engineers to begin transmissions on the 11th, between 3.0 p.m. and 7.0 p.m. G.m.t. The signals were to consist of repetitions of three dots (the Morse letter "S"), so that an automatic sender could be employed, and the wear and tear on the transmitter of long operation avoided.

On 12th December a full gale was blowing, but despite this a kite was flown carrying an aerial to a height of 400 ft. The tunable receiver could receive no signals because the erratic movements of the kite were continually altering the angle of the aerial to earth, and therefore its capacitance. Marconi, decided, therefore, to revert to the older, untuned receiver, using a telephone earpiece in series with the coherer.

The type of coherer used is of particular technical interest in that it is described as consisting of a glass tube with a plug of iron at one end and another of carbon at the other, with a globule of mercury between them. The device was self-restoring and had to be used in conjunction with a telephone earpiece. It would seem, therefore, that what is described as a coherer was in fact a true semiconductor rectifier with either the dissimilar plugs or oxide film on the mercury, or possibly other surface impurities, performing the rectification process.

At 12.30 p.m. Newfoundland time, on 12th December 1901, Marconi heard, faintly but distinctly, the groups of three dots which could only have been emanating from Poldhu, 2200 miles away. The feat was all the more remarkable when it is remembered that no amplification was possible at the receiver, and so the signal itself had to be strong enough to operate the earpiece.

In February 1902 tests were carried out between Poldhu and the liner *Philadelphia* en route from Southampton to New York in which S's were received on the ship at a distance of 2099 miles. Ten months later two-way communication was effected between Poldhu and a new high-power transmitting station at Glace Bay, Canada.

Until the tests between Poldhu and the *Philadelphia* it had not been realized that much longer ranges were obtainable at night. Indeed it was only then that it was realized that for the transatlantic experiment a listening watch had been kept at the worst possible time of the day!

An exhibition commemorating the anniversary of Marconi's experiment was arranged at the Science Museum, London, from 13th December to 25th January, 1962. The Institution was represented at the official opening by the General Secretary, Mr. Graham D. Clifford.

U.D.C. 522.21:523.164

The Australian 210-ft Radio Telescope

By

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AND

H. C. MINNETT, B.Sc., B.E.†

Presented at the Convention on "Radio Techniques and Space Research" at Oxford on 5th–8th July 1961. The paper was read at the Convention on behalf of the authors by Mr. J. P. Wild of the Radiophysics Laboratory.

Summary: A steerable radio telescope 210 ft in diameter is under construction near Parkes in New South Wales. The instrument is intended primarily for research in radio astronomy and is expected to commence operations at the end of 1961. The paraboloid has an f/D ratio of 0·41 and the surface error should be less than ± 9 mm under normal operating conditions. High aperture efficiency should therefore be realized at the hydrogen-line wavelength of 21 cm and the overall wavelength range should extend from metre wavelengths down to approximately 10 cm. The mounting is of the altazimuth type and its movement in equatorial co-ordinates is achieved by means of a unique master-equatorial control system. The overall pointing accuracy of the telescope is expected to be 1 minute of arc.

1. Introduction

A steerable radio telescope 210 ft in diameter is now under construction near Parkes in New South Wales for the C.S.I.R.O. Division of Radiophysics. When completed, the telescope will be the second largest in operation and the accuracy of the surface and the precision of pointing should set new standards for an instrument of this size.

The telescope is sited in a region with a very low electrical noise level and with a large flat area available for additional installations. Although some time will probably be devoted to the tracking of space probes, the telescope is intended primarily for research in radio astronomy.

This paper briefly describes the history of the project, the principal features of the design and the progress of the construction work.

2. History of Project

The project became possible early in 1956 following generous grants from the Carnegie Corporation of New York and the Rockefeller Foundation. These grants amounted finally to half the total cost of £500 000 (or £650 000 with site facilities), the balance being contributed mainly by the Australian Government.

A detailed functional specification would not at that stage have been possible, since several engineering problems of fundamental importance had first to be resolved. The basic performance criteria were defined by C.S.I.R.O., and Freeman Fox and Partners, consulting engineers of London, were appointed to carry out a thorough study of the engineering and financial factors involved and to submit a feasibility report.

Owing to the novelty and scope of the design problems, very close liaison between C.S.I.R.O. and the consultants was essential. Only in this way could the detailed radio and astronomical requirements of the users be related continuously and expeditiously to the results of the design study.‡ As the work proceeded and solutions satisfying the basic criteria were found, detailed specifications covering C.S.I.R.O.'s requirements were gradually evolved.

Freeman Fox and Partners' feasibility report was submitted to C.S.I.R.O. in December 1957. It demonstrated that for paraboloids less than 300 ft in diameter, the surface accuracy specified for normal operating conditions could be achieved without resorting to automatic shape-adjustment mechanisms.

The report proposed a compact and rigid form of altazimuth mounting combined with a novel control device suggested by Dr. Barnes Wallis§ for guiding the telescope along a path in equatorial co-ordinates. Design principles were also formulated for a servo-drive system capable of forcing the massive altazimuth mounting to follow the control commands with the very high precision and stability required. For telescopes with diameters above 150 ft, it was shown that an altazimuth mounting of this type would be both cheaper and more accurate than comparable equatorial mountings.

The report concluded that the proposed design of

† C.S.I.R.O. Radiophysics Laboratory, Sydney, Australia.

‡ For this purpose, Mr. H. C. Minnett was attached to the consultants throughout the project.

§ Vickers-Armstrongs (Aircraft) Ltd., England.

telescope was feasible for operation down to at least 21 cm with a dish diameter in excess of 200 ft and at a cost within the funds available.

These recommendations were accepted by C.S.I.R.O. and early in 1958 Freeman Fox and Partners commenced the detailed design of an instrument with a paraboloid diameter of 210 ft. Figure 1 shows a model of the final design. Tenders for the construction work were invited from American, German and British firms and in July 1959 the prime contract was awarded to Maschinenfabrik Augsburg-

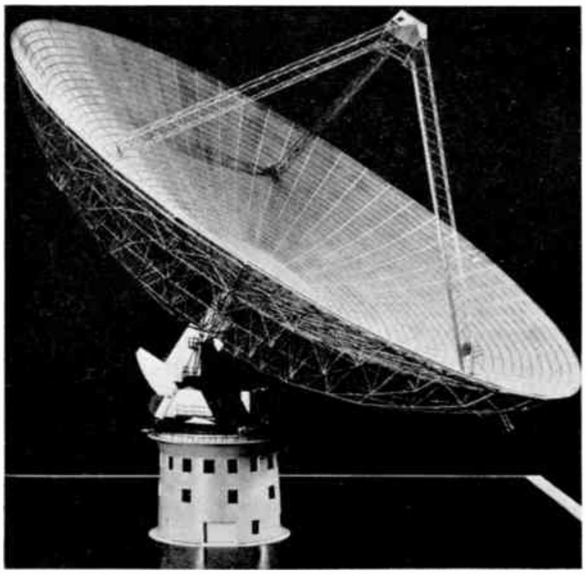

Fig. 1. Scale model of 210-ft radio telescope. (Photograph by courtesy of M.A.N. Germany.)

Nürnberg A.G. (M.A.N.). The sub-contract for the equatorial control system was given to Askania-Werke, West Berlin, whilst Associated Electrical Industries (Manchester) Ltd., were made responsible for the servo-drive system and all cabling, lighting and inter-communication equipment.

Site work on access roads and foundations commenced in September 1959, while work was proceeding in Germany and England on the fabrication of the altazimuth mounting and the drive and control equipment. Following a trial assembly and partial tests of the servo-drive system, the mounting was dismantled and shipped to Australia in September 1960.

Site erection work then proceeded steadily and by May 1961 the telescope had reached the stage shown in Fig. 2. It is now expected that the programme of performance and acceptance tests will be completed by the end of 1961.

3. Main Features of the Telescope

The paraboloid and its mounting are constructed throughout from steel rather than one of the light alloys, in order to minimize deflections from wind loads and differential temperature effects.

3.1. *Paraboloid Reflector*

The 210-ft diameter paraboloid has a focal length of 86·1 ft (focal ratio 0·41). The supporting structure for the reflecting surface consists of a series of radial ribs, cantilevered from a central hub and joined together by a ring girder system. The whole of this supporting structure was site-fabricated from Australian steel on jigs and then lifted into position in sections by means of a 230-ft derrick (Fig. 2). This derrick was used for all lifting operations during the construction.

The upper chords of the ribs are interconnected by a grid of equiangular spiral members which join at their inner ends to a thick welded-steel shell 54 ft in diameter. This solid shell forms part of the reflecting surface of the paraboloid and Fig. 3 shows a rotating template used for measuring its shape during final adjustments.

The remainder of the paraboloid surface consists of wire mesh panels supported on a series of radial purlins. Stacks of panels are visible in Fig. 3 ready to be set in position on the radials which can be adjusted vertically relative to the underlying spiral members by means of some 700 screw devices. Isolation gaps between groups of panels facilitate this movement, which allows the mesh surface to be adjusted for optimum results.

The wire mesh has been chosen so that 98% of the power is reflected at a wavelength of 10 cm. It is expected that the mesh surface will be accurate in shape to better than $\pm$ 9 mm for any orientation of the paraboloid, whilst the errors in the solid centre will

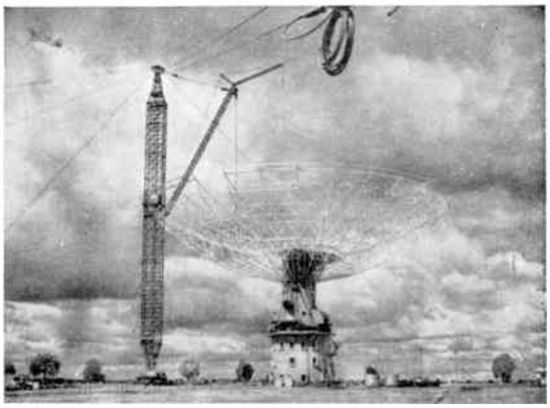

Fig. 2. Final section of the reflector supporting structure being lifted into position (May 1961).

not exceed ± 3 mm. The efficiency of the paraboloid should therefore be maintained to wavelengths well below 21 cm.

A small weatherproof cabin is supported on a tripod structure just above the focal plane to house parts of the radio equipment which must be close to the aerial feeds. Suspended below the cabin is a 10-ft diameter platform which may be moved axially on screwed adjusters to position the feeds relative to the focal plane (see Figs. 1 and 3). The feeds themselves are carried on a rotary mount which can be operated from the control room to vary the polarization accepted.

Fig. 3. View of the paraboloid after construction of the spiral purlin system, the centre plating and the erection of the tripod.

3.2. *Altazimuth Mounting*

The hub of the paraboloid is supported on two altitude-axis bearings mounted on top of the turret structure as shown in Fig. 4. The load is transferred at the base of this structure to four tapered rollers, 21 inches in diameter, which run on a flat azimuth track 37 ft in diameter. Lateral loads are transmitted by a central bearing to the circular concrete tower to which the azimuth track is bolted.

The counterweights attached to the bottom of the hub are overbalanced so that the equilibrium position of the paraboloid is near the zenith. This eliminates backlash from the altitude servo-drive and is also a safety feature which allows the telescope to be moved to the stowed position at the zenith under manual control. Driving racks of 27-ft radius are attached to the lower faces of each counterweight structure, and these are driven by individual d.c. servo motors and gearboxes.

Two of the four azimuth rollers are driven by d.c. servo motors through gearboxes attached to the turret structure. The final stage of the drive is therefore by friction between the rollers and path, thus reducing backlash in the azimuth motion.

The altitude drive system permits motion from the zenith down to 30 deg from the horizon. From the astronomical point of view there is no great need for the telescope to point down to the horizon and this restriction allows considerable simplification in design. In azimuth, the operating range of motion is ± 225 deg. A special cable-twisting device permits flexible radio and control connections between the supporting tower and the rotating turret without resorting to slip-ring devices.

The turret structure contains two identical rooms, one of which is intended for radio equipment and provides convenient access for waveguide or heavy coaxial line to rotary joints at the adjacent altitude bearing. The second room houses rotary amplifying sets associated with the altitude and azimuth servo-drive systems.

3.3. *Supporting Tower*

The 39 ft diameter reinforced concrete tower which supports the azimuth track is 42 ft high and contains

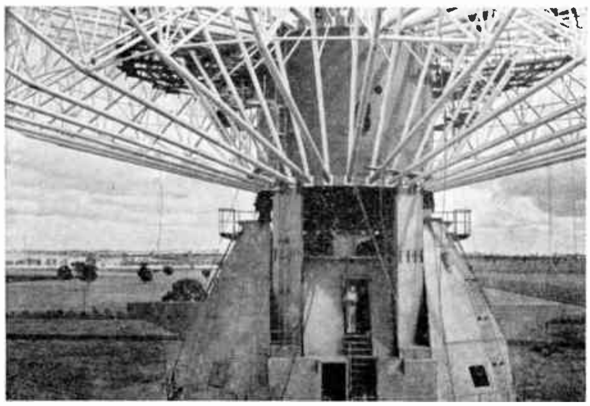

Fig. 4. The turret structure with the altitude-axis bearings supporting the hub of the paraboloid and the counterweights.

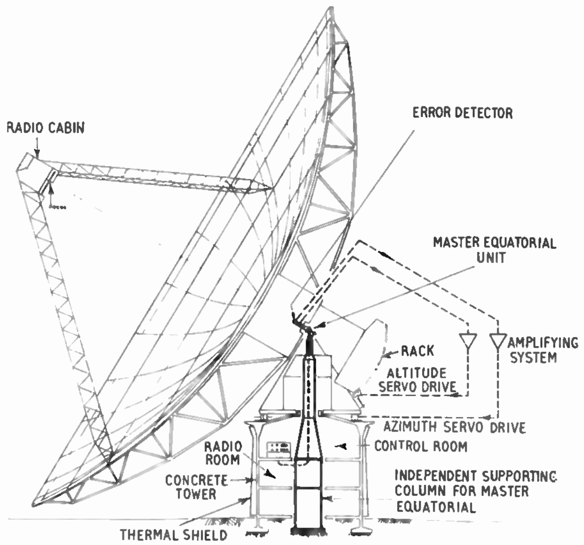

Fig. 5. Schematic of the master equatorial control system showing the arrangement of the control units in the telescope.

three floor levels. The top floor will be used as the control centre and the intermediate floor level will house the radio equipment racks.

The building is fully air-conditioned and, in addition, the walls of the tower are protected from direct sunshine by a 2-in thick shield of sprayed concrete separated from the walls by an air gap. This reduces thermal bending of the tower and thus the magnitude of the pointing error when the mounting is under altazimuth control. When the telescope is operating in equatorial co-ordinates such errors are automatically corrected, but the shield reduces the magnitude of the correction needed.

3.4. *Control System*

Figure 5 shows the system used for controlling the telescope in equatorial co-ordinates. On the central axis of the tower is a long column which is structurally independent of the tower and has separate foundations.

At the top of this column is the master equatorial unit. This is a relatively small and precisely-made equatorial mounting (Fig. 6) which is positioned so that the intersection of its rotational axes is coincident with the intersection of the axes of the altazimuth mounting. The equatorial mounting, which carries a flat mirror, may be driven from the control room in the tower so that the mirror normal follows the desired equatorial path on the sky.

In the bottom of the hub is mounted an optical error-detection unit which projects a beam of light on to the flat mirror and receives the reflected beam on a chopper-type photocell system. This system measures the misalignment of the hub axis from the mirror normal, and provides altitude and azimuth error signals which are amplified and fed back to the servo-drive motors of the altazimuth mounting. The large paraboloid is therefore constrained to follow accurately the motions of the small master equatorial unit.

An important advantage of this method of control is the correction of many of the pointing errors of the altazimuth mounting. These include errors due to gravitational and temperature deflection, gearing inaccuracies and azimuth track irregularities. It is expected that the overall error between the direction of the radio beam and the indicated direction of the control desk will not exceed 1 minute of arc.

When the telescope is under altazimuth control, the direction of pointing is measured by means of magslips geared to the altitude and azimuth axes. These magslips are connected into a closed-loop velocity-control system operated from the control desk.

Figure 7 shows the control desk during installation. Altazimuth and equatorial co-ordinates together with sidereal and solar time are indicated numerically by optical projection units and can be printed-out by electric typewriter either on command or at pro-

Fig. 6. Master equatorial unit during installation and adjustment.

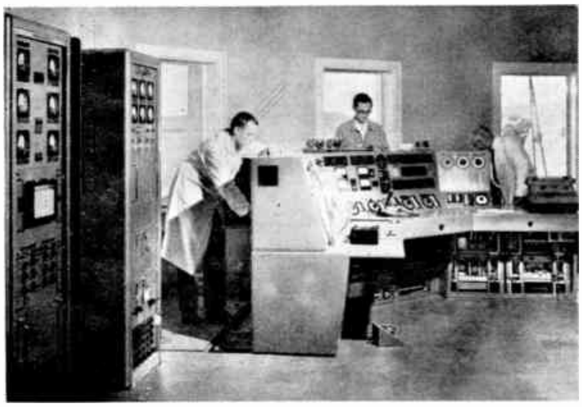

Fig. 7. Control desk of telescope on top floor of supporting tower.

grammed intervals. A wide range of continuously-variable altazimuth and equatorial rates as well as solar and sidereal rates are available. A simple automatic-scan programmer has also been provided.

The domed unit on the left-hand side of the desk is used for aligning the altazimuth and equatorial mountings within a degree or so preparatory to closing the equatorial servo loop. Various controls and indicators concerned with stowing the telescope and with the interlocking and emergency-stop systems are located on the adjacent panel.

An intercommunication system connects the desk to twelve stations on the telescope. When requested the control desk operator can provide a circuit from any one of the stations to any other.

3.5. *Radio Installations*

The C.S.I.R.O. is developing a series of receivers for use with the 210-ft telescope. Initially, conventional crystal-mixer receivers operating on 10, 20 and 75 cm will be used for performance tests and continuous-spectrum work, while a 21 cm receiver is available for hydrogen-line studies.

At a later stage, the 10 and 20 cm receivers will be replaced by receivers employing parametric amplifier input stages and a narrow-band, multi-channel receiver will be installed for the hydrogen-line investigations. In addition, a 21 cm parametric receiver is being developed in co-operation with the University of Leiden, Holland, for the study of hydrogen in external galaxies.

A comprehensive system of radio cables is being installed in the telescope. The various radio rooms are interconnected by 50 and 75 ohm coaxial lines and by multi-core control and monitoring cables. Because of the length of some of the runs, a number of the coaxial lines are of the low-attenuation, nitrogen-pressurized type.

The high sensitivity of the receiving equipment has necessitated great care to minimize the radiation of interference by the electrical system of the telescope. This has been achieved by screening all units and the interconnecting cabling. In particular, the d.c. rotary-amplifier machines and servo motors have been totally enclosed and all access cover flanges are sealed with knitted monel-wire gaskets. In addition, the rotary amplifiers are housed in a metal room. Similarly all heavy-duty relays and contactors are contained in metal compartments and the cabling throughout the telescope is enclosed in conduit or an overall screening braid. Special glands are used to connect these braids to the metal enclosures.

4. Site

The 410-acre site selected for the radio telescope is situated in the Coobang Valley, 180 miles to the west of Sydney and 14 miles by road from the town of Parkes, which has good air, rail and road connections with Sydney.

The site satisfies the primary requirement of very low radio-noise level. It is shielded from man-made electrical interference by mountain ranges in the direction of Sydney and by a series of hills in the direction of Parkes. The level of radio noise at the site is thought to be at least as low as that at any other radio observatory.

The surrounding terrain is reasonably flat for a considerable distance in all directions. It will therefore be possible in the future to combine other aerials with the 210-ft radio telescope to form an interferometer system. Other advantages of the site are a relatively low average wind speed and a dry, non-corrosive atmosphere.

Buildings on the site have almost been completed to house the resident staff and to provide full accommodation facilities for visiting scientific observers from the headquarters in Sydney.

5. Research Programme

The detailed programme of research will naturally depend to some extent on the performance tests of the telescope.

Since the effective aperture of the instrument at 21 cm will exceed that of any existing fully-steerable telescope, hydrogen-line studies will figure prominently in the programme. The first tasks will include the detailed 21 cm exploration of our own galaxy, including a survey of the galactic centre for which the telescope is geographically well placed. The Clouds of Magellan, the nearest of the external galaxies will also be major fields of investigation.

The size and precision of the telescope should allow existing surveys of discrete radio sources to be extended to distances which have not previously been accurately explored. Source identification studies will therefore form an important part of the programme.

Similarly, the large aperture will permit investigations of the radiation from planets to be extended to the more distant members of the solar system and will allow more detailed studies of the nearer ones.

For some years to come, the telescope will probably be the most powerful instrument available for tracking and communicating with space probes at great distances from the earth. It is therefore very likely that a portion of its time will be devoted to co-operation with agencies engaged in this new field of space research.

Manuscript received by the Institution on 26th October 1961. (Paper No. 696.)

DISCUSSION

Mr. J. R. Millburn (*Graduate*): The master equatorial system is most ingenious. However, the telescope mounting is essentially an altazimuth one and high azimuth rates of rotation would be necessary to track a fast object, such as a satellite, passing close to the zenith. I would therefore like to know the maximum rate of rotation of the mounting in azimuth.

Mr. L. Malling: Can the authors say if it will be possible to utilize the higher accuracy near the centre of the reflector for operation at wavelengths shorter than would be allowed by the errors near the periphery?

Secondly, I would like to know a little more about the relative advantages of steel and light alloys for the structure.

Finally, how are the feed aerials to be mounted at the focus of the paraboloid?

Mr. J. D. Barr: I would like to ask if deflections of the dish and mounting due to wind loading are more important than those due to gravity?

Authors' Replies

In reply to Mr. Millburn, the maximum azimuth rate of rotation is 24 deg/min. The value was determined by C.S.I.R.O.'s requirement that it should be possible to scan across the sky at rates up to ten times the sidereal rate and at any zenith angle exceeding 5 deg. This covers all our requirements in radio astronomy, but not satellite tracking for which the telescope is not intended and for which there are facilities elsewhere. However, it will of course be possible to track distant space probes, for which purpose a very large aperture is essential, but not high rates of rotation.

The answer to the first of Mr. Malling's questions is that one of the advantages of supporting the reflector structure from a central hub is that the surface errors should be fairly symmetrically distributed about the paraboloid axis. It will therefore not be difficult to design a series of feeds which respond less and less to the more inaccurate outer regions of the surface as the operating wavelength is reduced.

As regards the choice of material for the structure, the basic requirement is of course minimum deflection under applied loads. For gravitational loading, light alloys have no advantage over steel since their lower density is offset by a Young's Modulus which is lower in almost the same ratio. Moreover, wind load deflections are greater in the same ratio and the coefficients of expansion of light alloys are also several times as high as that of steel.

The aerial feeds will be horns at the shorter wavelengths and dipole-pairs at the longer. They will be mounted on circular metal plates attached to a rotary mounting which can be operated from the control room to vary the plane of polarization accepted. The circular plates will register accurately in the mounting so that the radio axis of the paraboloid is not disturbed when feeds are changed.

In answer to Mr. Barr, deflections due to winds up to an average speed of 20 miles/hour, which is the maximum operating value, are several times smaller than those due to gravity, but are still significant both as regards pointing accuracy and surface distortion.

U.D.C. 523.72:621.386

X-Ray Spectrometer for Scout Satellite

By

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Presented at the Convention on "Radio Techniques and Space Research" in Oxford on 5th–8th July 1961.

Summary: The paper describes one of the experiments planned for the U.K.1 Scout satellite on the investigation of solar x-ray emission. The device uses a proportional gas counter and a measurement is made of the magnitude of individual pulses which are proportional to the energy of radiation and the average pulse rate which is a function of the intensity of radiation. The paper discusses circuit details, power consumption and reliability.

1. Introduction

One of the experiments planned for the U.K. *Scout 1* satellite is an investigation of the solar x-ray emission in the wavelength range 3–14 Å. The experiment is being carried out by the Physics Departments of University College London and Leicester University.‡

Previously, general experiments measuring the total x-ray flux have been carried out, so in this instance it is intended to carry out a more detailed study and produce an intensity spectrum over the range. The earlier experiments have given a guide to what can be expected.

It is expected that the satellite will be operating for about 1 year and in this time, there can be a wide range of activity ranging from quiet sun periods to periods of high activity. The rate of occurrence of large solar flares is expected to be low because the experiment will take place during a time of solar inactivity. Nevertheless, the range of activity requires that the instrument shall have a wide dynamic range.

2. General Principle of Operation

For the wavelength range under consideration, a proportional gas-counter is the most suitable detector. In principle, the output of the detector is a series of pulses, and the magnitude of any pulses is proportional to the energy of the incident radiation which produced it. Also, the average pulse rate is a function of the intensity of the radiation. Thus, the pulses from the detector provide all the necessary information to produce an energy spectrum of the incident radiation.

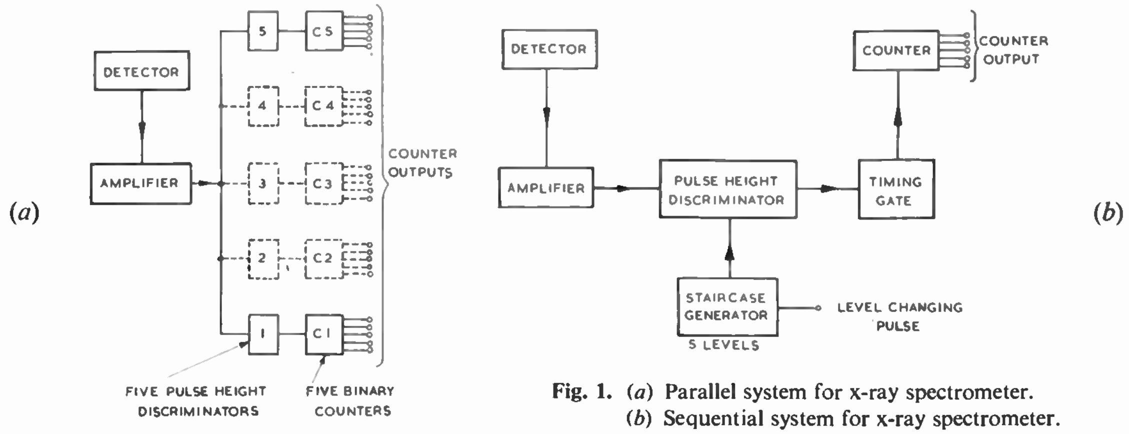

Fig. 1. (*a*) Parallel system for x-ray spectrometer.
(*b*) Sequential system for x-ray spectrometer.

To produce the spectrum, it is only necessary to count how many pulses having amplitudes within a selected range arrive in a known time. It is also possible to interrogate all the ranges under consideration simultaneously or sequentially. The former method has been used in *Skylark* experiments, but more equipment and consequently power is required than with the latter method which is used in the *Scout* experiment (Fig. 1). Only one pulse height discriminator and counter is used in the *Scout*

† Bristol Aircraft Limited, G.W. Engineering Dept., Bristol.

‡ K. A. Pounds, "Measurement of solar x-radiation", *J. Brit.I.R.E.*, 22, pp. 171–5, August 1961.

equipment, but a staircase generator is necessary to cycle the discriminator through the various ranges. A third system has been developed by the Goddard Space Flight Center for measuring the spectrum of a shorter wavelength band. This system measures the rates of all pulses bigger than a series of selected amplitudes; thus to produce a conventional spectrum, it is necessary to carry out a further operation on the results.

3. Design Considerations

It is not necessary to emphasize that economy in weight, volume, and power demand are of vital importance in satellite engineering and that reliability is a primary consideration. It is sufficient to state that in the case of the x-ray spectrometer the power consumption had to be less than 100 mW, the diameter

Fig. 2. A printed circuit card as used in the x-ray spectrometer.

less than 5½ in. Figure 2 shows the printed circuit card. All components used must be of proved reliability and be used well within their ratings over the entire environmental range.

There are the restrictions imposed by performance limitations of the various elements in the unit, and also by the input conditions. The four most important factors are

(1) Detector resolution.

(2) Dynamic range of input pulse rate.

(3) Wavelength range to be considered.

(4) System noise.

Items 1 and 2 combine to determine the requirements of the counter and the window area of the detector. The window size of the detector must be small enough so that at the highest incident flux, the x-rays will not produce pulses so close together that they cannot be resolved. The minimum pulse spacing allowable is about 1 μs; thus the maximum average pulse rate will be about 10^5 per second owing to the random nature of the pulses. From an estimate of the dynamic range of the incident x-rays, the minimum expected average p.r.f. can be determined and thus a value can be arrived at for the timing period. With this time fixed, and returning to the maximum counting rate, the necessary capacity for the counter can be determined. In this equipment 15 binary stages are required to cover the full range.

The third requirement governs the design of the detector. The material in the window of the detector is the main controlling factor, but the counting efficiency does vary with the wavelength of the radiation. The detectors used with this equipment give a range of about 3 to 14 Å.

The fourth requirement governs the number of steps into which the spectrum can be resolved. System noise includes amplifier noise, statistical variations of the detector output and uncertainties in the triggering level of the pulse height discriminator. The discriminator triggering range is limited by the power supply voltages available, and in this instrument is about 2 volts. The detector output pulses are amplified to this range, and the zero is offset by adding a bias voltage. The total noise present can amount to about 9% of the discriminator range; 3% is attributable to the amplifier and about 5 or 6% is due to the detector. Consequently, the wavelength range is divided into only 5 bands.

Finally, the equipment must be compatible with the rest of the satellite's services. Timing and initiating pulses for the equipment can be obtained from the telemetry master clock, thus ensuring that operation is synchronized with the telemetry read-out periods. Compatibility with the telemetry calls for two types of output from the spectrometer. The first is in

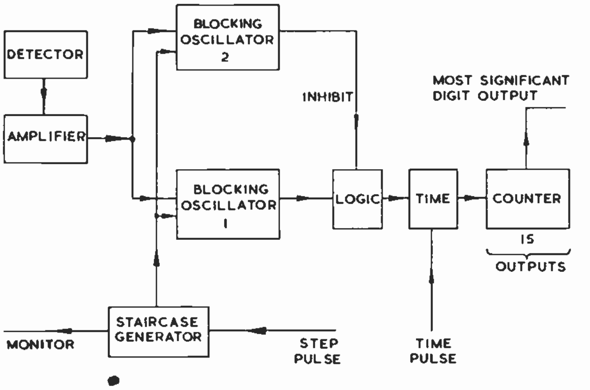

Fig. 3. Detailed block diagram.

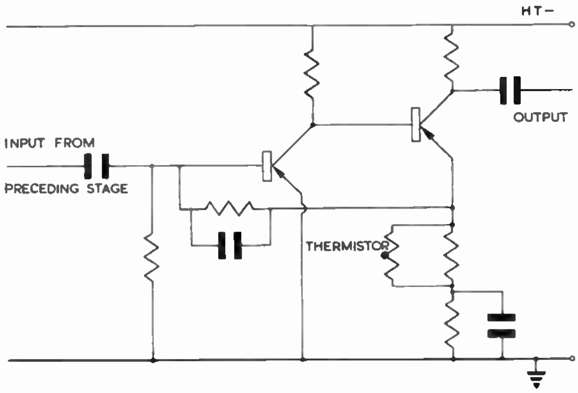

Fig. 4. Last stage of amplifier.

parallel binary form which is fed to the telemetry sender via an encoder, and the second is in analogue form, which is stored in a tape recorder when the satellite is out of contact with a ground station.

4. Circuit Details

As has been seen, pulses from the detector are amplified (Fig. 3), sorted out in the pulse height discriminator and passed through the timing gate into the counter. The sequence of operations is as follows. A pulse from the master clock clears the counter, and sets the staircase generator, which controls the general level of operation for the pulse height discriminator, to a new level. A second pulse opens the timing gate for a fixed period, and finally, the encoder samples the output of the counter and the state of the staircase generator.

4.1. *Pulse Amplifier*

The amplifier comprises three pairs of transistors, and each pair of transistors has feedback incorporated to maintain stability. The gain per pair is about 24 dB. Capacitive coupling is used between each pair, and as the amplifier is only dealing with narrow pulses, the coupling time constant is made small. This reduces the effects of low frequency noise in the system. Because of the non-linearity of the transistor input impedance, which is in evidence owing to the very low power conditions, a measure of d.c. restoration takes place. The effect of this is to introduce a d.c. component to the signal which depends on the p.r.f. This d.c. component affects the amplitude of the output because of the bias condition of the first transistor in each pair. A short coupling time constant also reduces this effect. To cover a fairly wide temperature range, the feedback circuit of the last pair includes a thermistor. This is shunted by a resistor to give it a suitable temperature coefficient (Fig. 4 shows the last stage of the amplifier).

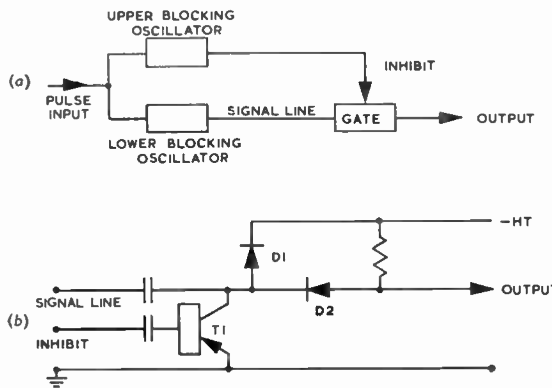

Fig. 5. Inhibit gate.
(*a*) Block diagram of logic system.
(*b*) Schematic circuit of gate.

4.2. *Pulse Height Discriminator*

As seen from Fig. 4, the amplifier drives two blocking oscillators which together with a logic gate comprise the pulse height discriminator. The two blocking oscillators are isolated from each other by emitter followers which also reduce the amplifier loading. Conventional diode isolation is insufficient owing to the low currents being used. The transistors in the blocking oscillators are held cut off by biasing the emitters, and one, the upper blocking oscillator, is biased by a larger amount than the other, the lower

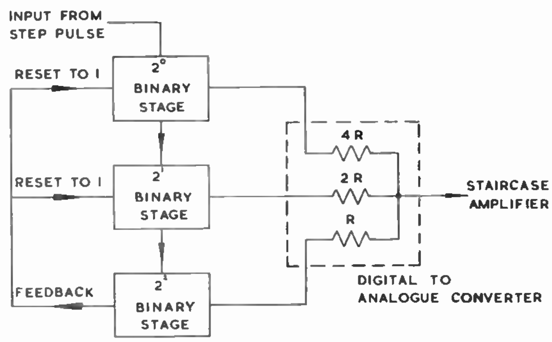

Fig. 6. Block diagram of staircase generator.

blocking oscillator. This has the effect of separating the trigger levels of the two blocking oscillators by a fixed amount. When a pulse is presented to the inputs of the oscillators, one of three conditions will occur depending on the amplitude of the pulse. If the pulse is small, neither oscillator will trigger. If the pulse is within a specific range, the lower oscillator only will trigger, and if the pulse is large, both oscillators will trigger. A gate circuit which is inhibited by a pulse from the upper oscillator performs the necessary logical sorting to pass on only those pulses with amplitudes within the given range. Figure 5 shows block and schematic diagrams of gate. Negative pulses on the line are normally transmitted through D2, but if a negative pulse is applied to the base of

T1, this transistor acts as a closed switch and the signal line is short-circuited.

4.3. *Staircase Generator*

A staircase voltage subtracted from the input signal to the blocking oscillators varies the amplitude of the input signal which falls within the pass range of the discriminator. This staircase voltage is to be changed by pulses from the programming unit, so a convenient way to derive it is to use a binary counter followed by a digital to analogue convertor, a block diagram of which is shown in Fig. 6. The convertor gives a different output voltage for each state of the counter, so successive input pulses will give a series of voltage levels. Five levels are required, and these are obtained by using three binary stages with feedback to give a repetition after five input pulses. The feedback arrangement used is to reset the counter to 3 after an output pulse. This gives five successive states, and does not require the coincidence gates which would be necessary to reset to 0 after 5. The fact that the levels do not start at zero is not important, as the pulse height discriminator is biased and also the spectrum has an offset zero.

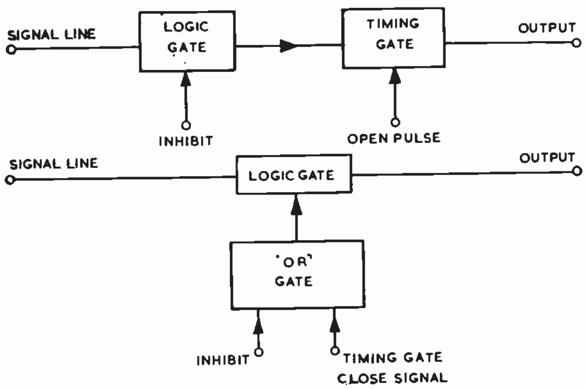

Fig. 7. Combination of logic and timing gates.

4.4. *Timing Gate*

Having used the pulse height discriminator to select a wavelength range, it is only necessary to count the output pulses from the logic gate for some selected time in order to determine the average flux in that wavelength range. In previous block diagrams, a timing gate has been shown following the logic gate. In practice the logic and timing gates can be combined as shown in Fig. 7. The inhibit gate has an extra input which holds the gate normally closed, and the input is removed during the timing period. In terms of circuit elements, this is simply an extra line feeding through a diode on to the base of the transistor in the logic gate.

4.5. *Counter*

The counter which records the pulses is a straight binary counter with two read-out systems. One is a simple 15-digit parallel binary read-out. The other is an indication of which is the most significant digit present in the accumulated count. This latter system enables a coarse measurement with a wide dynamic range to be stored in a tape recorder which has a low data capacity. Driving the counter from the logic gate introduced an interesting problem. As a continuous range of amplitudes is present at the input to the discriminator, and as the blocking oscillators are not perfect, it is possible that some threshold signals will occur which only partially close the gate in the inhibit state. Thus pulses from the gate can also occur in a wide range of amplitudes. Some pulses are too small to affect the binary stages at all, and some pulses are big enough to turn over the first binary stage. Neither of these pulses cause any trouble. However, there is a threshold range within which the pulses can appear at the collector of one of the transistors as an amplified pulse. It does not change the state of the first stage, but it is transferred to the second stage which can amplify it still more. This process carries on through the counter until the pulse is big enough to change the state of a binary stage. Thus a single pulse which should not have been counted can introduce a very significant error. The effect is eliminated by subtracting a voltage from the first transfer pulse such that only a genuine change over of the first binary stage will cause a signal to be applied to the second stage.

4.6. *Read-out*

To obtain the most significant digit read-out, an additional output is taken from each binary stage. This is taken from a tapping on the collector load of one of the transistors, so that the voltage output in the "1" state can be controlled. The schematic of binary with 2 outputs is shown in Fig. 8. The tapping

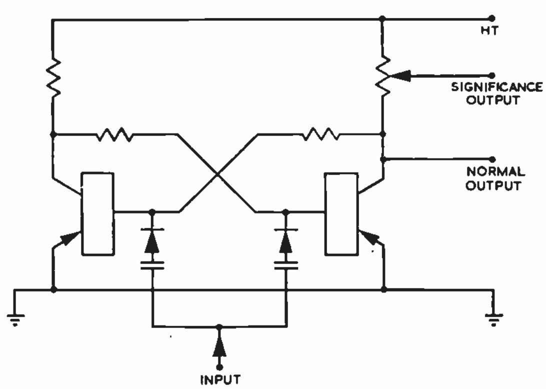

Fig. 8. Skeleton circuit of binary counter.

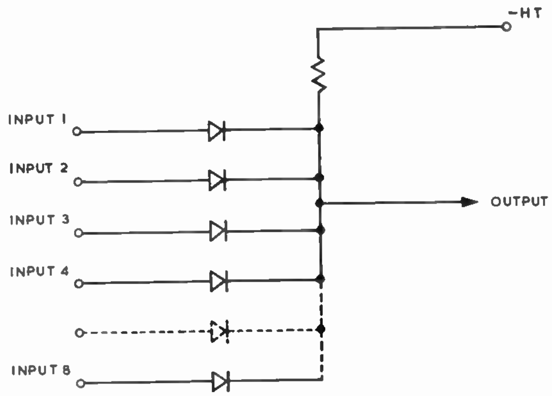

Fig. 9. Gate for selecting most significant digit.

point is adjusted so that the output voltage obtained in a "1" state is proportional to the significance of the stage in question. The most significant stage is arranged to give the most positive voltage. From stability and telemetry resolution considerations, it was decided to apply this read-out to only 8 of the 15 stages in the counter. From a consideration of the expected counts, it was decided to apply this read-out to stages 4 to 11 inclusive. The significance outputs are fed into an eight input AND gate (see Fig. 9). The important property of this gate is that the output obtained is equal to the most positive of the inputs present, and so with the arrangement described it will correspond to the number of the most significant binary stage which is in the "1" state. The overall accuracy of this read-out is $\pm 33\frac{1}{3}\%$ of the indicated count, but the dynamic range is about 200 to 1.

5. E.H.T. Generator

In addition to the spectrometer equipment for processing the detector's output pulse, an e.h.t. generator was designed to provide the priming supply. A block diagram is shown in Fig. 10. Earlier experiments have used solid electrolyte dry batteries, but as their temperature stability is suspect, a d.c.–d.c. convertor was used in this instance. The convertor uses an intermediate pulsating voltage of about 700 volts at 7·5 kc/s which is rectified in a voltage multiplier array to give about 2·2 kV. A corona stabilizer across this supply gives the required output of 1·6 kV nominal which is stable within ±3 volts.

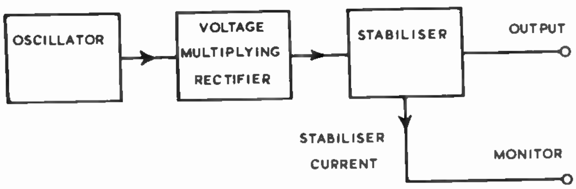

Fig. 10. Block diagram of e.h.t. generator.

The amount of power consumed by the detector is very small, only a few milliwatts. Thus losses in the circuit due to transistor leakage and transformer losses are large compared with the required output power so the efficiency is inherently low. Figure 11 shows the output power/efficiency characteristic of the unstabilized convertor. Furthermore, the use of a shunt stabilizer again lowers the efficiency. To keep the input power low, the transformer must be designed to keep the losses as low as possible. The output voltage of the multiplier must be chosen to be the lowest consistent with adequate stabilization over the full input range so that minimum power is consumed in the stabilization network. Monitoring is achieved by measuring the current in the corona discharge tube, as any direct method would use too much power.

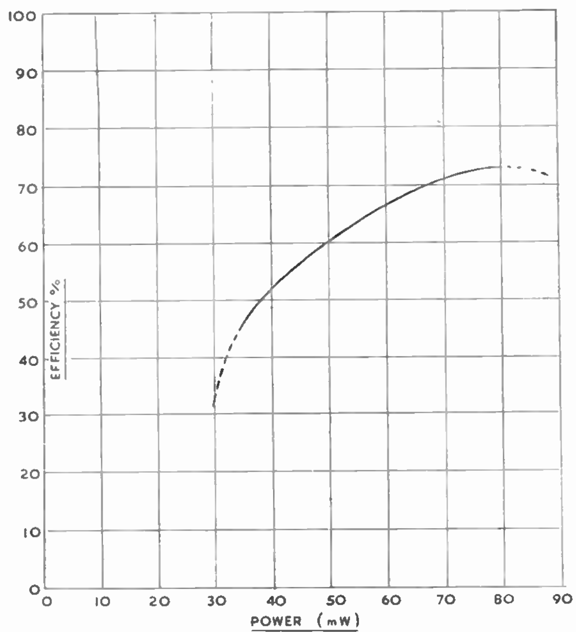

Fig. 11. Graph showing efficiency (%) plotted against power (mW) for an unstabilized convertor.

The operation of the corona tubes at low power tends to introduce the problem of noise, which is aggravated by severe vibration. To avoid trouble from this source, tubes are selected for use after they have been vibrated. The need for high stabilization can be seen from the gas gain priming voltage curve for a proportional gas counter.

It is typical of e.h.t. generators which have to work under low pressure that physical layout and the avoidance of sharp points is very important if unwanted corona discharges are not to occur.

The avoidance of unwanted corona discharge with this equipment is particularly important as power is

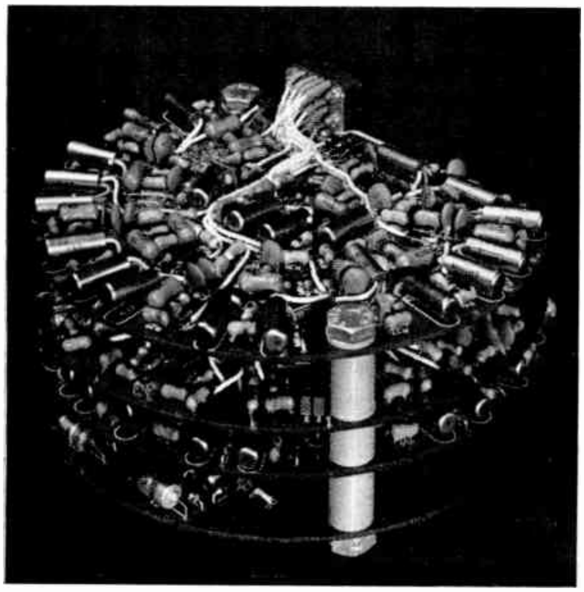

Fig. 12. The x-ray spectrometer circuitry.

in very short supply, and there is the danger of overloading the driving transistor in the generator. Having determined the optimum layout for the generator, corona discharge is completely suppressed by filling the unit with insulating foaming resin. The unit has been tested over the range of pressures from atmospheric down to 0·3 microns of mercury. Finally, the unit is screened with copper foil to prevent r.f. interference problems.

6. Reliability

The estimated mean time to failure for the complete spectrometer is of the order of 4 months, but whether this figure means anything or not is debatable. In the fields of aircraft and missile electronics, where large numbers of the same types of equipments are flown, it is possible to obtain the statistics of failures. However, for satellite experiments, where only one equipment of a type will be flown, and it is impossible to put in a representative number of ground running hours, one can only use the most likely formula available and hope that the answer is of the right order. The practical steps which have been taken to achieve reliability include the use of proved components which are not run at their limits of performance, very careful manufacture, and thorough environmental testing. Figure 12 shows the mode of construction adopted for the electronic circuitry of the spectrometer.

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POINTS FROM THE DISCUSSION

Mr. S. D. Abercrombie (*Member*): What precautions are taken in the selection and testing of component parts before they are assembled in the equipment? Are the components "aged" and tested under vacuum conditions?

The authors (*in reply*): The precautions taken with components before assembly depend upon the types of component. Some components of which we have a great deal of experience are incorporated into the equipment without test. Others are thoroughly tested and selected before incorporation. However, some components have had to be taken on trust because, in the short time available for manufacture, it has been difficult enough to obtain sufficient components for construction purposes, let alone for batch pre-testing. Components have not been aged under vacuum conditions.

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The Canadian Defence Research Board Topside Sounder Satellite

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Presented at the Convention on "Radio Techniques and Space Research", in Oxford on 5th–8th July 1961

Summary: This satellite is designed to measure the characteristics of the outer levels of the ionosphere above the region of maximum ionization. The Topside Sounder will cover the frequency range from 1·8 to 11·5 Mc/s in 10 second sweeps for periods of twelve minutes on command from ground stations. Much of the surface is covered with solar cells which will charge nickel cadmium batteries. The sounding transmitter will produce 200 W pulse power in 100 μs pulses at a rate of 67 per second.

1. Introduction

The Telecommunications Establishment in Ottawa has been studying the ionosphere over Northern Canada for the past thirteen years in an effort to provide a better understanding of high frequency communication problems in Canada, particularly at high magnetic latitudes and in the auroral zone. Ionospheric data obtained there are usually complicated and interpretation is frequently difficult or impossible at the present state of knowledge. Consequently it is important to have all the information possible to explain polar events in the ionosphere.

Although the lower side of the ionosphere has been studied by radio methods from the earth's surface for many years, there is a serious lack of information concerning the upper side of the ionosphere due to the reflecting and absorbing properties of the ionized layers. Information on the electron density is available up to the height of maximum ionization, but extremely little is known about the ionosphere beyond this point. Details of the diurnal and spatial variation in the electron density under the varying magnetic and auroral conditions are also desired with particular emphasis on high latitude effects. At present one can only estimate the electron density above the ionosphere and supplement this information with some rocket data and some indirect measurements, such as the twinkling of radio stars. Rocket measurements are limited to a particular time and place, and do not tell of variations in space or time. Changes in the electron density above the ionosphere as solar particles arrive from the sun would also be of great interest. The D.R.T.E. Topside Sounder satellite experiment is designed to supply more information above the ionosphere. Figure 1 shows a distribution of free electrons per cubic centimetre with height. The curve above the F layer maximum is considerably in doubt. Figure 2 shows diagrammatically how the ionosphere will be sounded from above by the Topside Sounder satellite while it is simultaneously sounded from below by ground based sounders.

† Defence Research Telecommunications Establishment, Ottawa.
‡ Defence Research Member, Canadian Joint Staff, London.

2. Topside Sounder Experiment

D.R.T.E. has the facility of ground ionospheric stations at St. John's (Nfld.), Ottawa (Ont.), Winnipeg (Man.), Fort Churchill (Man.) and Resolute Bay

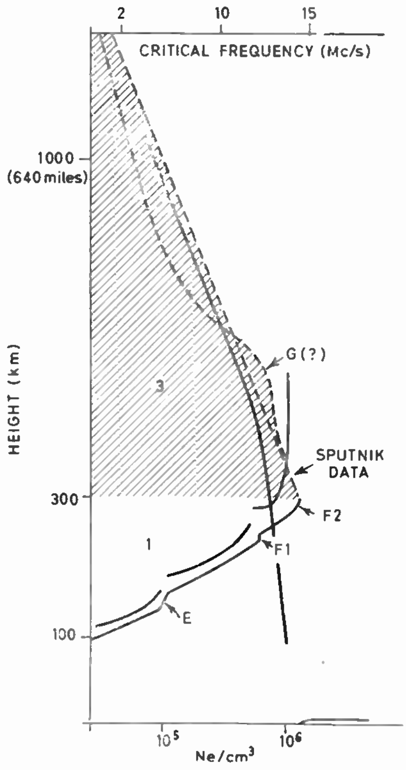

Fig. 1. The distribution of free electrons in the ionosphere. The Topside Sounder will measure the distribution above the F region maximum.

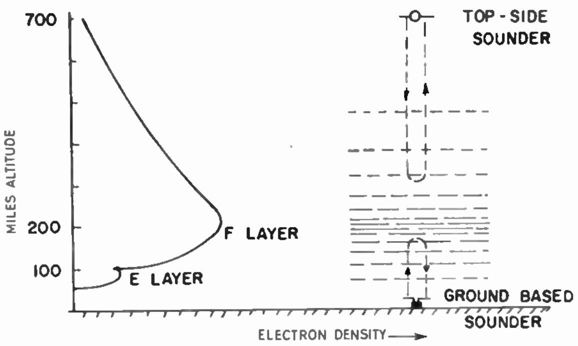

Fig. 2. Illustrating ionospheric sounding.

(N.W.T.). It has a programme to study the ionosphere and upper atmosphere by rockets fired from Fort Churchill. It also has the knowledge and experience in transistor circuitry, electronic instrumentation and packaging, solid state physics, and environmental testing necessary to design a satellite package. Hence, it is very reasonable that D.R.T.E. should participate in a programme to study the ionosphere from a satellite. The U.S. National Aeronautics and Space Administration (N.A.S.A.) has authorized the launching of two satellites, using U.S. launching vehicles, to sound the upper side of the ionosphere by radio means. One satellite will be the D.R.B. Topside Sounder satellite known as S-27 which is being designed and built by the Defence Research Telecommunications Establishment. This satellite will be a sweep frequency sounder covering the frequency range 1·8 to 11·5 Mc/s. Its operation will be similar to that of the ground ionospheric station.

The other satellite is being developed by a U.S. company, the Airborne Instruments Laboratory, under the scientific guidance of the Central Radio Propagation Laboratory of the National Bureau of Standards. This satellite will sound on six fixed frequencies in rapid succession. The data collected by both satellites will be telemetered to the ground in real time and received at the same ground stations. The D.R.B. satellite will be launched early in 1962 from the Pacific Missile Range in California and the other satellite somewhat later. The data collected by the two satellites should complement each other, but the D.R.B. satellite will concentrate on high latitude problems, while the N.B.S. satellite will be more interested in studying the ionosphere to the south, in particular along the 75-degree parallel.

The D.R.B. satellite will be placed in a circular orbit 625 miles above the earth. In order to study spatial changes in the electron density, the orbit will be inclined at 80 deg. The orbit will precess clockwise (looking down on the north pole). This will give a complete coverage of local time in a three-month period.

The ionospheric sounder transmitter of the D.R.B. satellite will normally be off, and will be switched on by transmitting a command signal from the ground station. The sounder will sweep from 1·8 to 11·5 Mc/s in about 10 seconds. After each 12 minutes of sounding, the sounder will switch off automatically. This means that it will operate for about 3600 seconds after being commanded on.

Besides sounding the ionosphere from above, the D.R.B. satellite will measure galactic radio noise above the ionosphere over the frequency range 0·5 to 12·0 Mc/s. It will also measure the plasma frequency in the neighbourhood of the satellite by the cut-off of the galactic noise background.

The satellite will carry four particle counters supplied by the National Research Council. These will measure a spectrum of particle energies, and this information will greatly enhance the other ionospheric data because of the connection between ionospheric disturbances and the arrival of high energy particles in the upper atmosphere. It will also carry a v.l.f. whistler receiver.

In Canada the information from the satellite will be received at St. John's (Nfld.), Ottawa (Ont.), Resolute Bay (N.W.T.), and Prince Albert (Sask.). The information from above the ionosphere will be compared with that received at ground ionospheric stations. Figure 3 shows the geographical distribution of these stations. The straight lines are 10 computed passes of the satellite showing how effective Resolute Bay will be as a Command Station. The auroral zone is shown by the hatched circle and the

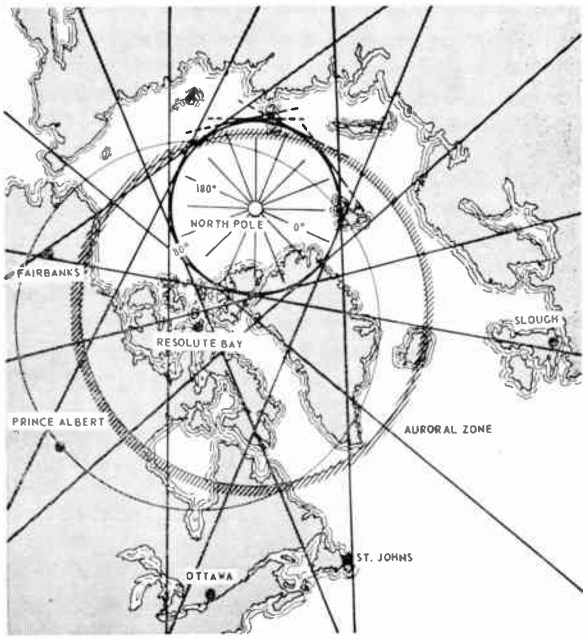

Fig. 3. Geographical distribution of Canadian sounding stations.

solid circle shows the radio horizon of the satellite from Resolute Bay.

Outside Canada the satellite will transmit to U.S. Minitrack stations particularly along the 75-degree parallel. The satellite will also be read at the Radio Research Station, Slough (England), and possibly elsewhere. The Canadian interest will be chiefly confined to Canadian territory, in particular the complicated northern situation.

Two telemetry transmitters will be used on frequencies near 136 Mc/s which will not be affected by the ionosphere. The first, operating continuously, will radiate ¼-watt and will serve both as a tracking beacon and a narrow band data link. Its power may be reduced to 50 milliwatts on command in order to conserve battery power. The second transmitter radiating 2 watts will operate on command and will carry the wide band ionospheric data. The data will be recorded on magnetic tape and Canadian information analysed at a data centre in Ottawa where it will be re-recorded as ionograms on 35 mm film.

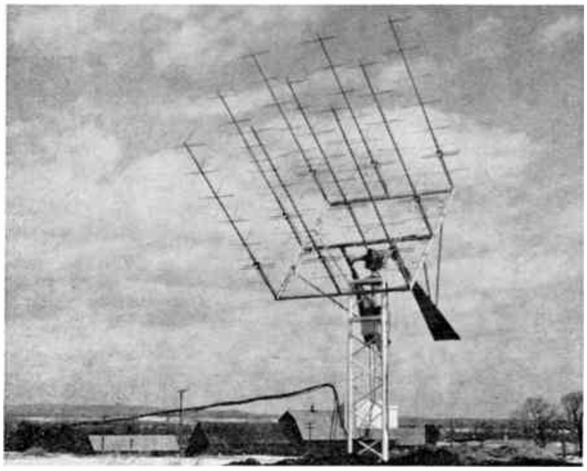

Fig. 4. A typical tracking antenna.

The incoming data will also be reconstituted in real time ionogram displays at each receiving station to stimulate operator interest and to permit photography as a back-up to the tape recorder.

Figure 4 shows a typical tracking antenna for telemetry and command now installed at Resolute Bay. Crossed Yagis are used to provide two polarizations. The centre Yagi carries the command channel, the fin on the back of the antenna is to balance the wind load.

3. The Satellite Package

The configuration of the satellite package is shown diagrammatically in Fig. 5. The shape is a near-spheroid about 42 inches in diameter and 34 inches in height. Total weight will be about 275 lb. A large

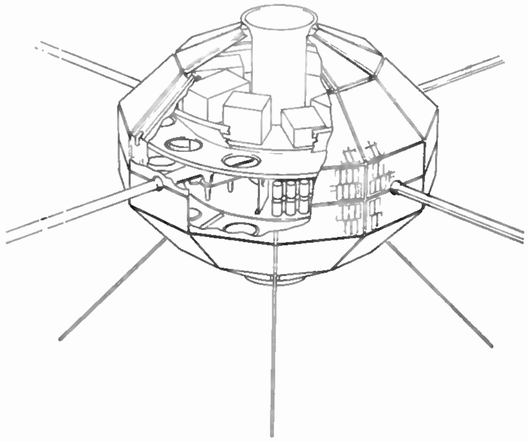

Fig. 5. Diagram of satellite package.

proportion of the surface is covered with 6480 silicon solar cells which will charge the nickel cadmium batteries through the use of solar energy. The package is designed to yield an optimum of three structural requirements.

(a) The package must be strong enough to withstand the stress of launching.

(b) Achieve as constant a solar cell illumination over the whole package as possible.

(c) Electronic packages and solar cells must be easily removable and separable from the outer shell.

Electronic components are placed on both sides of a load bearing central torus containing the sounding antenna units and battery pack. Attached to the

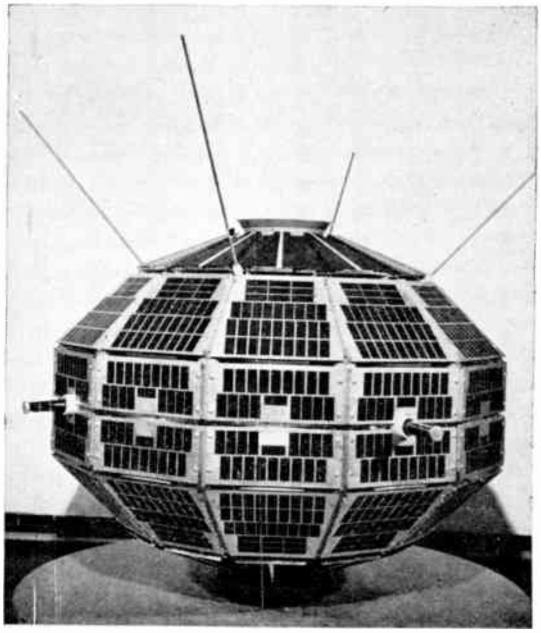

Fig. 6. The prototype satellite.

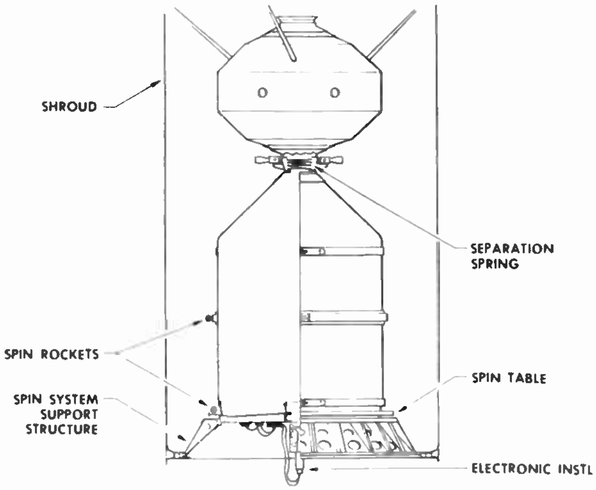

Fig. 7. The satellite mounted on the *Agena B* rocket

periphery of the central torus are two half shell aluminium spinnings which form the satellite shell. Figure 6 shows the prototype. The spun shell is covered with solar cell panels and end caps. The central torus is attached to the thrust tube through which the entire load is transmitted.

The net result is a vehicle with good mechanical access to solar cells and electronics, and a solar aspect ratio constant to within 10%.

The portion of the satellite not covered with solar cells is specially treated to provide a good thermal balance between a nearly constant room temperature environment in the interior for the electronic circuitry and a cold surface for high solar cell efficiency. The satellite is shown mounted on the *Agena B* rocket in Fig. 7.

3.1. *Antenna Design*

The design of the antennas for the ionospheric sounder required very special consideration. The frequencies being used (2–12 Mc/s) required that a rather long antenna be employed to obtain reasonable efficiency. Design considerations indicated that dipole antennas 150 ft from tip to tip would be necessary to enable the transmitter to radiate properly. Even with these long antennas matching networks would be necessary to match the antenna over the frequency sweep of the transmitter. No satellite launched to date has employed antennas longer than about 20 ft. Consequently these long antennas constituted a formidable design problem. It was finally decided that suitable antennas could be manufactured of thin steel ribbons which were rolled up somewhat like a carpenter's rule and ejected by an electric motor after the satellite was in orbit above the atmosphere. Fortunately the National Research Council had done considerable development on antenna masts of this type some years before and their experience was available, although their masts were limited to about 25 ft in length. The antenna consists of a 4 in. wide strip of spring steel 0·004 in. thick. The antenna is formed and annealed into a circular section with an overlapping open seam. When stored inside the satellite this steel ribbon is wound flat on a spool. When the antenna is ejected the tube passes through a fibreglass transition die which allows the tube to spring back into a circular shape. The result is that the 150 ft dipole is formed of two 73½ ft steel tapes which have a fair amount of rigidity. Figure 8 shows an antenna module.

In order to ease the antenna electrical matching problem there are two dipoles constructed of the steel tape, one 150 ft tip to tip and the other 75 ft tip to tip. The longer antenna covers the lower frequency band (1·8–4 Mc/s) and the shorter 75 ft antenna covers the higher frequency band (4–11·5 Mc/s). These two dipole antennas are mounted at right angles to each other in the central plane of the satellite package. To test the sounding antennas a qualification experiment (Sect. 5) was performed in which they were ejected from a *Javelin* rocket above the atmosphere and their behaviour measured.

In order to eject the steel ribbon it is necessary to pull it out rather than push it out. Attempting to push out the steel tape results in binding. In the earlier design of the De Havilland antenna mylar tape was used to pull out the steel ribbon. The antenna modules have now been modified by using rubber belts to pull the steel tape and to drive the drum. These were used in the recent rocket tests. In ground tests it was found that the mylar tape tended to bunch up and cause the antenna to jam. This problem seems to have been solved by using rubber belts on the edges of the storage drums. The fibreglass former which assisted the steel ribbon to go from a flat sheet to a rolled-up tube has been replaced by a nylon former. There were a number of rollers inside the guide tube formerly and these have been removed. Ball bearings have been placed on all the shafts to reduce the friction

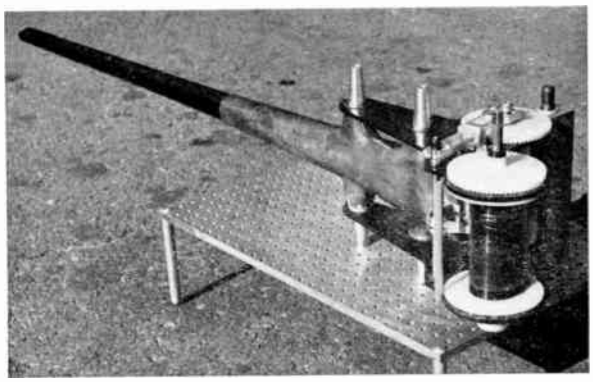

Fig. 8. An antenna module.

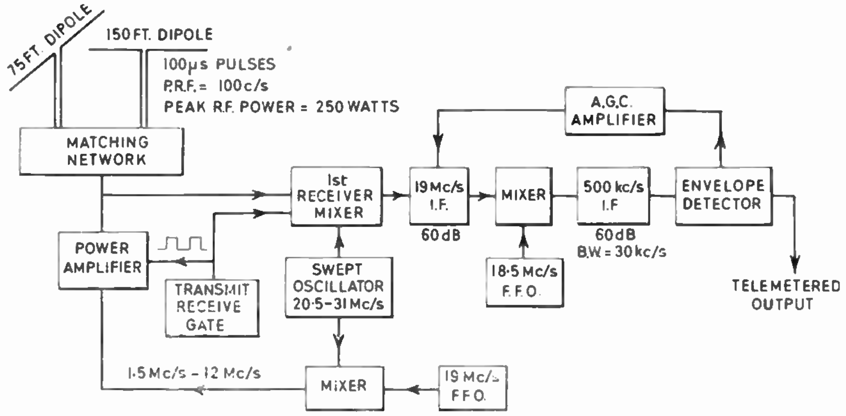

Fig. 9. Block diagram of pulsed system for Topside Sounder.

on the drive gears. It is possible that a slightly stronger nylon former will be used as a result of the rocket tests.

At one end of the satellite, whip antennas are mounted for the telemetry transmitter, command receiver and the beacon transmitter. Since these services operate on frequencies above 100 Mc/s the antennas are short and do not present any particular problem except that of assuring as wide angle coverage as possible.

3.2. *Power Supplies and Electronics*

Since the payload is expected to operate for one year, it is necessary to charge the nickel cadmium batteries with energy obtained from solar cells on the satellite surface. Six thousand four hundred and eighty (6480) solar cells arranged in 144 series groupings of 45 cells each provide the charging power for four separate 12 nickel-cadmium power supplies. Solar cells with a basic conversion efficiency of 9% operating at a temperature of 0°C and in the arrangement shown (aspect ratio 4·25) supply 22 watts of electrical energy to the batteries. This allows for such factors as micrometeorite damage, transmission losses and a safety margin.

One of the four battery supplies is to provide power for most of the continuously operating circuitry. The remaining three are to operate the commanded part of the instrumentation. These three supplies have capacities proportionally much larger than necessary when considered in the light of charging power per orbit. This excess capacity will be used to supply anticipated sounding power requirements for the greater part of three successive orbits, recharging then taking place over the remaining orbits. Construction techniques developed for presently orbiting satellites will generally be used in all phases of the power source construction. However, thicker (0·012 in.) than average solar cell cover glasses are being used to protect against higher energy electron damage from the lower Van Allen radiation belt.

It is now planned that the electronics in the payload will be solid state circuitry throughout and so contain no vacuum tubes. This is very desirable from a reliability and conservation of power point of view. Since the experiment involves parameters about which very little is known, it has been decided that a generous allowance of power must be used in the ionospheric

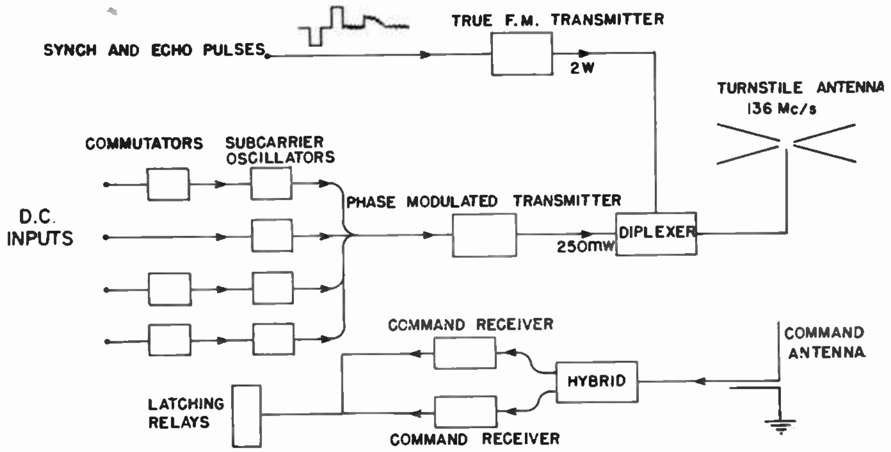

Fig. 10. Block diagram of telemetery and command system.

sounding transmitter although it may be more than necessary to get satisfactory data from the ionosphere. The final amplifier will now use 4 pairs of 2N1709 transistors which will produce at least 100 watts peak pulse power with 100 μs pulses 67 times per second. The result is a very reliable ionospheric sounder. A general block diagram of the sounder is shown in Fig. 9.

Data from the satellite will be telemetered to the ground station on a wideband frequency modulated link (bandwidth 20 kc/s) operating at 136 Mc/s. The telemetry transmitter in the satellite will radiate 2 watts of power which should allow a range of 2000 miles when the ground station uses an antenna with a 19 dB gain. Figure 10 shows the block diagram of the telemetry and command equipment.

electronic instrumentation and batteries in the interior of the package must be kept at near room temperature. At times the satellite will be in full sunlight and unless properly designed would certainly become too warm. Thermal insulation between the inner package and outer shell is obtained by use of a combined radiative and conductive insulation known as a Kropschot blanket. This consists of aluminized 1 mil mylar interleaved with unbonded glass fibre. The resulting insulation is sewn in the form of a quilt $\frac{1}{8}$ inch thick. Computations based on a 30 watt on/off duty cycle giving 11 watts average power were used in the thermal design. Fortunately the time of launch allows a certain amount of control concerning the length of time before the satellite will be in full sunlight. Figure 11 indicates the result of

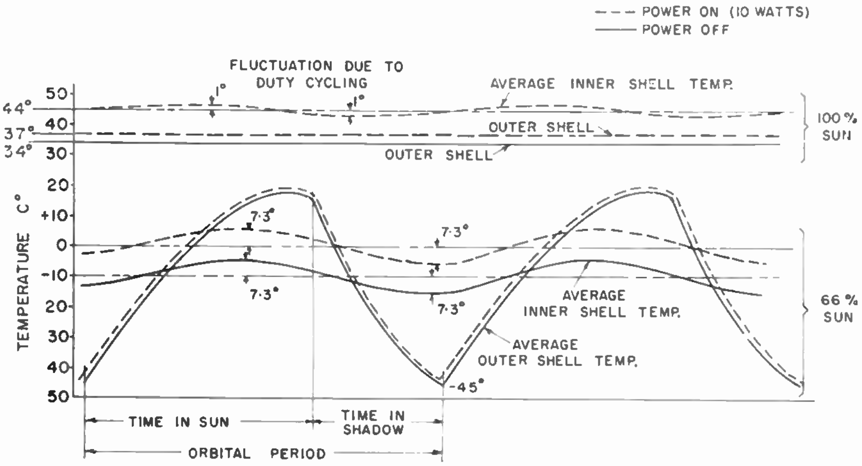

Fig. 11. Computed satellite temperatures. Average shell and payload package temperatures for maximum and minimum sun.

computations on the thermal design and estimated temperatures of the package. These have been compared with satellites already in orbit and have been found to be of the right order of magnitude.

4. Environmental Testing

The component parts and the whole satellite package are being carefully tested for the launching stresses and for space environment. A large environmental chamber which holds the satellite and allows evacuation to 1×10^{-5} mm of mercury is used to check the complete satellite. Simulated sunlight from arc lamps is radiated through quartz windows into the chamber. The walls of the chamber are refrigerated and infra-red lamps are mounted in a ring around the satellite package within the chamber. With these facilities the satellite can be tested under space environment conditions and can be "soaked" under high vacuum for weeks in order to de-gas the package to a reasonable extent and turn up any weaknesses in the components or materials.

A first order thermal design of the package has been completed. As mentioned above, for maximum efficiency the solar cells on the surface of the package must be kept as cool as possible. On the other hand,

Environmental testing to date has been a thermal test on the prototype satellite shell to investigate the efficiency of the insulation blanket. In general it was found that the predicted temperatures of the satellite shell and interior were within 15% of that calculated. When the prototype satellite is tested with all the electronics in place later this summer further information will become available.

Considerable testing was done on the *Javelin* nose-cone before it was fired. The vibration facilities of the Defence Research Board Armaments Research Establishment in Quebec were not large enough to vibrate the whole *Javelin* nose-cone. Consequently parts were vibrated and the main resonances estimated to be at 95 c/s and at 290 c/s. Finally the complete nose-cone was given the standard *Javelin* environmental test at the Goddard Space Flight Center and it was found that the resonances actually occurred at 11 c/s and at 260 c/s. The electronic packages had no trouble passing the test but the sounding antenna had to be modified as has already been noted.

5. Special Experiments to Test the Design of the Satellite

It was decided that the very long sounding antennas should be subject to a qualification test under space environment conditions. Consequently on 14th June this year two 73½ ft sounding antennas were launched in a *Javelin* rocket at Wallops Island and projected above the atmosphere. The antennas were mounted along the longitudinal axis of the rocket so as to fold out through 90 deg into the lateral plane prior to antenna tube ejection. The aim of the test was to check the antenna's mechanical, structural and electrical properties under actual flight conditions by providing a dynamic environment for the antenna during ejection similar to that of the actual satellite; thus maximum expected bending moments on the antenna tubes were to be applied in the transient manner to be found in the satellite experiments. Such loading would be extremely difficult to reproduce on a ground test. Although it was not a perfect test we feel that it was satisfactory in proving the possibility of running out 73½ ft of steel ribbon antenna.

The rocket worked perfectly as far as ballistics was concerned, rising to 576 miles. It would have gone to 600 miles except that the trajectory was a bit flatter than intended. However, for reasons not yet known the de-spin mechanism did not work as it should. The *Javelin* is spun up to 200 rev/min during flight and it was intended to de-spin this to 135 rev/min before unrolling the antenna. For some reason the *Javelin* de-spun down to 10 rev/min as far as the preliminary analysis of the records can tell. The antennas did fold down out of the nose cone quite smoothly and extended smoothly until they were about two-thirds extended. At this point something happened to one of the antenna modules and the antenna jammed. The motor current rose and the motor was able to drive out the other antenna to the full 73½ ft. It is suggested that the sudden removal of the spin beyond what was intended may have jammed the steel tape on the edge of the roll. Some minor improvements have still to be made to the antenna units. Nevertheless if the rocket had been the satellite, working antennas would have been obtained although there would have been a certain amount of mismatch.

Early in the system design of the Topside Sounder it was realized that an accurate determination of cosmic noise power level at an altitude of about 600 miles was very desirable.

Through the goodwill of the Applied Physics Laboratory of Johns Hopkins University, D.R.T.E. was given an opportunity to install suitable measuring equipment in their *Transit 2A* satellite placed into a 500 mile orbit in June 1960. Accordingly a single frequency receiver and a pair of ferrite loop antennas were designed and constructed at D.R.T.E. The receiver operated at 3·8 Mc/s and included calibrating circuits. Automatic gain control voltage with a time constant of 0·1 seconds was used as a measure of cosmic noise level. The antennas became part of the *Transit 2A* de-spin weights and the Canadian experiment was designed to be completed in the first five to seven days.

Excellent telemetry records were obtained from the Blossom Point, Maryland, and the D.R.T.E. Ottawa station. Good records were also obtained from some other Minitrack stations. The noise at 3·8 Mc/s as measured in the northern hemisphere indicated approximately 0·5 μ V/m equivalent broadside polarized field strength in 40 kc/s bandwidth or approximately 10^{6}°K brightness temperature. There was no indication of variation between day and night passes. On the other hand results from Woomera, Australia, showed a variation of 3 dB, the high value being 6 dB above the northern hemisphere value. Santiago, Chile, for which only one record of poor quality was received, showed no such increase. At present an explanation is still being sought and the ionospheric data may shed some light on this interesting result.

The error in the above readings is +1 to −5 dB. The error is of this form because the D.R.T.E. receiver operated near the limits of its sensitivity where increases would be evident but decreases are buried in receiver noise. However this experiment has indicated that the cosmic noise level is no greater (perhaps a few decibels less) than that predicted by the National Bureau of Standards in the U.S.A.

This measurement of galactic noise from a satellite was the first ever performed and provided very useful design data for the Topside Sounder satellite.

6. Conclusions

The Topside Sounder satellite programme is on schedule and there do not appear to be any problems remaining which cannot be solved. Four satellite packages are being constructed, two for testing and two which will be complete flight models. One of the latter will be used for launch early in 1962, the other being the required "back-up". There is no doubt that satellites will play an ever-increasing part in scientific investigations in the upper atmosphere and later for communications and other important uses. The experience gained in the Topside Sounder programme will be very valuable to the Defence Research Board and to Canada. The scientific information obtained will certainly help in gaining an understanding of communications problems in the north country.

7. Acknowledgments

Many individuals are contributing to the D.R.B. Topside Sounder programme and it may be said that almost everyone in the Defence Research Telecommunications Establishment is involved to a greater or lesser extent. It is not possible here to mention everyone by name but it should be pointed out that this is definitely a co-operative project.

The satellite package except for the electronics is being designed and built by the De Havilland Aircraft Company of Canada to specifications supplied by D.R.T.E. The electrical design of the sounding antennas has been done by the Sinclair Radio Laboratories.

8. Appendix

The Canadian Defence Research Board
Topside Sounder Satellite

Orbit	
Circular	625 miles altitude
Inclination	80° towards east
Injection point	22·3° S, 48·7° E
Sounder	
Transmitter frequency sweep	1·8 to 11·5 Mc/s
Receiver frequency sweep	0·5 to 12 Mc/s
Transmitter power	200 W pulse
Modulation	100 μs pulse with 67 c/s p.r.f.
Telemetry	
Frequency	136·080 Mc/s
Transmitter power	2 watts
Modulation	F.M., ± 75 kc/s deviation
Maximum range for 20 dB signal/noise ratio	2000 n miles
Ground telemetry antenna gain	19 dB
Beacon	
Frequency	136·590 Mc/s
Transmitter power	0·25 watts
Modulation	F.M./P.M., sub-carriers 3·9, 7·35, 10·5, 14·5 kc/s
Command Link	
Frequency	Not assigned
Transmitter power	1000 watts
Modulation	7 tone, A.M.

Manuscript first received by the Institution on 18th May 1961, and in revised form on 22nd August 1961. (Paper No. 698.)

POINTS FROM THE DISCUSSION

Mr. B. F. Gray (*Member*): What stresses would the extending aerial system be subjected to once terminal velocity of the satellite had been reached? If these stresses were negligible would it not be possible to design the aerial on the basis of thin wires and allow the centrifugal force exerted by the spin motion of the satellite to correct the aerial to its final position, thus saving a great deal of weight and complication of the aerial system?

Mr. J. C. W. Scott (*in reply*): The decision to use an antenna with good strength and some rigidity was decided on after careful investigations. Tests of first designs lead to considerable modifications and these tests included the operation of the antenna mechanism when launched by a rocket. We are well aware that another design is proposed by Cambridge University using thin wires which will depend on centrifugal force for extension.† Only actual operation in the final satellite will determine whether our design considerations have proved sound.

Mr. J. R. Millburn (*Graduate*): In view of the number of satellite failures that have been attributed to batteries, does Mr. Scott have confidence that Ni-Cd cells will last for a year in orbit?

Mr. J. C. W. Scott (*in reply*): We are aware of the failure of nickel-cadmium cells, but improvements have been made which lead us to hope that they will be satisfactory for a year in orbit.

† F. G. Smith, "Radio astronomy from rockets and satellites", Brit.I.R.E., 1961 Convention paper. (To be published.)

U.D.C. 621.318.3: 621.374.4

A Self-Indicating Magnetic Scaling System using Electro-Deposited Nickel-Iron Film Cores

By

E. FRANKLIN, Ph.D.†

Presented at a Symposium on "Electronic Counting Techniques" held in London on 26th April 1961.

Summary: The paper describes a method of application of electro-deposited magnetic films with rectangular hysteresis loops in logical elements. One of the principal difficulties, that of getting sufficiently close coupling between the film and the associated driving and sense coils, has been overcome. The application of the films to counting or scaling circuits in particular is described. A visual indication of the count stored in such a circuit is obtained by making use of the external fields from the magnetic films. With the electrodeposition technique developed, the films can be deposited in five minutes and batches of several hundred cores have been made with saturation flux and coercive force uniform within ±10%.

1. Introduction

A number of scaling systems have been described which employ rectangular hysteresis loop magnetic cores for storage of the received count and transistors, sometimes with semi-conductor diodes, for modification of the stored information on the occurrence of a new event to be counted.[1, 2] Such systems have generally used small ferrite cores, which are convenient when no direct indication of the stored count is required. Direct indication is inconvenient with this arrangement, though it has been done by the use of a separate magnetic indicator[1] or by means of cold cathode trigger valves.

This paper describes a magnetic decade scaling system in which direct count indication is obtained by use of the external magnetic fields of the storage cores themselves. The cores are made in the form of bar magnets of sufficient strength to control a suitably pivoted astatic pair of compass needles loosely coupled with them. Ten of the cores are arranged in a cylindrical formation with their longitudinal axes parallel with that of the cylinder. The compass needles are attached to a spindle which lies along the central axis of the cylinder, and they are so disposed along the length of this spindle as to be opposite to the two ends of each of the cores. At any given time between counts, nine of the cores are arranged to be magnetized (longitudinally) in one direction and the other one in the other direction. Receipt of a pulse to be counted is arranged to cause a rotation of this pattern of polarities by one core position. The astatic pair of compass needles follows the resulting rotation of the external field system of the cores or, if this is too rapid, finds the final rest position at the end of the counting. Since the information storage in such a system is in the form of remanent magnetic flux, it takes no power, energy being consumed only in changing the information (reversing the direction of magnetization of appropriate cores) and in supplying transistor leakage current. This amounts to a variable component of about 3·5 microwatts per count per second plus a fixed component of about 100 microwatts (at 20° C). The resolving time of the circuits is less than 1 microsecond.

The system described above is superior to cold cathode valve systems in resolving time, and has a very large advantage over both cold cathode and hard valve systems in respect of power consumption. At low counting rates, it takes less power than even a pure transistor decade.[3, 4] The latter point is of vital importance in portable instruments, but also has great importance in general use, since it results in cool running of all components, with resulting good effect on their reliability. The components used tend to be of high reliability types, in any case. Use of a ring type circuit makes the system useful in many types of sequential switching applications, and the large amplitude current pulses available from each of the ten stages of a decade make the system compatible with modern pulsed data handling circuits in general.

2. Arrangement of the Indicator

The general arrangement of the indicator is shown in schematic form in Fig. 1, the windings on the memory cores being omitted in the interests of simplicity and clarity.

There are two principal requirements of the indicator performance which conflict with each other. Fast response to changes in the stored count and freedom

† Atomic Energy Research Establishment, Harwell, Berkshire.

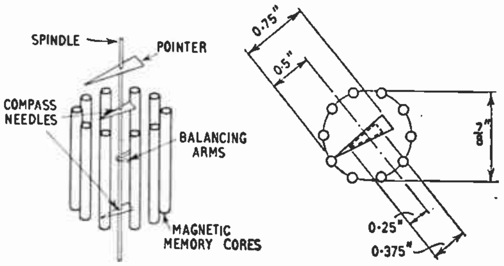

Fig. 1. Schematic arrangement of indicator.

of pivots require that the moving system shall be small and light in weight, while ease of readability at a reasonable distance calls for a fairly large bold pointer.

Let us consider first of all the simple case of a magnet of moment M suspended in pivots in a uniform magnetic field H. If the magnet is turned so that its direction of magnetization makes an angle θ with the direction of H, then a restoring torque $MH \sin \theta$ will operate in such a direction as to reduce θ to zero. If the magnet has a moment of inertia equal to I, the torque required for an angular acceleration $d^2\theta/dt^2$ will be $I\, d^2\theta/dt^2$ and the equation of motion of the magnet when deflected and released will be

$$I\frac{d^2\theta}{dt^2} = -MH\sin\theta \qquad \text{......(1)}$$

or, approximating for small values of θ,

$$I\frac{d^2\theta}{dt^2} = -MH\theta \qquad \text{......(2)}$$

As is well known, solution of this equation gives the variation of θ with time, t, as a damped sine wave of frequency

$$f = \frac{1}{2\pi}\sqrt{\frac{MH}{I}} \qquad \text{......(3)}$$

For convenience of production and mounting, the magnets in the indicator are made of thin sheet metal, the plane of the sheet lying at right angles to the spindle on which they are mounted. If the thickness of the sheet is varied, both M and I vary proportionately and f remains unchanged. However, if the dimensions of the magnet in the plane of the sheet are varied, M and I vary differently and f is changed. It can readily be shown that, for a given shape in the plane of the sheet (of fixed thickness) and a given density and axis of rotation, the value of I varies proportionately with the fourth power of the linear dimensions, while for a given shape and intensity of magnetization, the value of M varies proportionately with the square of the linear dimensions. We can therefore rewrite eqn. (3) in the form

$$f = \frac{1}{2\pi}\sqrt{\frac{HaL^2}{bL^4}} = \frac{1}{2\pi L}\sqrt{\frac{Ha}{b}} \qquad \text{......(3a)}$$

where a and b are constants dependent on the material of the magnet and L is one of the linear dimensions in the plane of the sheet. Thus for a given magnet material, the frequency varies inversely with the linear dimensions, and therefore, in the interests of fast response, the latter should be as small as possible. Also the ratio a/b should be as large as possible, and therefore a material with as high a ratio of intensity of magnetization to density as possible should be used.

The best available material from this point of view having mechanical properties suitable for cheap production is Cunife, which has a density of 7·4, a saturation flux of 4800 gauss and a coercive force of about 470 oersteds. It is sufficiently soft mechanically to allow of production of the magnets by stamping from sheet, and no subsequent heat treatment is required.

Equation (3a) is modified to some extent when applied to the indicator, owing to the fact that the moment of inertia of the moving system does not consist solely of that of the magnets, but includes the moment of inertia of the pointer, the balancing arms (for adjusting mechanical balance) and the spindle. If we take the combined value of these as being I_0, then eqn. (3a) becomes

$$f = \frac{1}{2\pi}\sqrt{\frac{HaL^2}{bL^4 + I_0}} \qquad \text{......(4)}$$

and the fastest response time (maximum f) is given by adjusting L so that the term $HaL^2/(bL^4 + I_0)$ has a maximum value. By equating to zero the differential of this term with respect to L, this maximum can be shown to occur when $bL^4 = I_0$, that is, when the combined moment of inertia of the two magnets is equal to the moment of inertia of the remainder of the moving system. Thus when the size of the pointer has been chosen on the basis of ease of reading, and its construction has been made as light as practicable, with due regard to the need for robustness, the size of the whole moving system (for minimum response time) has been largely determined.

The pointer is in the form of an isosceles triangle of height 0·75 in and base length 0·166 in cut from 0·001 in thick aluminium sheet. The moment of inertia of the whole moving system, apart from the magnets, is about 0·001 g cm^2 and the magnets therefore each have a moment of inertia of about 0·0005 g cm^2.

Some consideration must be given to the shape of the magnets. The highest M/I ratio would be given by a disc, but this shape would be optimum only if the field in which the magnets operated were uniform. Owing to the proximity of the magnets and the memory cores, even the field produced by the one core having reversed magnetization cannot be considered uniform, and it is further perturbed by the fields of the other nine cores. It is therefore advantageous to extend the magnet in a direction towards the reversed core, in order to reduce the effect of these perturbations and give a more specific indication. A similar extension in the diametrically opposite direction is to be avoided, since it would increase the disturbances in magnet position due to inequalities between the other nine cores. The shape finally chosen was a long narrow isosceles triangle pivoted at its centre of gravity, i.e. on the perpendicular bisector of the base and one third of the distance from the base to the apex. The distance from the pivot to the apex was chosen to be a little over half the radius of the circle of centres of the magnetic memory cores, since this gives a reasonable compromise between accuracy of indication and speed of response.

A further consideration when choosing the size and shape of the magnets is the effect which their presence will have on the operation of the memory cores. It can be shown that the field produced by a triangular magnet at a point along a continuation of its longitudinal axis beyond the apex is approximately $2M/R_1R_2$, where M is the magnetic moment of the magnet, and R_1 and R_2 are the distance of the point considered from its apex and base, respectively. This expression holds provided that the length of the base of the triangle is fairly small compared with R_2. With a magnet of length $L = 0{\cdot}375$ in $= 0{\cdot}952$ cm, base width 0·166 in = 0·419 cm, thickness 0·002 in = 0·0051 cm, and a remanent flux of 4800 gauss, we obtain a value for M of 0·387 e.m.u. If the memory cores are arranged with their centres on a circle of radius $\frac{7}{16}$ in, the value of R_1 at their ends will be $\frac{3}{16}$ in = 0·476 cm and therefore these ends will be subjected to a field

$$H = \frac{2 \times 0{\cdot}387}{0{\cdot}476 \times (1{\cdot}43)^2} = 0{\cdot}8 \text{ oersteds}$$

at right angles to their own direction of magnetization. This field rapidly diminishes as we move away from the end of the memory core towards its centre, and was thought to be sufficiently small compared with the coercive force of 3–4 oersteds of the memory cores not to have any serious effect on their operation in the scaling circuit.

Having determined the size and material of the magnets and the total moment of inertia of the moving system, it is possible to calculate approximately the size of memory core necessary to give a suitably fast response time of the moving system. The relationship of the cross-sectional area of the memory cores to their length must be chosen so that their self-demagnetizing effect is sufficiently small not to cause appreciable deterioration of the rectangular hysteresis loop shape. The magnetic flux density must therefore remain constant and equal to the saturation remanence value over substantially the whole length of the cores, with very little flux passing radially through the surface. The field strength near to the end of a core will then be very nearly equal to that which would be produced by a single free pole. It can be shown that if such a pole is placed near to the pointed end of one of the triangular indicator magnets, the couple, c, experienced by the magnet is, to a fair degree of approximation,

$$c = \frac{mJtW}{R_2 - R_1}\left[\log_e \frac{R_2}{R_1} - \frac{(R_2 - R_1)}{R_2}\right] \sin\theta \quad \ldots\ldots(5)$$

where m is the memory core pole strength, J the intensity of magnetization of the magnet, t its thickness, W its width at the flat end, R_1 and R_2 the distances of its near and far end, respectively, from the pole and θ the angle between the direction of magnetization of the magnet and a line joining its centre of gravity and the free pole. With the values previously given for magnet strength, size and disposition relative to the memory cores, i.e. $J = 382{\cdot}5$ e.m.u., $W = 0{\cdot}419$ cm, $R_1 = 0{\cdot}476$ cm, $R_2 = 1{\cdot}428$ cm, $t = 0{\cdot}00508$ cm, this gives

$$c = 0{\cdot}37M \sin\theta \quad \ldots\ldots(6)$$

Assuming a total moment of inertia, I_t, of 0·002 g cm² and approximating by substituting θ for $\sin\theta$, this gives a frequency of oscillation

$$f = \frac{1}{2\pi}\sqrt{\frac{0{\cdot}037m \times 2}{0{\cdot}002}} = 3{\cdot}06\sqrt{m} \text{ c/s} \quad \ldots\ldots(7)$$

An oscillation frequency of 1 c/s thus requires m to be about 0·1 e.m.u. and this is the value of m used because, as discussed in Section 3, it gives also convenient electrical properties with a fairly easily manufactured core and windings. Equations (5), (6) and (7) neglect the effect of the nine cores which are normally magnetized, and, in practice the oscillation frequency is about 1·5 c/s. The necessary mechanical damping can be obtained by either filling the indicator with a thin silicone oil or operating the spindle in an oil of correspondingly higher viscosity.

The moving system, is mounted in standard micro-ammeter jewel pivots and static mechanical balance is achieved by bending two aluminium arms which are mounted in the form of a right-angled **V** on the opposite side of the spindle to the pointer. The unit can be operated in any position after being balanced.

3. Construction and Properties of the Magnetic Memory Cores and their Windings

3.1. *Requirements*

The size, shape and magnetic properties of the magnetic cores and the form of their windings are constrained by a number of performance requirements, the most important of which are:

(a) The magnetic moment of the cores has to be sufficiently great to give satisfactory control of the compass needles used for count indication. For a given magnetic material (given intensity of magnetization) this determines the minimum volume of each core.

(b) The saturation flux density and cross-sectional area of the core must be such as to produce, in a winding of a reasonable number of turns, an e.m.f. of a few volts during a period of magnetization reversal of say 0·75 microseconds. The number of turns which is reasonable will, of course, be a function of the winding space available and the convenience of the method of winding.

(c) For reasons described below, it is essential that current changes in windings should not cause any appreciable e.m.f.s to appear across the windings, except in cases where reversal of magnetization of the core occurs. It is therefore necessary that the core material should have a flat-topped hysteresis loop (remanence $\nless 95\%$) and that the coupling between the core and windings be tight, to avoid the production of stray flux.

(d) The dynamic characteristics of the magnetic core material should be such that saturation–saturation magnetization reversal can be brought about in about 0·6 microseconds by a current of a few hundred milliamperes flowing in a reasonable number of turns. Such a current is the highest which can conveniently be produced by a low-power high frequency transistor. Since the scaling circuit is required to discriminate between large and small pulse currents in order to avoid spurious counting, it is desirable also that the magnetic core material should have a hysteresis loop with fairly square vertical sides (well defined threshold field) and that the field required for 0·60 microsecond reversal shall not greatly exceed the coercive force.

(e) A winding of the number of turns required by (b) and (d) must have a resistance sufficiently low to be compatible with the low voltage high current transistor coupling circuits, i.e. not greater than 1 ohm.

(f) Since an open magnetic circuit is used, the length to cross-sectional area ratio of the magnetic cores must be sufficiently great that the self demagnetizing effect does not appreciably deteriorate the rectangularity of the hysteresis loop.

(g) The coercive force of the magnetic material must be sufficiently large to avoid any appreciable influence by the earth's magnetic field or other small stray fields, and also to make it possible to meet requirement (f) with a core of practicable shape. However, the coercive force must not be so high as to demand embarrassingly high operating currents, and 3–4 oersteds is optimum.

3.2. *Consideration of Methods of Construction*

The requirements of rectangularity of hysteresis loop and moderate coercive force could be met conveniently by the use of manganese-magnesium ferrites developed for computer applications. However, the very large ratio of length/cross-sectional area demanded by the requirement for small self-demagnetizing effect in a bar core would be quite impracticable with such a material without the use of laborious and expensive grinding techniques. The use of metal tape cores was considered initially, but, after a preliminary investigation, the problem of obtaining a coercive force in the required range, while retaining rectangularity of hysteresis loop, seemed extremely difficult.

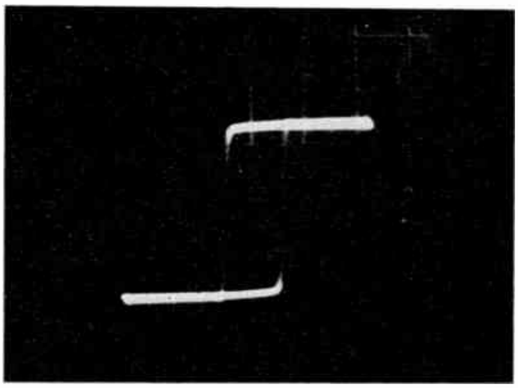

Fig. 2. Typical hysteresis loop
$V_c = 2{\cdot}15$, $W_c = 4{\cdot}0$, $\phi_s = 0{\cdot}665$ lines.

The problem was eventually solved by the use of electrolytically deposited nickel-iron alloy films in which, by suitable control of the conditions of deposition, the coercive force could be controlled within $\pm 10\%$ of any chosen value between 3 and 4 oersteds, and suitably rectangular hysteresis loops obtained. A typical hysteresis loop is shown in Fig. 2. The cores are deposited individually on pieces of electrolytically-polished copper of the required shape for final use and there is no subsequent processing of the magnetic material. A longitudinal magnetic field is applied during deposition, in order to produce a preferred direction of magnetization, a rectangular hysteresis loop not being otherwise obtained. Since the nickel-iron alloy core is left attached to the copper for support, it is necessary to use an alloy with low magneto-striction, in order to avoid undesirable modification of its magnetic properties due to mechanical constraint exerted by the copper. Low magneto-striction is desirable also, in order to reduce the effects of mechanical handling and an alloy with approximately 80% of nickel is used to achieve this.

As discussed in Section 2 the memory cores are required to have a pole strength of about 0·1 e.m.u. in order to give a suitably short response time of the moving system. This corresponds with a total flux of about 1·25 maxwells and, since the 80% nickel alloy has a saturation flux of about 10 000 gauss, a core cross-sectional area of about $1{\cdot}25 \times 10^{-4}$ cm^2 is required. Now, as already mentioned in Section 1 and enlarged upon in Section 4, the memory cores are required not only to operate the count indicator, but also to act as logical elements in the counting circuits. This means that when a core is "interrogated" by application of a current pulse to one of its windings, the output signal from other windings on the core should be large or small (ideally zero) depending upon which of the two possible directions of saturation remanence the core previously had, i.e. depending upon whether the pulse causes magnetization reversal or not. In computer parlance, the core is required to give a "1" or a "0" output in its windings depending upon which state it was left in by previous circuit operation.

In the interests of ease of design and reliability of circuit operation, the ratio between the "1" and "0" outputs should be as large as possible, and this means that any magnetic coupling between the various windings of the core, other than that arising from the presence of the nickel-iron film, must be reduced to a minimum. The coupling between the windings and the core must therefore be very tight, with all opportunities for the production of stray flux minimized. The very small cross-sectional area of the core makes this difficult, unless care is exercised in the geometrical arrangement of the core and windings. The arrangement adopted is shown in Fig. 3.

The nickel-iron alloy film is deposited on to a cylindrical swaged copper rod of 0·092 in dia. (13 SWG) to a thickness of 1·8 microns, this giving approximately the required cross-sectional area of $1{\cdot}25 \times 10^{-4}$ cm^2. The five windings required for circuit operation (see Section 4) are then applied (only one winding is shown in Fig. 3), each as a single layer winding of 0·003 in thick enamelled copper tape, with 0·0005 in paper insulation between layers. Minimization of stray magnetic flux demands close spacing of turns and small winding diameter, while a minimum is set to the copper cross-sectional area by the need for low winding resistance. The use of the flat copper tape allows of the best compromise between winding diameter and resistance for a given number of turns.

The copper rod performs two functions. It forms a firm support for the nickel-iron film during winding, and eddy currents produced in it prevent any appreciable build up of flux inside the hollow cylindrical magnetic film within the duration of the 0·75 microsecond drive pulses. Flux change during the pulse periods is thus limited almost entirely to the magnetic film itself and the small annular inter-winding spaces. With reasonable care in winding, it is thus possible to achieve the necessary close coupling.

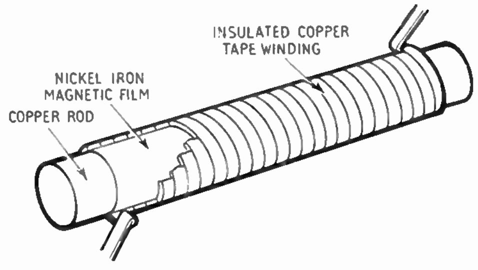

Fig. 3. Sectional diagram of memory core and windings.

It now remains to fix the length of the magnetic core and this will be determined largely by requirements (b), (d) and (f) of Section 3.1. The total flux change involved in reversing the magnetization of a memory core between saturation limits will be about 2·5 maxwells, and for operation in the transistor coupled counting circuits, a convenient mean voltage for such a change to produce across a winding during the 0·75 microsecond pulse period would be about 2·5–3·0 volts, i.e. a voltage-time integral of about 2 microsecond volts is required. This will require a winding of 75 turns. All five windings have the same number of turns and the same size of copper tape, in order to simplify the winding procedure. The length of the memory core can now be fixed by consideration of the number of turns per unit length required for fast magnetization reversal with a current of, say, 150 milliamperes, provided that the conditions for small self-demagnetization effects are met at the same time and provided also that the distance between the poles of the core is fairly large compared with the distance between one pole and its compass needle. The latter is really part of requirement (a) in Section 3.1, and is desirable in order to avoid the reverse torque produced by one pole on the needle at the opposite end of the indicator. This has been neglected in the torque calculations in Section 2. A core length of 3 cm was chosen, and it is shown in Appendix 1 that this is sufficiently great to reduce self-demagnetizing effects to negligible proportions. The current required in a 75 turn winding to produce a field of 3·5 oersteds (the coercive force of the nickel-iron film) in a core of this length is

$$\frac{10}{4} \times \frac{3{\cdot}5 \times 3}{75} = 111 \text{ milliamps}$$

which was thought satisfactory.

3.3. *Performance of Memory Cores and Windings*

3.3.1. Stray flux

The total unwanted flux associated with each winding can be determined by exciting the outer winding with uni-directional flat-topped current pulses and measuring the voltage time integrals of the pulses on each of the other windings. The magnetization of the nickel-iron film will not be reversed by the uni-directional pulses and, under these conditions, there would ideally be no signal produced across the windings. The inductive component of the signals produced in practice will arise from

(a) the stray flux occurring in the small annular spaces between the core and first winding and between adjacent windings,

(b) flux build up in the copper bar due to its finite resistance, and

(c) flux changes occurring in the nickel-iron core due to the existence of a finite slope of the top of the hysteresis loop.

By far the greater contribution arises from (a) in practice and this is quite easily calculable.

Table 1 shows the voltage/time integrals obtained on each of the four inner windings when the outer winding was excited by 400 milliamp uni-directional pulses. This is approximately the peak pulse amplitude occurring in the counting circuits.

Table 1

Outer winding excited by 400 mA uni-directional pulses

Winding	Voltage/time integral volt. seconds $\times 10^{-6}$	Differences
1st (inner)	0·10	0·10
2nd	0·125	0·125
3rd	0·37	0·145
4th	0·53	0·160

From measurements of the outer diameter of the outer coil and of the copper bar, the mean effective spacing between layers of copper appeared to be about 0·005 in. Thus taking the mean diameter of the annular space between the nickel-iron and the inner winding as 0·097 in the cross-sectional area of this space would be approximately

$$0{\cdot}097 \times \pi \times 0{\cdot}005 \times 2{\cdot}54^2 = 0{\cdot}0096 \text{ cm}^2$$

The strength of the magnetic field produced by the current of 400 milliamps in the 75 turn coil of length 3 cm would be

$$\frac{4\pi \times 75 \times 400}{10 \times 3 \times 1000} = 12{\cdot}5 \text{ oersteds}$$

Thus the voltage/time integral to be expected across the 75-turn inner winding due to flux in this annular space would be

$$0{\cdot}0096 \times 12{\cdot}5 \times 10^{-8} \times 75 = 0{\cdot}09 \times 10^{-6} \text{ volt seconds}$$

This agrees as well as can be expected with the measured value of $0{\cdot}1 \times 10^{-6}$ V.s and it can be seen that similar agreement would be obtained between measured and calculated values of the differences in voltage/time integrals of adjacent windings. The gradual increase in diameter of successive windings gives the increasing differences in voltage/time integrals observed. These observations confirm the relative smallness of the flux changes in the copper bar and the nickel-iron film (when its magnetization is not reversed).

It is seen from the above that the voltage/time integral of the spurious pulse obtained on the inner winding with a drive pulse on another winding of about four times the coercive current is about 5% of that of the pulse obtained when the magnetization of the film reverses. This is approximately the same as the ratio obtained on the first winding applied to a small ferrite ring core, under corresponding drive conditions, and is satisfactory for operation in the counting circuits.

3.3.2. Speed of magnetization reversal

Figure 4 shows curves of the inverse of the time for magnetization reversal or switching time plotted against the amplitude of the field applied by drive current pulses of alternate sign.

For these measurements, the switching time was taken as the time from the start of the current pulse to the instant at which the falling back edge of the voltage pulse on a winding coupling the core had fallen to 10% of the peak value. The drive current pulse which had a rise time of 0·010 microseconds was applied to a separate winding.

It will be seen that the slope of the curve (curve 1) for the nickel-iron film (0·160 oersted-microseconds)

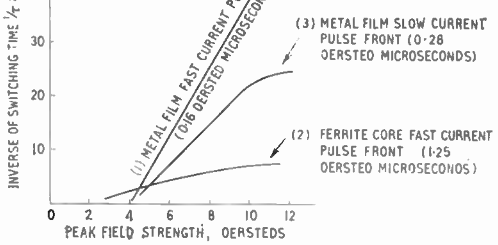

Fig. 4. Variation of speed of magnetization reversal with field.

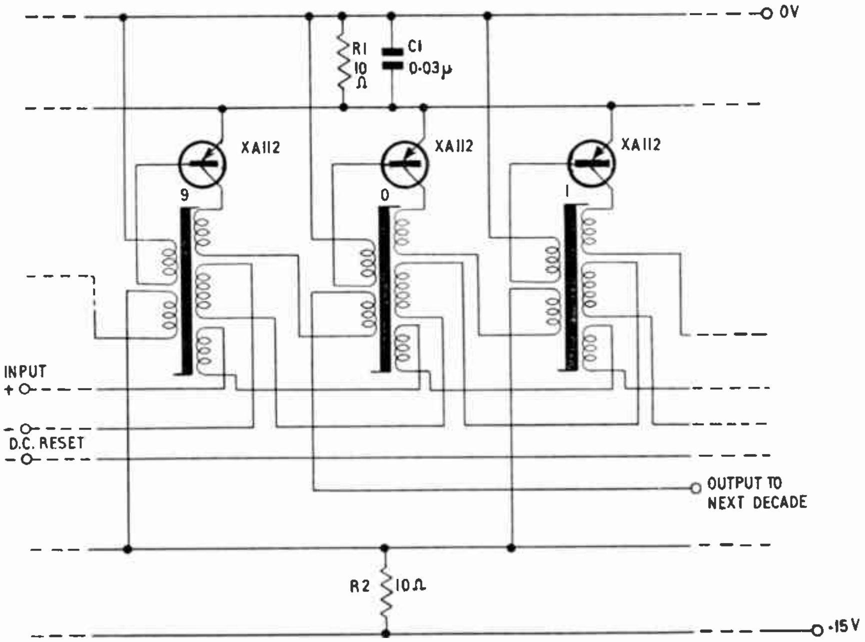

Fig. 5. Three stages of the decade circuit.

is much greater than that (curve 2) for the ferrite core (1·25 oersted-microseconds), and since the former has the greater coercive force, its switching speed for a given multiple of its coercive force is very much greater. The switching speed of the metal films is very dependent upon the rate of rise of the drive current pulse, as is shown by curve 3 of Fig. 4, which was obtained with a drive pulse having a rise-time of 0·12 microseconds. The latter rise-time approximates more closely to that of the current pulse produced in the transistor coupled counting circuits, but even so the required 0·60 microsecond switching time is achieved with a driving field not much greater than the minimum field for reversal which itself is a little greater than the coercive force.

The dynamic properties of the films are thus quite satisfactory for use in the scaling circuits.

4. Electronic Circuits

4.1. *Decade Circuit*

In early versions of this type of scaler,[1] the ten indicator memory cores were arranged in a two-phase ring circuit operating on the current routing principle.[5, 6] Phase splitting was accomplished by inserting a scale-of-two circuit between the incoming signals to be counted and the ring-of-ten. This circuit had the advantage of employing only two transistors, which were very expensive at that time, but used twelve semi-conductor diodes in the ring-of-ten. It had the disadvantage that each transistor had to drive not only the two scale-of-two magnetic cores, but also half of the ring-of-ten cores. Only three of the seven cores reversed their magnetization on each circuit operation, but the resistances and leakage inductances of the windings of all seven were involved. This resulted in increased transistor power dissipation during the whole pulse period, but particularly during the turn-off periods at the ends of the pulses. The transistor power dissipation in such circuits tends to occur mainly during the turn-off periods, when both the current and voltage to which the transistor is subjected are quite high, and the large collector voltage overswing due to the inductance of the seven windings added to this power dissipation directly, and also indirectly by increasing the turn-off time. As a result of this, the counting rate of a scaling circuit employing 2 mm ferrite cores as memory elements and XA112 transistors was limited to about 200 kc/s by the transistor power dissipation. The upper limit of count rate could, of course, have been increased by operating a greater number of transistors in parallel.

Since the energy involved in reversing the magnetization of the cores used in the present type of indicating scaler is about 2½ times greater than that required for the 2 mm ferrite cores, and since the maximum counting rate is required to be at least 1 Mc/s, some means was required of reducing the inductive loading on the transistors. This was done by expanding the scale-of-two circuit itself into a ring-of-ten, so that the decade circuit consists merely of ten transistors and ten memory cores with a few auxiliary components. As a result of the large fall in price of transistors over the last few years, this change can be made with very little change in cost of the complete circuit. Each transistor now drives only two cores and operates only on every tenth incoming pulse, instead of every second one, and the circuit can count continuously at its maximum possible rate of about 1·3 Mc/s, with a transistor dissipation well below the rated maximum.

Figure 5 shows three stages of the ring-of-ten. A rectangular hysteresis loop shape is used as a symbol for the memory cores in this diagram, to distinguish them from normal transformer cores. Each transistor and its associated memory core form a half-cycle blocking oscillator, the base and collector windings being arranged to give positive feed-back. Polarities are so arranged that the flow of collector current tends to drive the core towards the normal and away from the reversed state of magnetization, and this direction of change tends to turn the transistor on. Thus, the application of an input pulse in such a direction as to drive all cores towards the normal direction triggers on only the one blocking oscillator whose core is in the reversed state of magnetization. This stays on until its core is returned fully to the normal direction of magnetization. Each of the other nine transistors passes a small amount of current during the rising edge of the input pulse, due to the coupling by stray flux between the input and base windings, but this effect is not sufficiently great to be serious. The collector current of each transistor is arranged to pass through a winding on the next core in the ring in such a direction as to change its magnetization to the reversed state, and the net result of applying an input pulse is thus to advance the position of reversed magnetization around the ring by one core spacing.

The numbers between the cores and transistors in Fig. 5 indicate the position of the core in the ring, and it will be noted that the collector current of transistor 9, after passing through the appropriate windings on cores 9 and 0 is taken out to trigger the next decade. Outputs can be taken in a similar manner from any of the other nine stages, if required, the remaining stages sharing a common ballast resistor, R_2.

Prior to the commencement of a count, it is generally required to set the decade to zero, i.e. put the 0 core into the reversed state and the other nine into the normal state. This is done by applying a d.c. potential for an instant between the points marked D.C. RESET, which are connected to windings of appropriate polarity on each of the ten cores.

The parallel combination of resistor R1 and capacitor C1, which is common to the emitter circuits of all ten transistors, serves three purposes,

(a) By providing base-emitter feed-back which is directly related to the collector current, it tends to control the pulse-length and current amplitude in relation to the dynamic characteristics of the memory cores which are fairly uniform and stable, and to minimize the effects of transistor base-emitter voltage tolerances. Since the voltage/time integral per pulse across any winding, for example the base winding, is fixed by the saturation-saturation flux change in the memory core, the pulse length is inversely proportional to the mean voltage between the transistor base and the positive supply line.

(b) By providing a negative emitter bias (peak value about 3 volts) which is maintained by the capacitor for a short period after the transistor begins to turn off, it hastens the turn-off and thus substantially reduces the transistor power dissipation.

(c) The negative emitter-bias maintained during the turn-off period helps to prevent the next transistor in the ring from being turned on by the inductive surge resulting from the rapid fall of current in one of the windings of its core.

For a resolving time of 0·75 μs, the total transistor conduction time must be about 0·75 μs, and, allowing for say 0·15 μs turn-off time, the period during which the transistor is being driven on by the base winding e.m.f. must be about 0·6 μs. The memory cores must therefore reverse their magnetization in this time and, with a 75 turn winding, this requires a current of about 160 mA. The reversal brought about by transistor collector current is partially opposed by base current in a winding of its own core, and by input current in the case of the next core in the ring, so the total collector current will need to be about 350–400 mA for part of the pulse period. Some transistors of the type used have a pulse current gain of only about 5 at these high currents, and so, allowing for a possible minimum of 3, the base current will need to be about 130 mA. The base-emitter voltage required for this current is generally about 1 V. Now, as previously mentioned, the voltage/time integral per pulse across the 75 turn base winding will be 2 μs.V, giving a mean voltage for 0·6 μs of 3·33 V. The mean voltage across the emitter load (R1 and C1 in parallel) will thus need to be about 2·33 V and R1 and C1 are adjusted to give this. The collector current rises to about 270 mA in the first 0·2 μs, then rises more slowly to a peak of about 400 mA during the following 0·4 μs, and, finally, falls steeply to zero in the next 0·15 μs. This current waveform gives the required mean emitter bias voltage with the values of R1 and C1 shown and gives a final value of about 3 V, which is sufficient for purposes (b) and (c) above.

The minimum value of input current for triggering is determined largely by the width of the hysteresis loop of the memory cores, and is about 110 mA. The maximum value is influenced by the fact that the

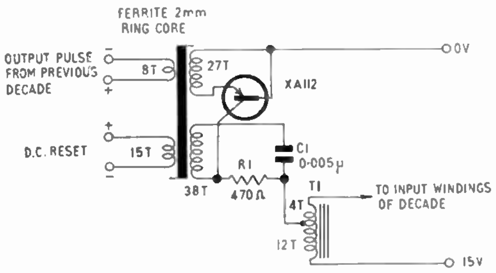

Fig. 6. Inter-decade coupling circuit.

input current tends to oppose the change of magnetization from the normal to the reversed state of the next core in the ring by the collector current of the transistor which is in conduction. This maximum varies with the width of the input pulse and for a 0·5 μs pulse is about 440 mA. If the width is greater, the maximum current is reduced, while if it is much less the minimum current is increased. About 0·5 μs gives the maximum ratio of maximum to minimum and the optimum design value for input current is about 220 mA with this pulse width.

4.2. *Interdecade Coupling*

As mentioned in the previous section, an input pulse of approximately 0·5 μs width is required for satisfactory triggering and the 0·75 μs output pulse from transistor 9 of the previous decade cannot be used directly. Passive pulse shaping networks can be designed to modify the latter pulse suitably, but this is difficult, in view of the fact that there is little excess power available in it, and insufficient allowance can be made for circuit tolerances. Instead the circuit shown in Fig. 6 is used. The transistor and the rectangular hysteresis loop ferrite core form a blocking oscillator with collector-emitter feedback.

Initially the ferrite core is in a state of saturation remanence of opposite polarity to that which would tend to be caused by the flow of collector current. Thus when a pulse of appropriate polarity and sufficient amplitude is applied to the 8-turn winding on the core, the transistor begins to turn on and is turned on fully by the feedback. Practically the whole of the supply voltage is then applied across the series combination of C1 and the leakage inductance of the input windings of the decade as reflected by the auto-transformer T1. The input winding inductance forms a tuned circuit with C1 and its value is such that the resultant current waveform is approximately a half sine-wave of half-period 0·5 μs and peak amplitude about 300 mA. This when transformed down by T1 gives about 220 mA in the input windings of the decade. Cessation of this current causes the feedback via the ferrite core to cease and the transistor begins to turn off. C1 then discharges through R1 and the 38-turn winding on the ferrite core, the discharge current resetting the core to its original state of saturation remanence ready for the next pulse. This resetting action produces a negative voltage on the emitter, which helps to turn off the transistor rapidly. After the ferrite core has saturated, the discharge of C1 is controlled by R1 giving a discharge time constant of 2·5 μs. This is sufficiently short for an interdecade circuit, because the minimum spacing of successive output pulses from even the first decade could not be less than ten times its resolving time of 0·75 μs, i.e. 7·5 μs.

Owing to the charge on C1 the potential of the transistor collector is held near to that of the positive supply line during the turn-off period, and the power dissipation in the transistor is therefore small. Use of the rectangular hysteresis loop core in this circuit gives a threshold field and therefore a threshold input current below which the circuit will not operate. This is useful in preventing unwanted operations of the circuit by small spurious signals occurring in the output of a decade, due to stray inductive coupling between windings (see Section 4.1).

4.3. *Drive Circuit for the First Decade*

As discussed previously, when a transistor in the decade circuit is turned on by an input pulse, reversal of the next core in the ring tends to be opposed by the input pulse itself. Therefore, if the input pulse is too long, or two pulses occur with an insufficient time interval between them, this reversal can be prevented and the decade thrown out of action. For triggering the first decade, therefore, we need a circuit which will deliver 0·5 μs, 220 mA pulses with a minimum possible spacing of 0·75 μs, and be capable of operating continuously with this pulse spacing (i.e. a recurrence frequency of 1·33 Mc/s). It has not been found possible to design a simple and satisfactory circuit to do this using low price transistors available, and the input windings of the decades have therefore been arranged to be operable in a two-phase mode.

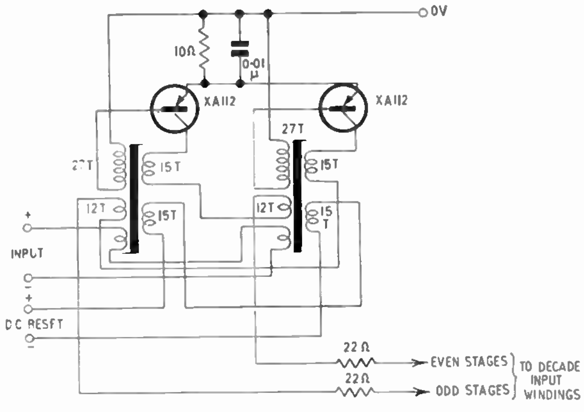

Fig. 7. Drive circuit for first decade.

The input drive circuit is arranged as a scale-of-two of which each side drives alternate stages of the decade. Opposition of the input current and transistor collector current in the windings of the core of the following stage is therefore avoided and there is thus no limitation on the length of the input pulses. Each side of the scale-of-two also has a full 0·75 μs to recover after each operation. The scale-of-two is arranged to give 0·75 μs pulses and the minimum spacing between pulse fronts from opposite sides of it is thus 0·75 μs.

The circuit arrangement is shown in Fig. 7. It is basically the same as the decade circuit, but having only two stages and having 2 mm rectangular hysterisis loop ring cores as memory elements. This circuit must have the following properties:

(a) It must not be "tripped" out of action by a close spaced bunch of input pulses.

(b) It must not give output pulses which are of sufficient amplitude partially to trigger the decade but too small to trigger it fully.

If a bunch of pulses ends at too short a time after the end of a scale-of-two pulse, it may fail to re-trigger it and yet move the magnetization of the appropriate memory core some distance away from saturation magnetization. If the core magnetization is moved sufficiently far, the next successful triggering may result in a pulse which is too short to cause reversal of magnetization of the other core, and the circuit will become inoperative. This is the "tripping" action referred to in (a) above. It can be avoided by having a sufficiently large voltage/time integral available on the base feedback windings of the memory cores so that the point of decision between triggering and failing to trigger is reached by use of only a small fraction of it. It is, of course, theoretically possible to design the decade itself so that it cannot be tripped in this way, but the practical difficulty of winding the nickel-iron film cores with large numbers of turns prevents this.

Requirement (b) can be met by making the collector current required to commence magnetization reversal of one of the scale-of-two cores and provide a little base current small compared with the full operating current. The "misfire" current is then too small to disturb the decade. The "misfire" current of the circuit of Fig. 7 is about 50 mA, which is less than half that required to exceed the coercive force of the nickel-iron film cores of the decade and therefore causes no disturbance. The full pulse current to the decade input windings is about 250 mA.

The number of turns on the input windings of the scale-of-two can be adjusted to suit the source of input pulses. The minimum number of ampere turns for triggering is about 1·3 and the back e.m.f. on the windings is about 0·12 volts per turn.

4.4. *Transistor Junction Temperature Rise*

Transistor power dissipation is difficult to calculate accurately in pulse circuits in which the turn-on and turn-off periods form a substantial proportion of the total pulse period. It was therefore thought desirable to measure the actual junction temperature rise of the transistors during normal circuit operation. This was done by switching the transistor under test out of circuit for a few milliseconds every second and measuring its collector leakage current. A d.c. test was then performed to check the ambient temperature which gave the same collector leakage current, and this ambient temperature was taken as the junction temperature existing as a result of the pulse circuit operation. The switching was done by relays and the leakage current measured by a microammeter.

When using XA112 transistors in the decade, continuous operation at a counting rate of 1 Mc/s was found to give a junction temperature rise which varied from transistor to transistor over the range 6°C to 12·5°C with an average of about 9°C. The maximum rated junction temperature of 75°C therefore allows of operation at this count rate with ambient temperatures up to 66°C.

The estimated power dissipation per transistor at this frequency was 45 mW, which with a 9 deg C temperature rise corresponds with a thermal resistance of 0·2 deg C/mW. This is only half of the figure of 0·4 deg C/mW quoted by the manufacturer, but the correctness of the lower figures was checked by d.c. tests, in which the power dissipation was accurately calculable.

The junction temperature rise of transistors used in the interdecade coupling circuit was not measured, since, for reasons discussed in Section 4.2, the power dissipation in these transistors is small.

In the case of the input scale-of-two, each transistor operates on every second input pulse, and this gives a measured temperature rise from 22°C to 49°C at a count rate of 1 Mc/s. In order to keep the maximum temperature rise down to say 25°C at 1 Mc/s count rate, two transistors must be used in parallel on each side of the scale-of-two. When this is done, satisfactory current sharing can be achieved by operating each pair of transistors with a separate emitter load. Each emitter load impedance is made equal to twice that used with a single pair of transistors the time constant remaining unchanged. The resistance is therefore double and the capacitance in parallel with it is halved. This principle can obviously be applied to a larger number of transistor pairs if a lower maximum junction temperature rise is required.

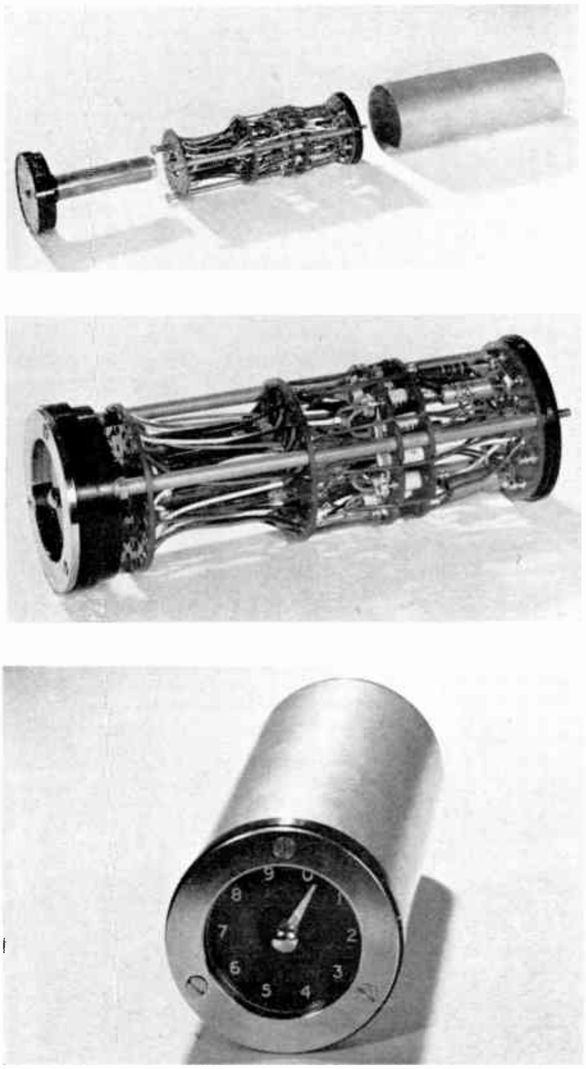

Fig. 8. A unit decade. The indicator is at the left-hand end and the electronic circuits are at the other end.

5. Mechanical Construction

Figure 8 shows the general arrangement of a unit decade as developed by Messrs. Avo Ltd. This contains the decade proper with an interdecade coupling circuit as an input circuit. It takes the form of a cylinder of diameter $2\frac{3}{16}$ in and length 6 in, the indicator occupying one end and the electronic circuits the other end. Arrangements are made for panel mounting, the face of the indicator passing through a $1\frac{1}{2}$ in diam. hole in the panel. The total weight of the unit is $6\frac{1}{2}$ oz. (12 oz. if a mu-metal screen is used instead of a thin dust cover).

In a multi-decade system the unit decades can be directly connected, and, up to an input count rate of 100 kc/s, the first decade can be triggered via its own interdecade coupling circuit. At higher input count rates the latter circuit is disconnected by means of a system of links, and the input to the decade is taken from a scale-of-two input unit (Fig. 7).

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7. Appendix

Self Demagnetizing Field of Memory Cores

For reasons given in Section 2, at positions along the cores remote from the ends, the field can be considered as that due to two free point poles. Thus, if the cores are of length $2l$ and pole strength m, the field at a distance d from their centre will be

$$H = \frac{m}{(l+d)^2} + \frac{m}{(l-d)^2}$$

Since $m = 0{\cdot}1$ e.m.u. and $2l = 3$ cm, the field at the centre where $d = 0$ will be

$$H = \frac{2 \times 0{\cdot}1}{1{\cdot}5^2} = 0{\cdot}089 \text{ oersteds}$$

and at a point mid-way between the centre and one end where $d = 0{\cdot}75$ cm,

$$H = \frac{0{\cdot}1}{0{\cdot}75^2} + \frac{0{\cdot}1}{2{\cdot}25^2} = 0{\cdot}198 \text{ oersteds}$$

At points near to the ends of the cores, it is not permissible to consider their ends as point poles, but at points very near to the ends, the field will not differ very much from that which would be produced by the edge of a flat film of infinite width. It can be shown that the field at a distance d from the edge of a film of pole strength m per unit length is $2m/d$. The value of m for a film of saturation flux density 10 000 gauss and thickness $1{\cdot}8 \times 10^{-4}$ cm will be 0·143 e.m.u./cm and, therefore, the value for d for which the field becomes equal to the coercive force of 3·5 oersteds will be $2m/3{\cdot}5 = 0{\cdot}082$ cm. Thus the length of the portion of each end of the core which will be seriously disturbed by the demagnetizing field will be less than 1 millimetre.

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Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Abstracts of papers published in American journals are not included because they are available in many other publications. Members who wish to consult any of the papers quoted should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. Translations cannot be supplied. Information on translating services will be found in the Institution publication "Library Services and Technical Information".

TRANSISTOR AMPLIFIER TEMPERATURE STABILIZATION

A Czech paper discusses temperature stabilization of the gain of a common emitter transistor a.f. amplifier in the range $\pm 40°$ C. Instead of stabilizing the gain with the aid of thermistors or semiconductor diodes the author exploits a suitable value of the generator resistance facilitating good gain stabilization under the assumption of good temperature stabilization of the d.c. working point. In the paper the h parameters measured on a Tesla 104NU70 transistor are stated as a function of the temperature for the range $\pm 40°$ C. It is shown that the h parameters change with temperature in such a way as to facilitate good gain stabilization in the entire temperature range. The mutual relation of h_{21} for various temperatures is pointed out. The theoretical results are verified by measuring an amplifier with the proposed temperature stabilization of gain.

"Temperature stabilization of the gain in transistorized a.f. amplifiers", J. Mikula. *Slaboproudy Obzor*, 6, No. 11, pp. 659–63, November 1961.

SHORT WAVE PROPAGATION

A recent paper from the Ionosphere Research Laboratories at Andhra University deals with the interpretation of periodic fading observed in oblique incidence c.w. transmissions as due to changes in phase-paths of the interfering waves produced by critical frequency changes in the reflecting layer. Using Booker's equation as modified by Rao and Rao in 1958, changes in path lengths and hence the number of interference maxima have been calculated and compared the theoretically calculated values with experimentally obtained values due to the interference of the different modes, the possible modes by which the transmissions from Calcutta and Madras arrive at the receiving station (Waltair), have been determined. By using the number of interference maxima and the critical frequency values at any instant, a method of calculating critical frequency changes in small time intervals has been proposed.

"Periodic fading in oblique incidence short-wave transmissions", B. R. Rao, M. G. S. Rao and D. S. Murty. *Indian Journal of Physics*, 35, No. 9, pp. 475–83, September 1961.

R.F. MONITOR FOR PROTON SYNCHROTRON

A transistor r.f. monitor has been developed for use in the proposed proton-synchrotron at the Australian National University, Canberra. The accelerating signal is developed at low level by a master oscillator whose frequency sweeps from approximately 1 to 7·5 Mc/s during the acceleration cycle which lasts about 0·8 seconds. To maintain the protons in orbit throughout the cycle, the oscillator sweep must follow a definite law which relates the speed of revolution of the particles to the strength of the guide-field in the synchrotron's orbital air-cored magnet. The r.f. monitor which is described in a recent paper has enabled the initial adjustment of the tuned circuit parameters in the master oscillator to be made so that its dynamic sweep follows the theoretical law to the required accuracy of 0·1%. Detailed examination of the sweep may be made for guide-fields in the range 0 to 20 kilogauss: a frequency measurement is made at a predetermined value of field, and meters give an indication of the percentage frequency error in the sweep at that point. The monitor can perform a total of six such measurements at selected points throughout a single sweep storing the errors obtained and presenting them on meters for inspection when the sweep is completed. In this way, the monitor can be employed to check the oscillator's adjustment periodically. An examination of the possibility of using this feature of the monitor during an actual acceleration cycle shows that the instrument should also provide useful information concerning the performance of the oscillator under these conditions.

"Transistorized r.f. monitor for the Canberra proton-synchrotron", B. F. Wadsworth, *Proceedings of the Institution of Radio Engineers Australia*, 22, No. 11, pp. 701–710, November 1961.

PASSIVE REFLECTORS

The relations for designing passive reflective surface for beyond-the-horizon radio relay links are described by a Czech engineer in a recent paper. The relations are derived from additional loss and efficiency in cases of using reflectors for deviating electromagnetic energy, the condition of validity of the transmission equation for free space, and the planeness factor of the reflective surface. From the geometric configuration, the transmitter-reflector distance, the reflector-receiver distance, the transmitter-receiver distance, and the heights of the transmitter, the reflector, and the receiver, the azimuth and elevation for orientation of the reflective surface in the field are established. The procedure of deriving the radiation pattern of a rectangular reflector is then stated and the zero directions of the radiation diagram as well as the width of the main lobe between the first zeros of the diagram in the incidence plans are determined. The paper is supplemented by an example of the design of a reflective surface for a beyond-the-horizon link.

"Plane reflective surfaces in beyond-the-horizon radio relay links", F. Stranak, *Slaboproudy Obzor*, 6, No. 6, pp. 350–5, June 1961.