Founded 1925
Incorporated
by Royal Charter 1961
To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering

Volume 51 Number 1
January 1981

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

Resource Management: A Key to Immediate Improvement in Productivity?

The Presidential Address of

JOHN POWELL

T.D., M.Sc., F.Inst.P., C.Eng., F.I.E.E., F.I.E.R.E.

Delivered after the Annual General Meeting of the Institution in London on 23rd October 1980

At about this time last year my predecessor in the high office to which I have just been elected described the manner in which engineers had been prepared for the profession and the consequences of failure to recognize, or to do very much about, their quality, quantity and utilization in the wealth-generating process. He also indicated in eloquent fashion a possible path in the future development of the profession.

There is, I believe, a third element in the current debate on where we have come from and where we should be going. It is perhaps as important in the current circumstances as planning for the future, the results of which cannot be experienced for some time yet. I have called this element 'resource management' but, of course, this simple phrase requires definition and elaboration. It is used here to mean the management of human skills possessed by chartered engineers, technician engineers and technicians and their associates in other disciplines. Application of the skills possessed today, not those to be acquired after the passage of a few years' time, are responsible for the current generation of ideas and their conversion to market-worthy products. It is in the better management of these skills that the first fruit could be obtained from the wide-ranging examination carried out by the (Finniston) Committee of Inquiry into the Engineering Profession, which published its report[1] and defined the engineering dimension at the beginning of this year.

Motivation in Industry

For some time I have had the impression that at least some of the problems which British manufacturing industry has to contend with are very much reduced in the telecommunication service industry by the manner in which the workforce is treated in terms of the employment conditions offered.

From my own experience in the telecommunication service field, which has embraced nearly all facets of the work to be found under that heading, I have hardly ever felt that I was not part of a team with a common and interesting objective, although sometimes it may have been ill-defined. Furthermore my terms of employment have remained substantially constant as I have moved from being a new entrant operator over 30 years ago to my present post. In these matters who would deny that I have been more fortunate than most employees in British industry.

I believe strongly that these two factors of 'being wanted' and 'being well and uniformly treated' are amongst those providing the highest motivation to corporate effort.

Social conscience is a phrase which is interpreted in many different ways. At one end of the scale it can be said to be the motivation for advocacy of a community relationship wherein all contribute according to their ability to do so, and receive according to their needs. An ideal concept which cannot ever be made entirely

The Radio and Electronic Engineer, Vol. 51, No. 1, pp. 1–9 January 1981

0033–7722/81/010001 + 09 $1.50/0

effective simply because people are not ideal. They have the weaknesses of the human being.

At the other end of the scale there is the motivation of survival. Only if an adequate minimum social concern is demonstrated can the threat of disturbance be avoided to whatever the current social structure may be.

Between these extremes one could define an arrangement which, with an improvement in social attitudes, might be viewed as feasible. Within this, team effort and the support given to or required from other groups of people would be recognized as part of a work pattern established to optimize the use of the skill of each individual wherever employed.

Who would argue that increasing benefits would not accrue to our society if such a general change in outlook were to be brought about and continued into the future. But can it be done, and is my appreciation of the situation shared by others? High unemployment levels[2] are forecast to remain with us until the end of the century, subject to no major catastrophes occurring, and the existence of a highly-educated, ambitious and vigorous group of the population without work opportunities might well have a deleterious effect on attitudes. Certainly if one looks back the increase in the average length of the period of formal education and the very much increased number of young people undergoing further education have not resulted in a general improvement in social behaviour. The incidence of crime is a most depressing statistic.

The State of British Industry

It is rather sad to note how frequently blame for particular difficulties encountered in British manufacturing industry is assigned to another party or parties. One finds union leaders expressing concern about the industrial action they say they have been forced to take by the intransigence of this or that employing organization. Industrial action usually means withdrawal of labour and intransigence usually means an unwillingness to meet pay levels sought by the unions. The problems seem to arise when the facts concerning the means to increase employee rewards are not known or fully understood. With published company reports and accounts this should never be a mystery. However, comparison with others working in a different company, different environment or different specialization and the changes in the cost of living are often stated to be the reason for a specific level of claim or demand for improvement. What does not often receive comment is that when work stops wealth-generation stops. If there are no ingredients there can be no cake.

Recently Edward Heath[3] commented on the tendency for Government, unions and industry to blame each other for the state of the country and indicated the urgent need for bridging the gaps in understanding between them which currently exist. Attention has also been drawn to this matter in the Finniston report and in a House of Commons debate on information technology during July. All this indicates that a deplorable situation exists and that team spirit must be improved throughout British manufacturing industry if it is to achieve anything like its potential performance.

There are, however, encouraging signs from a variety of quarters that this problem is being tackled. Whatever our role may be in technological society we should encourage this movement and help it to gather momentum in any way we can.

In delivering the 24th Graham Clark Lecture in March this year Sir Frederick Page[4] stated that, in one division of British Aerospace, employment schemes currently being tested included staff status for all manual workers, abolition of piecework and individual performance ratings, and universal participation in a value-added bonus arrangement related to actual earnings. Some interesting pointers to future progress in this area of prime importance had already been discerned and evidence obtained to show that, once a well ordered and understood pattern of work has been established and a corporate spirit achieved, performance in the UK could be as high as that found anywhere in the world.

It was Winston Kock[5] who said that the economic growth and strength of a nation are directly related to the ability of its people to make discoveries and their ability to transform these discoveries into useful products. I suggest that it is only in our conversion of discoveries into useful products that we have not lived up to our past achievements, but it is a weakness which can and must be eradicated. Here again the use to which our engineering talent is being put has a question mark over it.

Automation and the Microchip

Over thirty years ago John Sargrove[6] was developing automated manufacturing facilities for the electronics industry and these were demonstrated to be highly effective in releasing technicians from repetitive work for more interesting activity. They were also seen as a means of overcoming the labour shortage in the early post-war years. However, because of the state of technology at that time, the reliability of the control equipment as it was introduced to larger scale and more complex tasks meant that it only worked satisfactorily for brief periods. Maintenance attention was then required before the machinery could be brought into use again. This factor and the concern expressed by those who feared they would lose their jobs if automation caught on caused interest to wane and financial support to disappear.

At the next stage of automation where machinery could be programmed and therefore made much more versatile, this country has also played a leading role, but failed dismally in capitalizing on its ideas and developments. The consequence is that we are now buying robots incorporating those ideas and developments from overseas where their commercial value was recognized from the time they were made known in published papers. Even today there still seems to be a general reluctance to vigorously examine whether investment in robots can bring about a reduction in the cost of production and an improvement in job interest for those engaged in the production process by reducing the number of monotonous tasks they have to perform.

Yet the TUC is reported to be in favour of the introduction of new technology in factories providing appropriate consultation takes place with the workforce. Furthermore, in a recent analysis of the likely effects of microelectronic equipment[7] being used on a wide scale in processes and products in a spread of industries within the Greater Manchester area, job losses in the next decade have been assessed as being about 2%, and this on the basis of output, demand and other factors remaining unchanged. However, as the use of such equipment widens there could well be associated changes in the companies concerned and the job losses from this cause may be four or five times that already quoted. But what about new industries and growth in some of those existing now? A palliative effect there must be but who could quantify it with any confidence?

As more and more of the routine tasks in manufacturing industry are automated and machinery design is made more efficient, it follows that the demand for various types of labour will reduce. The evidence for this is all around us. However, the demand for engineering skills must increase as a consequence since the design, construction and maintenance of such machinery, of ever increasing complexity, will be of as much importance as, and in addition to, the design of the factory products. A movement for employment in the service industry to increase as the manufacturing workforce contracts is also clearly discerned.

Employment Practice in the United States

What is the current employment practice in the USA, and the background against which it has developed?[8–13]

A general increase in the educational and economic standing of employees in the USA has resulted in job interest becoming as important to many of them as the level of pay. Income must support an adequate standard of living, however that may be defined, and be perceived as equitable, but high income alone is not enough.

There is growing national concern about the overall quality of life both at home and in the office or factory. People have a real desire to do more, to carry meaningful responsibility and to have personal involvement in decisions and actions affecting their jobs and the products with which they are associated. In addition they are seeking through their trade unions greater leisure, income and job security and substantial advance notification to the affected employees if a factory is to be closed or re-located.

Employees as a group have not been accorded the substantial civil liberties enjoyed by individuals or other groups in American society. In most companies employees are tightly constrained and are sometimes denied ordinary rights of speech, protest or impartial review of their complaints. However, there is a major exception to this generalization and it has been developed in the collective bargaining process in which about a quarter of the total workforce is involved. Apart from having a right to file grievances, there is an entitlement to request union advocacy and an ultimate appeal to an impartial arbitrator.

Some public employees who are not members of a union are covered by the protection of civil service systems and in some private companies personnel officers function to a certain extent as advocates of the complainants in disputes with line managers. It has also been noted that increasingly liberal attitudes are being taken by companies and the constraints on employees reduced.

Some controversy exists between those who emphasize the value of the material rewards for effort and those who believe that the quality of life is the more important aspect but it is worth noting that the initiative for many of the beneficial changes introduced into the work scene has emanated from the workforce itself. There are many well-documented experiments showing that productivity increases and social problems decrease when people participate in the work decisions affecting their lives, and when the responsibility for their work is buttressed by participation in profits.

The USA remains one of the least paternalistic countries in the industrial world. Companies and their managers are expected to operate with a high degree of self-sufficiency and to accept the risks involved. This is at variance with the situation in some other countries, particularly Japan, where the emphasis is on job security and status.

Most American systems of management currently emphasize short-term goals, individual achievement, competition and financial incentives to motivate employees often with little assurance of employment security. Not only is it accepted that managers have the right to direct work but they have an obligation to do so. This is matched by the obligation of those employees being directed to perform the assigned tasks. Where it is felt that the assignment is ill-advised or prohibited under a collective bargaining agreement the obligation to carry out the work remains until any complaint is examined and a conclusion reached.

Managers believe that the retention of this right is important in preserving the orderly flow of work, maintaining efficiency and controlling costs. Until recently major unions largely accepted this viewpoint; it is certainly deeply imbedded in the provisions of collective bargaining agreements and favourably treated by arbitrators in their decisions and in court opinions. It is now, however, being questioned by unions.

The policies adopted by companies over a period of years appear to have been motivated by three related aims; development of the skills and potentialities of personnel, obtaining the highest level of contribution from each member of the workforce and reducing to a minimum the cost of production. These policies have been changing and are likely to continue to change as the character of various groups of employees alter.

In contrast with the forecast UK position, the slowing of the annual increase in the labour force has led to a prediction of labour shortage by the mid-1980s even though immigration may off-set the forecast shortage to some extent. This factor may also have a bearing on policy changes.

Lessons from Japanese Industry

Japan has long been admired for her industrial performance and it seems to be generally accepted that there are three very important institutional factors which have been primarily responsible for the success achieved. These are, life-long employment, the seniority wage system and enterprise trade unionism.[12, 14–17]

Out leading the attack on world markets are the large, tremendously efficient and profitable companies but they are supported by a multiplicity of smaller firms in primarily a sub-contractor role. There are no clear-cut boundaries between these two sectors of Japanese industry but the features of employment in the larger firms are very much less well established in the smaller ones; in some cases they may be completely absent.

In times of recession it is in those firms which are primarily engaged in sub-contracting activity where redundancies have to be declared in order to maintain the life-long employment system of the large companies.

When an individual joins a company operating a life-long employment system he does so with a tacit understanding that, in normal circumstances, he will remain an employee of the company until retirement. The company will not discharge the employee before he reaches retirement age unless an exceptional situation arises.

It is claimed that the advantages of the system outweigh the disadvantages and that companies have been just as keen as the enterprise unions to continue with it. It provides strong employment stability which the employees appreciate and rigidity in the workforce size which constrains the companies in times of business recession. For the company it also serves as a guarantee against future labour shortages.

But perhaps the principal reason lies in the special relationship between groups and individuals which are a feature of Japanese society as a whole. There is a very strong emphasis on group effort towards achieving a specific business target which is hardly present in the USA where the emphasis is on individual performance; and to some extent this applies in the UK also.

The system allows the employee to feel that he can place his trust in the company, he can rely on it and therefore obtains a deeper interest in its affairs than he might otherwise acquire. The company is encouraged to place its trust in the continuing co-operation and service of its regular employees. The result is collective dedication to achieving the company's objectives.

Employees do not find it necessary to resist technical change and innovation even though this may mean assignment to other jobs because they recognize that such changes are unlikely to affect adversely either their security of employment or income. Nevertheless, it would be wrong to assume that employees are servile. The emphasis is on a reasonable approach being made by both company and employees to issues of common concern which allows the company to maintain a high level of productivity so that the *status quo* continues.

However, there are signs that, notwithstanding the success the country has achieved in designing, manufacturing and marketing its products, many of the tenets of the Japanese employment system are being questioned. This is primarily related to the desire for greater personal freedom and the former level of dedication to work not being as great in the younger members of the workforce who have developed an interest in leisure pursuits akin to that found in the USA and Europe.

Under the seniority wage system the income of an employee is directly related to length of service with the company. Such factors as individual ability, responsibility and the demands of the job itself play a smaller part in the determination of an employee's income within a group having similar tasks. It follows that there are no comprehensive company salary or wage structures. Job evaluation, as we know it, is also missing.

Such a system ensures that income increases with time in much the same way as the demands on it increase for the greater proportion of a family man's career. This is viewed as at least part of the explanation for the particularly high level of university education found in Japan.

However, there is evidence that companies are reviewing at least the weighting assigned to length of service and the other factors which determine pay levels. The reasons for this are primarily that there is competition for those who are highly-skilled and the increasing value placed on employees who are capable of assimilating new techniques and acquiring new skills. In addition younger employees are becoming dissatisfied with the disparity in reward for work, especially when their level of productivity is higher.

An enterprise trade union is one which serves the employees of one company only. It is organizationally and financially independent and indeed must prove itself to be so before being eligible to join any federation of unions.

The relationship between a company and the enterprise union serving the employees is close because both recognize that, in effect they are in partnership. About 35% of the total workforce in Japan has membership of an enterprise trade union. Only rarely is there a major or continuing conflict of interest and demarcation disputes are unknown.

Strikes are viewed generally as being more in the nature of demonstrations and they occur far less frequently than in the UK. In fact, in the last decade the average number of days lost through this cause per thousand employed each year has been 148 whereas the comparable figure for the UK is 481.

There is no equivalent to what are called 'worker directors' in this country. The unions are not in favour of extending their influence to this extent. On the other hand there are indications that employees are being encouraged by the leaders of some companies to share in the ownership of the company which employs them. The reasons for this appear to be the same as those advanced in the USA and the UK, namely, that there is likely to be a greater employee interest generated in the company's fortune and increased stability amongst its shareholders.

How British Industry Operates

But, to return to consideration of our own country's problems.

It is common practice for the return earned by the assets employed in a business to be used as a measure of business performance, and consequently any proposal to acquire additional assets must be examined with this point in mind, as well as many others. At a time of financial stringency, such as now, the importance placed on such an examination, always great, is even greater.

The workforce may be viewed as a cost to the business or as an asset, investment in which should be subject to the same depth of examination as that in buildings, plant and materials. Certainly wise and full utilization of skills already available to a business will have its effect on company health.

In the recruitment of new staff there should be a very clear appreciation of what the business needs. So often frustration and loss of heart arises from employee expectations not being met. Specific duties and an appreciation of where good performance may lead to in due course should be understood from the outset.

The Finniston Inquiry has resulted in recommendations being made to deal with many matters but one issue, at least, requires very much more attention. This is the general lack of enthusiasm for work at non-professional levels in many areas of British manufacturing industry and its consequential effect on the state of industrial relations.[18] Regardless of the final outcome of the work done by the Finniston committee the evidence collected is sufficient to provide the stimulus for many companies to make a close examination of what they are doing in this sphere to ensure that an opportunity to sharpen their competitive edge is not missed.

With British engineers and engineering under the spotlight it is not surprising that here and there some sensitivity exists but no one should overlook the fact that the scales are heavily weighted on the other side, the side of achievement.

For example, those engineers concerned with the design and manufacture of electronic equipment and systems incorporating it have been consistently associated with high export success for their products, thereby indicating that technical and business skills are not missing from this sphere of professional engineering practice. Furthermore, the electronic and radio engineers of this country are held in very high esteem overseas, particularly in the USA. This view was frequently confirmed, I understand, in the discussions which members of the Finniston committee had during their investigatory visits to foreign countries.

The Telecommunication Service Industry

Can the telecommunication service industry offer any pointers to a solution of the problems which have been outlined?

Allusion to this possibility has already been made and I now propose to say something about the management of its staff resource by one company in the industry.

From the time telecommunication service was first introduced there has been an almost continuous increase in the demand for additional varieties of service and capacity to handle higher rates of information flow. It follows that this situation has been reflected into the telecommunication equipment manufacturing sector of industry and hence has provided a degree of market security for it which is not generally found to the same extent in other sectors of industry.

At the present time and in the foreseeable future no change is envisaged in the general demand for more and improved services. This then must be a source of some satisfaction to those engaged in the design and manufacture of telecommunication plant and the provision and operation of telecommunication services.

The history of the telecommunication service organization which has now become Cable & Wireless commenced in the middle of the last century and can be said to have been volatile throughout the 130 years which have elapsed since then. Although uncertainties and problems still abound perhaps there is something to be learnt from its experience. It is for others to judge that, but the fact is that this organization, using electronic technology, is still alive and well.

Political, financial and technological developments have all influenced the changes which have taken place, and are taking place even today. However, the stimulus which stems from a recognition of the business base has, thus far, always resulted in adjustments being made which ensured survival. Traumatic changes have been accommodated with comparative ease, a reflection on the overall quality and loyalty of staff employed over the years at all levels.

The company will continue to live, as an organization, until its owners decree otherwise or until its customers decide to obtain the same service from elsewhere. In this respect it is no different from any other company.

Practically the whole of the business is dependent on the ability to satisfy Governments around the world that the service provided is of as high a quality and as efficient as can be found anywhere. This point may be illustrated by a tale from the past when the War Office (as it was then) cleared its telegraph messages to the Far East by passing them to a Cable & Wireless office in London because difficulties were being encountered with its own lines of communication.

Training Engineers and Support Staff

Let us now look at how this company has acquired, trained, used and conserved its workforce. Over the past thirty years, as Fig. 1 shows, the number of employees has remained substantially constant, with a mix of about 75% being nationals of the territories where branches of the company exist and 25% being UK nationals forming the corporate, central service department and mobile staffs. Members of the mobile staff may be appointed to a branch anywhere in the world, and they would normally serve about three years there before reassignment.

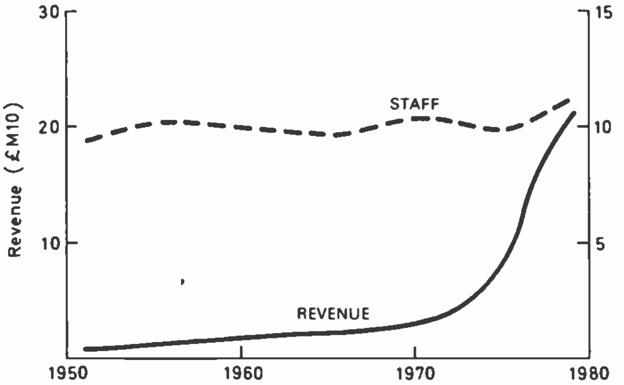


Fig. 1. Relationship between revenue and staff employed by Cable & Wireless.

The first consideration is the need of the business for skills of all types and at all levels of responsibility.

In any organization primarily concerned with the operation and maintenance of telecommunication plant the principal requirement is for engineering technicians, some technician engineers and a smaller number of chartered engineers to carry out this work. However, in the planning and project spheres the emphasis is reversed, the main requirement being for chartered engineers with adequate field experience.

The numbers of technical staff required each year and for some time into the future can be derived from manpower planning activities associated with the formulation of business plans. Engineers make a contribution to the development of these plans which are formally revised on an annual basis.

In the engineering sphere UK school-leavers with at least five O-level examination successes to their credit, including English language, together with two A-level passes in mathematics and physics and, as far as can be determined, an interest in and aptitude for technical work are recruited for an initial basic telecommunications course which is provided at the company's own engineering college and is of 18 months' duration. This is intended to provide an appreciation of the range of techniques and devices used in the business and some familiarity with equipment likely to be found at overseas branches.

High personal qualities are also sought in new entrants so that their candidature for movement through various levels of responsibility and, perhaps, in differing non-technical specializations is not adversely affected at any time. In this way the major part of the mobile staff is prepared for initial consolidation duties at a branch.

At the present time students from overseas make up about 80% of the student population following the same course. They are required to have successfully completed an induction course and acquired some work experience in their own countries. In addition they must have demonstrated that they have a sufficient command of the English language to benefit from such a course. In many cases they have UK academic success behind them.

After a minimum of three years' experience following success in the basic course students may return for an advanced course of instruction in technical subjects lasting six months. Enrolment is subject only to assessment that the student can take full advantage of the instruction offered.

Training schools are set up overseas when it is economically favourable to do so and closed down when some other arrangement offers advantages. Generally the courses of instruction are geared to the craftsman and engineering technician needs of a branch or a geographical area containing a number of branches, the higher level training usually being carried out in the UK as already described.

Following success in the advanced course it is normal for students to seek registration as Tech.Eng. (CEI). They are certainly encouraged to do so.

For UK-recruited staff a life spent overseas in various parts of the world and a career which leads into general branch management may be more attractive than engineering practice at a higher level. But where this is not the case, after further work experience, there is the opportunity to enrol for a 4-year thin sandwich course leading to a CNAA degree in engineering.

Arrangements currently exist for up to six students a year to commence CNAA studies and since the scheme started in 1956 the results obtained by the students following this course have been highly satisfactory.

This is illustrated in Fig. 2, which shows some details of student performance, and by the award of several medals and prizes.

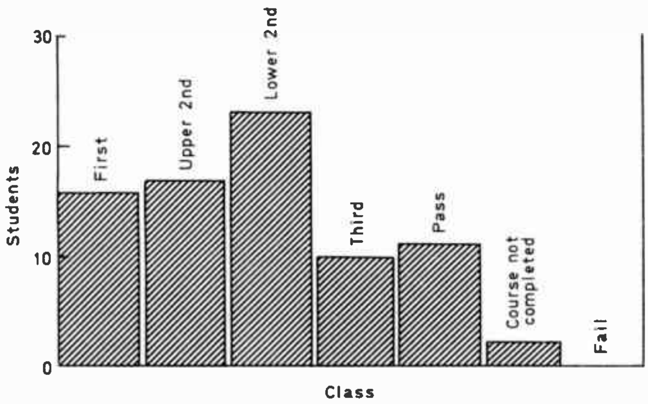


Fig. 2. Student CNAA degree performance.

The principal reasons adduced for this success are, first, that the students are a few years older than most of their college contemporaries and therefore are more likely to appreciate the value of their studies. Secondly, the selection process is based not only on previous academic achievements but also on work performance. Thirdly, the students have a reasonably wide appreciation of the requirements of the telecommunication service business and consequently have firmer views about developing their careers in it than would otherwise be the case.

All these factors probably have the effect of increasing the dedication of the students to obtaining the maximum benefit from the scholastic opportunity offered to them.

Thus the early preparation of the technical recruit for high levels of responsibility is carried out in a phased manner, academic and work experience being interleaved in time. Increasing confidence levels in an employee's choice of career and his ability to contribute to the success of the business are the sole determinant of the magnitude of the investment made in his training. Neither seniority nor pay level is directly affected by appointment to any training course.

This then is the pattern followed in preparing young people for a career in telecommunications requiring particular levels of technical proficiency. However, other methods of acquiring skilled staff are employed from time to time and may be described as supplementary. Direct entry from a place of higher learning is normally on the same employment basis as for those who join from school but those with experience may be offered the opportunity to choose a short-service contract instead.

In the field of electronics and those spheres of activity based on it retraining is already as important as training. Consequently courses of a day or two's duration up to courses lasting several months are provided for particular purposes, the aim always being to provide the instruction immediately before it is able to be directly applied in a work assignment.

Some retraining courses are provided in the UK and overseas at the schools already mentioned but others are provided through arrangements made with various research or teaching bodies and equipment manufacturing companies.

On both the training and retraining courses provided in-house it is not unusual to find fee-paying students from other telecommunication authorities. However, such instruction is normally provided as an adjunct to engineering project work being carried out for customers and is not marketed in isolation.

Earth Satellite Stations and their Management

An example of how staff may be used, and affected by technology, may be seen by following Earth station developments since the advent of the INTELSAT series of Earth-satellite transponders in 1965. At this time a standard Earth station performance specification was introduced which ensured compatibility between stations and the satellites and allowed maximum flexibility in the voice circuit arrangements. Thus any Earth station using a particular satellite could work to any other Earth station using the same satellite, if so desired, by the purchase of additional equipment at minimal cost. Use of a standard specification also ensured the most economic use of transponder bandwidth and power.

These initial Earth stations were sited well away from centres of habitation or industry for technical reasons. As a consequence there was a need to make special provision for the personnel required to operate and maintain them. The installed cost of such a station, now known as a Standard A station, is about £6 million at the present time and a team of something like 17 people is needed to run it.

In 1976 due to pressure from those concerned with smaller streams of telecommunication traffic, and therefore less able to justify investment in a Standard A station, another specification was agreed which is termed Standard B. The effect of using this specification is dramatic in several ways. The installed cost is about one-fifth of that quoted for a Standard A station. Because the technical performance parameters allow it the antenna is much smaller and the station may often be operated satisfactorily in built-up areas. The effect of these and other factors normally results in only one person being required for full-time duty with perhaps one other person devoting half his time to station work. Thus the cost of running the station is very much lower than that incurred with a Standard A station.

Most members of staff who devoted themselves to Earth station operations in 1965 came from other areas of radio work but as the number of stations increased younger men entered the field and acquired experience of these duties. When the Standard B station evolved the demand for staff was substantially unaffected since the additional manpower requirements were quite small. Today Standard A stations are being installed for primarily the same reason as previously, which is, that the telecommunication traffic volume, diversity and re-routing considerations make the provision of such a station the best commercial path to follow in ensuring that the quality and reliability of service to the customer is maintained or enhanced.

Where a Standard B station is advocated it is usually the case that it supplants h.f. radio facilities and provides the first high-quality broad-band facility for a particular territory. Thus in addition to improvement in the telephone and teleinformatic (non-speech) services, real-time television programmes from overseas become feasible with all that can mean in the development of the political and social life of the community being served.

The relationship between the demand for voice circuits with time from installation of Standard B Earth stations in a number of places around the world is as shown in Fig. 3.

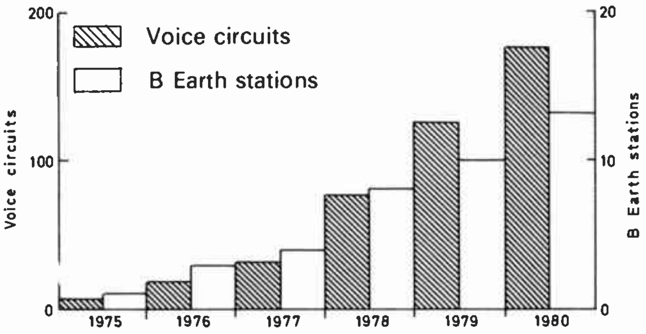


Fig. 3. Demand for voice circuits with time from installation of a number of Standard B Earth stations.

Apart from the training bulge at the time the Standard A stations were beginning to proliferate there has been a need for only a slight increase in the number of staff trained for Earth station work and employed on it.

Although this picture is not complete it is, nevertheless, illustrative of the background to the variation in revenue with time which is shown in Fig. 1.

The investment in trans-oceanic telephone cables, which had stimulated telecommunication traffic levels a decade before, and that in Earth stations from 1965 onwards together with the retraining and reassignment of staff as the character of the business changed, are primarily responsible for the divergence of the two quantities displayed. And this against a background of a steady reduction in real terms of the tariffs for telecommunication services. People are now so dependent on these services that their provision is generally viewed as being as much a social matter as a business one. One effect of this is that high profit levels for the companies providing and operating them cannot be contemplated although of course, the return on investment must be adequate to allow the business to react satisfactorily to the demands made upon it.

Conclusions

I have tried to show how one company with an unusual set of constraints has achieved success in the management of its workforce. However, this success does not mean that the value attached to the regular review of methods and procedures in use is in any way diminished; on the contrary, such work is viewed as being of increasing importance.

In summary one might say there is an affinity to the employment pattern found in the large Japanese companies. There is a career opportunity should the recruit wish to take it up and, even though the company is not insulated from market influences, salaries are at least partially dependent upon service seniority. Work assignments may vary widely in character throughout the employment period and good relationships exist with unions representing various categories of staff.

In some countries a union represents only company staff and in others, where unions are not permitted, consultation and discussion with employees takes the place of formal union negotiations. Strikes are practically unknown, but where they have occurred they have usually encompassed only small groups of staff and have been associated with political influences rather than being concerned with employment conditions alone.

I believe that employment practices in British manufacturing industry tend towards those generally found in the USA and therefore differ considerably from those developed in Cable & Wireless. Would there be value in rethinking this whole issue of resource management? My answer is an unqualified yes.

This is by no means the end of the story, only the future can determine that, but it is the end of mine and perhaps it is appropriate at this point that we remind ourselves of the essence of William Wickenden's theme in 1941: that every calling has its mile of compulsion, its daily round of tasks and duties, its standard of honest craftsmanship, its code of man-to-man relations, which one must cover to survive. Beyond that lies the mile of voluntary effort, where men strive for excellence, give unrequited service to the common good, and seek to invest their work with a wide and enduring significance.[19]

Therein lies the guide to our future efforts as engineers.

References

1 'Engineering Our Future', Report of the Committee of Inquiry into the Engineering Profession, HMSO, Cmnd. 7794, January 1980.

2 '2002: Britain plus 25', Chap. 4, p. 42. The Henley Centre for Forecasting, 1977.

3 Heath, E. R. G., 'What to say and how to say it', Tenth STC Communication Lecture (Standard Telephones and Cables, London, 1980.)

4 Page, F. W., 'Towards a New Industrial Revolution', 24th Graham Clark Lecture. (CEI, London, March 1980.)

5 Kock, W. E., 'The Creative Engineer' (Plenum Press, London, 1978.)

6 Sargrove, J. A., 'New methods of radio production', *Journal of the British Institution of Radio Engineers*, **7**, no. 1, pp. 2–33, January 1947. See also Hope, A., 'How Britain lost its lead in automation', *New Scientist*, **86**, no. 1204, pp. 183–7, 24th April 1980.

7 Coombs, R. and Green, K., 'Slow march of the microchip', *New Scientist*, **87**, no. 1213, pp. 448–450, 7th August 1980.

8 'Work in America', Report of a Special Trade Force to the Secretary of Health, Education and Welfare, 1973.

9 Mills, D. Quinn, 'Human resources in the 1980s', *Harvard Business Review*, July/August, 1979.

10 'The Personnel Function: Changing Objectives and Organisation', The Conference Board, 1977.

11 'The Worker and the Job'. The American Assembly, Colombia University, 1974.

12 Rehder, Robert R. 'Japanese Management: An American Challenge', *Human Resource Management*, Winter 1979.

13 Rock, M. L. and Sym-Smith, C. I. 'Incentives for foreign nationals', *Harvard Business Review*, March/April 1973.

14 'Labour Relations in Japan', Coventry and District Engineering Employers Association, 1979.

15 Sleigh, J. and Boatwright, B., 'New technology: the Japanese approach', Department of Employment Gazette, July 1979.

16 'Manpower Policy in Japan', OECD, 1973.

17 'The Industrial Policy of Japan', OECD, 1972.

18 'The Finniston Inquiry—the IERE's reply', *The Radio and Electronic Engineer*, **50**, no. 5, p. 197, May 1980.

19 Wickenden, W. E., 'The second mile', *The Radio and Electronic Engineer*, **49**, no. 10, p. 489, October 1979.

Scientific Instrument Makers Honour Radar Pioneer

L. H. Bedford receives Achievement Award

What many consider has been long overdue recognition was paid recently to an outstanding radio engineer, Mr Leslie H. Bedford, C.B.E., President of the Institution from 1948 to 1950, when the Worshipful Company of Scientific Instrument Makers gave him their Achievement Award for 1980.

At the Company's dinner at Scientific Instrument Makers Hall on October 28th, over 140 members of the Livery and guests, among them the President of the IERE, three Past Presidents and a dozen Council and other senior members heard Mr Harry Drew, C.B., a Past Master of the Worshipful Company and himself a Vice President of the Institution, make the presentation to Mr Bedford. After citing Leslie Bedford's academic and professional qualifications, Mr Drew said that there was so much to tell of his achievements that he would concentrate on one area.

'As it is the 40th anniversary of the Battle of Britain I will highlight Leslie's part in helping Anti-Aircraft Command. In the late 1930s contracts were placed for the first Gun Laying Radars, GL MkI, the transmitter with Metropolitan-Vickers and the receiver with A. C. Cossor, the research staff at Bawdsey working jointly with them and progressing the contracts. Leslie was Director of Research at Cossor and I was attached to Metro-Vick from Bawdsey to "final test" the first-offs and help train the firm's testers.

'By the end of 1939, 59 complete equipments had been delivered, followed by 344 in 1940 and I feel the position then was best summed up by General Sir Frederick Pile, who was in command of Anti-Aircraft at that time, in his book "Ack Ack" published in 1948. I quote:

> "The teething troubles with radar were enormous. By the beginning of October 1940 we had not succeeded in firing a single round at night. It was bitterly disappointing—we got the sets rigged up in wonderful time, but then we had the greatest difficulty in calibrating them. Every plan we made broke down and always from causes beyond our power to deal with.
>
> "The whole GL technique was so empiric that many were the disappointments we had to endure before radar settled down into the killer it became. That it ever became a killer at all was largely due to the work of L. H. Bedford of Cossor, a scientist who received very inadequate recognition of his services".

'The special attachment which Leslie invented, unofficially called the Bedford attachment, was an elevation finding system which provided a means of following continuously in bearing and in elevation, with a fair degree of accuracy through angles of about 15 to 45 degrees. The attachment was fitted to all GL's in the field and on the production line.

'Leslie spent a lot of his time with A.A. Command and two stories come to mind. We had to set up a transmitter and receiver in Hyde Park for Churchill to see. On reaching the receiver there was no Leslie and after a hue and cry he was found locked in the guardroom as he had the wrong pass.

'Another happening could have been the subject of a Bateman cartoon. General Pile had called a meeting of his Brigade Commanders and senior officers, and Leslie and I were invited together with other scientists working in the Command. Everyone had assembled except Leslie when, a few minutes later, the door was opened widely and there stood Leslie resplendent in his Home Guard private's uniform. He had been on duty all night and had no time to change.

'Before handing Leslie the award I felt I should give a pen picture of his character but in a letter to me one of his senior

Mr Drew handing the Achievement Award to Mr Bedford. The picture shows Liverymen and guests at the High Table with, from left to right, Sir Montague Finniston, F.R.S. (just visible), the Master, Mr R. H. Davies, Professor A. W. J. Chisholm, Mr G. Thomas and Mr J. R. M. McNally, M.B.E., Deputy Master.

Flanked by Past Masters McNally and Drew, Leslie Bedford responds.

staff at Cossor (and a member of our Livery Company) summed him up nicely by saying "In the long time since working with Leslie I have never come upon another person with such a breadth of mind and generosity of spirit. Unfortunately for his public image he is a tremendous debunker of pomposity and has very little patience with foolishness and unwillingness to 'have a go'."

'So Leslie, on behalf of all members of the Worshipful Company of Scientific Instrument Makers, I have great pleasure in presenting you with our Achievement Award for 1980—an award well and truly earned!'

In a brief and typically modest speech of thanks for the honour, Mr Bedford said he was especially grateful for the broadening of the terms of award since he could not claim to be an instrument maker: he regarded himself as being rather a reformed mathematician!

The Trophy of the Achievement Award is a glass tablet engraved with the Arms of the Company supported in a frame of stainless steel mounted on a block of polished green marble slate. Presented to the Company by a Past Master, Mr Frank Dawe, F.I.E.R.E., it is awarded annually for outstanding British or Commonwealth achievement in the scientific instrument field, including contributions to research, development and design. Although originally linked to new applications or techniques, the terms of award have been broadened recently and it thus proved possible to recognize a series of achievements such as led the Company to make this year's award to Mr Bedford.

The Trophy, which Mr Drew is handing to Mr Bedford in the photograph, is held by the recipient for a year and he also receives a memento, the Minerva Head in bronze on an onyx base which may be seen on the table just below the lectern.

Founded by the Company in 1965, when the first award was made to Professor Leslie Kay for his invention of the ultrasonic blind aid, the Achievement Award has on numerous occasions been made for electronic instruments. These included the scanning electron microscope (Professor C. W. Oatley), holography (Professor Dennis Gabor), photoelectronic image tubes (Professor J. D. McGee), the N.P.L. mekometer (Dr K. D. Froome and Mr R. H. Bradsall), the EMI whole body scanner system (Dr G. Hounsfield and Mr W. Ingham) and the Marconi Instruments spectrum analyser (Mr John Middleton).

CITATION FOR THE ACHIEVEMENT AWARD – 1980

The Company's Achievement Award for 1980 is made to L. H. Bedford, C.B.E., for his work throughout a long, distinguished and successful career which has encompassed the development of early electronic valves, cathode-ray tubes, radars, television receivers, guided weapons and many other devices and instruments well known to our Liverymen.

Mr Bedford was educated at City & Guilds Engineering College from 1917 to 1920, reading mechanical engineering, and at King's College, Cambridge from 1920 to 1923, reading mathematics. He is a Fellow of the IEE and Faraday Medallist (1968), Fellow and Honorary Fellow (and President 1948–1950) of the IERE, Fellow of the IRE (USA), of the City & Guilds of London Institute and of the Royal Aeronautical Society. He was appointed O.B.E. in 1942 and advanced to C.B.E. in 1956.

In 1924 he joined Western Electric as a student at Bell Labs and on his return to the U. K. initiated the Valve Development Laboratory at Hendon. In 1931 he moved to A. C. Cossor to initiate their development and manufacture of cathode-ray tubes, and with O. S. Puckle carried out work leading to the first production of television receivers in 1936. In 1937, when Watson-Watt brought his proposition about radar to Cossor, Mr Bedford formed a new department in which were made the receivers for the Chain Home sets, the first Marks of gun laying radar for anti-aircraft defence, and in particular the eponymous Bedford attachment which was to transform them into effective fire control instruments.

By now Mr Bedford was Director of Research at Cossor, and so responsible for work on such A. A. gunnery projects as the No. 9 and 11 Predictors, the A. F. 1 S–band autofollow radar (which led to the classic A. A. No 3 Mk 7), while for the RAF were *Monica*, a warning radar carried in bombers, beacons such as *Rebecca–Eureka* and instrumentation for a direct reading D. M. E.

Toward the end of the war he helped A. A. Command with a 'private venture' guided weapon project known as *Brakemine*, which rode the beam of an early production Radar A. A. No 3 Mk 4. Post–war activities at Cossor were directed toward resumption of television receiver production and development of an X–band marine radar, but in 1947 he joined English Electric, going to Marconi as Chief Television Engineer. In 1948 he took charge of a guided weapon study project: this led to the formation of a new Division of the company, where he became Director of Engineering, and the introduction of *Thunderbird*.

On retirement from what had by then become the British Aircraft Corporation (G. W.) Mr Bedford was able to devote more time to his theoretical and experimental work on electronic aids to musical instrument tuning, He is well known for a series of instruments (in partnership with our Liveryman, Freddie Robinson), the latest of which is ETA Mk 6, shortly to be followed by ETA Mk 7.

The British National Committee for Non-destructive Testing: a success story over 2 decades

When the first International Conference on Non-destructive Testing was held in Brussels in 1955 there was no single authoritative professional body in the UK recognized as predominant in this increasingly important field, and through which international communications and activities could be channelled. At about this time were formed the two bodies which, in 1976, would amalgamate to become the British Institute of Non-destructive Testing. Both were at an early stage of development, so with the help of the existing British National Committee for Materials, the British National Committee for Non-destructive Testing was established in 1956 as an umbrella organization under which UK NDT activities could be co-ordinated, and which would have recognizable authority to act for the UK internationally. For three years (1967–9), W. Campbell Heselwood was chairman of that Committee, and for 5 years chairman of its working party on the NDT Needs of Industry. As the representative of The Metals Society, he here outlines the Committee's work.

Any relevant British professional organization could become a member of the newly formed BNC for NDT, and could appoint one representative to the Committee. Since the Committee has no real funds of its own, during its formative years the Institution of Mechanical Engineers provided the secretariat and meeting facilities. More recently, other secretarial arrangements have been made, but the I.Mech.E. still provides meeting accommodation.

Principal terms of reference of the Committee are:

- To provide a forum for discussion and liaison between member organizations on matters concerned with NDT, and to assist where necessary in the organization of joint meetings, the publication of papers and the dissemination of information on prospective meetings, conferences and courses;
- To identify national requirements for co-operative activities in NDT which have not received sufficient attention, and to refer these to appropriate bodies;
- To provide informed opinion on matters of national or international interest of relevance to the Committee, as they arise;
- To undertake those duties concerned with international matters which properly devolve upon the National Committee. These may include co-operation with the organizers of international meetings, the nomination of delegates to represent the UK at such meetings, and the initiation of proposals or questions for discussion at those meetings;
- To co-operate with the Non-destructive Testing Centre, Harwell, by advising on national needs and assisting liaison with member bodies.

The domestic activities of the BNC are largely concerned with liaison, co-ordination, encouragement and promotion of NDT interests among its member organizations, and it is the body through which these organizations can speak with a collective voice. There is a network of good contacts with industry, research associations, government departments and educational establishments.

Meetings and conferences are important, but it is equally vital to avoid wasteful duplication of effort by encouraging joint meetings wherever appropriate.

On occasion, the Committee has been particularly effective in helping to influence government action. An outstanding example was the support given to the establishment of the Harwell Non-destructive Testing Centre in 1967 as part of AERE's diversification policy, thus making some of the Establishment's expertise and techniques available for other purposes. Later, Harwell consulted BNC when its NDT Centre Advisory Committee was formed; by a reciprocal arrangement the chairman of the BNC is an *ex-officio* member of that Advisory Committee, and the Head of the Harwell NDT Centre is an *ex-officio* member of the BNC.

Similarly, BNC supported a successful application for government aid to British manufacturers exhibiting NDT equipment abroad. The Committee has also been in communication with the government concerning the implications of EEC regulations.

The British Institute of Non-destructive Testing, created by merging the Non-destructive Testing Society and the Society of Non-destructive Examination, was mentioned earlier. It is the only member of the British National Committee concerned solely with NDT: member organizations can look to it for leadership, and give it support and co-operation in, for example, education and training.

About two years ago the Institute and the BNC set up a joint Working Party on Certification to examine and compare

---

CURRENT MEMBERSHIP OF THE BCN FOR NON-DESTRUCTIVE TESTING

The British Institute of Non-destructive Testing
The Concrete Society
The Institute of British Foundrymen
The Institute of Physics
The Institute of Quality Assurance
The Institution of Chemical Engineers
The Institution of Civil Engineers
The Institution of Electrical Engineers
The Institution of Electronic & Radio Engineers
The Institution of Gas Engineers
The Institution of Mechanical Engineers
The Institution of Production Engineers
The Institution of Structural Engineers
The Metals Society
The Nationalised Industries Working Party on Materials Science, NDT Study Group
The North East Coast Institution of Engineers and Shopbuilders
The Pipeline Industries Guild
The Royal Aeronautical Society
The Society of British Aerospace Companies
The Society of Engineers
The Society of Environmental Engineers
The Welding Institute.

The Head of the Non-destructive Testing Centre, Harwell, is an *ex-officio* member.

Reproduced from Metals and Materials, January/February 1980.
© The Metals Society

existing schemes with reference to those in other countries. The working party now forms the Organising Committee for a UK Certification Scheme. This committee is now involved, together with inspecting authorities and other interested bodies, in the establishment of nationally and internationally recognized standards for the certification of operatives.

WORKING PARTY ON THE NDT NEEDS OF INDUSTRY

Seventeen years ago the BNC established this working party to consider and report upon particular problems that arise in industry. Like the parent Committee, the Working Party has no funds available for research and development, but within its membership from inside and outside the BNC, and among specialists invited to attend particular meetings, there is a wealth of academic and industrial knowledge which can be called upon. Subjects which have received recent attention include the following.

Detection of hydrogen attack on steel containers

This was concerned not with familiar hairline cracking, but with chemical attack on mild steel vessels containing hydrogen at high temperature and pressure.

Combination of hydrogen with carbon in the steel not only causes methane to form under pressure in the steel, but also weakens the steel through removing the carbon, so that fissures can occur. This action is irreversible, but if the hydrogen could be detected on its first entry into the steel, then the process could be reversed by heat treatment. The correct answer, of course, would be to use low-alloy vessels, but the requirement would still remain for monitoring the many vessels already in use. No clear answer has been forthcoming, but Harwell now suggests a positron annihilation technique, and this has been referred back to the enquirer for him to follow up.

In the wider consideration of micro-fissuring, from whatever cause, the Working Party is aware of studies being made of natural frequency changes due to defects, and the assessment of defect location from such changes in different modes. Another approach involves measuring the ultrasonic attenuation of both longitudinal and shear waves, and incipient hydrogen penetration has been detected.

Much work remains to be done to determine whether these laboratory experiments can be adapted for use under plant conditions.

Evaluation of ultrasonic test equipment

Two years ago the Working Party alerted the BNC and British industry to certain undesirable aspects of a German tentative standard for calibration tests to characterize ultrasonic flaw detectors, which had been proposed for international adoption. After a CEGB-sponsored practical assessment, it appeared that many of the proposed tests, though useful in the laboratory, could not be justified for routine application, while other tests of fundamental importance were not included. A smaller number of more directly used tests would be preferable, and it now seems less likely that the German proposals will be adopted in their present form.

Testing of reinforced plastics

Fibre-reinforced plastics are increasingly used in the electrical and aircraft industries, making reliable NDT techniques essential both at manufacture and during service life. Recent work has shown that for carbon-fibre reinforced plastic honeycomb structures, no single method will detect all types of defect. The most generally useful and easily applied are by vision, cointapping, X-ray radiography and roller-probe ultrasonic examination. Fibre and pore concentrations can be determined by measuring the compressive and shear-wave velocities. For glass-fibre reinforced plastics the measurement of density by optical or gamma-ray attenuation is necessary to obtain comparable results. A study of concrete, considered as a porous matrix containing particles of aggregate, has been conducted in the same way, and shows possibilities as a test for strength-characterizing this material.

Examination of adhesive-bonded joints is another problem. Lack of bonding can be detected, but so far there is no NDT method of assessing mechanical bond strength, or of detecting stress corrosion on adhesive bond lines between CFRP and metal.

The education of NDT staff for industry

There is a choice of well-established training courses in NDT, mostly at technician and operative level, provided by industrial organizations and technical colleges. There is a difference between training and education, however, and as an expressed need of industry, there was a case for looking closely at the position of NDT in more broadly-based educational courses. The main conclusions were:

- There is no real demand for a first degree in NDT, industrial graduate needs being satisfactorily met by scientists and engineers in other disciplines whose skills and knowledge of NDT are obtained subsequently. For those choosing to specialize, there is a higher degree in NDT available.
- It is essential to convince engineers of the need to test, and therefore for design engineers to understand the scope and principles of relevant tests, and to incorporate proper provision for them. Engineering first degree courses should include a planned content of NDT.

Small-scale meetings or colloquia have sometimes been arranged to allow an informal exchange of views between product manufacturers, users and the manufacturers of particular test equipment, covering the detection and significance of any defects.

Recent colloquia were concerned with 'Depth and rate of growth of surface cracks' and 'Automatic inspection of pipes.' Each succeeded in bringing together people with different experience, and establishing contacts. One prompted a subsequent open meeting organized by a member body of BNC. They also brought out clearly that, when assessing a test method, it is important to determine not only how small a defect it can detect, but also how large a defect it can miss.

THE INTERNATIONAL COMMITTEE FOR NON-DESTRUCTIVE TESTING

The primary object of the International Committee for Non-destructive Testing is to promote international collaboration in any matter relating to the development and use of all methods of NDT. This it does by encouraging international conferences and the formation of international organizations, by assisting in the formulation of global standards on NDT methods and certification, and by issuing an international bulletin.

World conferences have been held in Belgium in 1953, the United States in 1957, Japan in 1960, Britian in 1964, Canada in 1967, West Germany in 1970, Poland in 1973, France in 1976 and Australia last year.

Currently the Committee comprises representatives of about 30 countries. UK membership operates through the BNC, which appoints the two representatives allowed (one voting). It also appoints the UK representative on any sub-committee or working party, such as the International Committee's Working Party on Training and Certification.

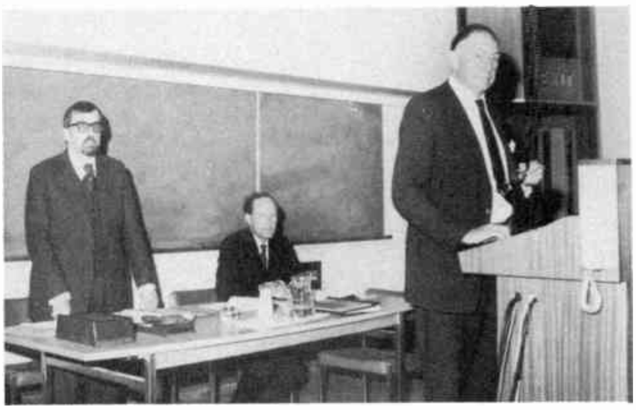
The 55th Annual General Meeting of the IERE

Held at the London School of Hygiene and Tropical Medicine on Thursday, 23rd October 1980

The meeting was opened at 6 p.m. by the President, Professor William Gosling, when 56 members were present.

It was confirmed by the Secretary, Air Vice-Marshall S. M. Davidson, that due notice of the meeting, the nineteenth Annual General Meeting of the Institution since its incorporation by Royal Charter, had been sent to all corporate members in the September 1980 issue of *The Radio and Electronic Engineer*.

The Secretary then reported that the minutes of the 54th Annual General Meeting, held on 25th October 1979, had been published in the December 1979 issue of *The Radio and Electronic Engineer* (Volume No. 49, no. 12, pp. 595-596). No comment having been received on these minutes, it was unanimously agreed that they be taken as read and the President thereupon signed them as a correct record.



The President asks for members' comments on the report on the accounts just presented by Mr S. R. Wilkins, (right) in the centre the Secretary, Air Vice Marshal S. M. Davidson

ANNUAL REPORT OF THE COUNCIL

The President then presented the 54th Annual Report of the Council for the year ended 31st March 1980 and said:

'My main task this evening is to present the 54th Annual Report of the Institution covering the year ended 31st March last, which was published in this month's issue of our Journal. As is our well established practice, this Report is presented to the membership in detail and fully describes both the work of the Institution during the year and the state of our finances at the year end. Our Honorary Treasurer will have something to say on that last point later in our meeting. Meanwhile, I would just like to make three points to introduce the main section of the Report.

'First, concerning politics of the profession, I would like to assure you that your Institution is still participating fully in the continuing debate on the Government's proposals consequent upon the Finniston Inquiry. Our Annual Report being concerned with the year ended 31st March last, says nothing about the Government's decision not to set up the statutory body recommended by Finniston but to sponsor instead another body under Royal Charter to do the same (or much the same) job. Your Council is of the view that if this is the way the Government wishes to proceed to improve the nation's performance in the critically important business of productive engineering, our best course of action is to contribute as constructively as we possibly can to the preparation of the ground rules and regulations for the new body whilst—of course—safeguarding the best interests of our members and the future of the profession of electronic and radio engineering as we see it in the public interest.

'Second, concerning our publishing and professional activities during the year under report, I would like to say how pleased I was to see the launch of our own newspaper during my year of office (not that I can take any personal credit for the venture). I know, however, how much many of our members have wanted a better means of regular communication from Institution headquarters and between Sections, and I am particularly pleased with the opportunity the newspaper presents for publicizing our Section meetings more widely. Like all other such professional newspapers, *The Electronics Engineer* is competing in a very harsh advertising market at present but we have every confidence that we shall be able to weather this particular storm in good shape to continue our planned development when the industrial up-turn does come—as it must if the nation is to survive economically.

'I must also mention in the context of professional activities the highly successful conference programme completed during the year under report: a programme which will be very hard to beat in future years, because not only was the professional standard very high indeed, it was also most successful in financial terms—a point which the Treasurer will no doubt develop in his comments on the Accounts.In all this we would do well to remember that the primary role of the Institution is the advancement of the art, science and practice of electronic and radio engineering in the public interest, and I suggest that you can all feel that this aim has been satisfactorily achieved through our publications and conference activity this year.

'Third, I would draw your attention to the very extensive cover given in the Report to the activities of our Education and Training Committee. The role of the Institution in this area of support for our primary aim is all too easily forgotten, and I want this year to particularly commend the work of this Committee under its Chairman, Mr Derek Smith. Much very painstaking staff work has gone into the preparation and development of the position papers that have had to be produced to give effect to the wide range of work of national importance in the context of the future of our profession and which is summarized for you in the Report. And here I am very glad to be able to pay tribute to Mr K. J. Coppin—the Secretary of the Education and Training Committee—who has since retired from the staff of the Institution after 10 years' sterling service. He has, however, been retained in a consultative capacity so we are not to lose the benefit of his encyclopaedic knowledge of matters scholastic and academic. He is also to continue to represent us as a member of several influential outside committees concerned with the profession's education and training affairs.

'In conclusion, and bearing in mind that I know the Treasurer is not displeased with our financial affairs, I suggest to you that the Report on our 54th year gives clear indication of the soundness of our Institution's general health and its

Professor Gosling congratulates Mr Pat Fowler on his receiving the first Mountbatten Premium.

readiness to play its part in support of the wider British engineering profession in the difficult days that undoubtedly lie ahead of us. But before I move the adoption of that Report I would both invite and welcome comment from the floor.'

No questions were asked and the President moved from the Chair that the Annual Report of the Institution for the year ended 31st March 1980 be adopted: this was approved unanimously.

AUDITORS' REPORT, ACCOUNTS AND BALANCE SHEET

The President called upon the Honorary Treasurer, Mr S. R. Wilkins, to propose the adoption of the Institution's Accounts for the year ended 31st March 1980, who said:

'It is with a modest sense of achievement that the Council is this year able to report a significant surplus of income over expenditure. This eminently satisfactory result, achieved in a period of continuously increasing inflation, reflects much credit on all concerned with the Institution's revenue earning activities and on the continued efforts to effect economies exercised by the administration staff.

'Of the £82,000 increase in total income, no less than £43,000 was due to the increase in publication sales and fees from colloquia and symposia, the remaining £39,000 arising from the increase in membership subscriptions and fees which came into effect on 1st April 1979.

'On the expenditure side the total increase of all costs and expenses has been kept within 6% of last year's figure—in a year when inflation has been running at over twice this figure. Particularly praiseworthy is the increase of only 4% in the total administration expenses, which account for practically half the Institution's expenditure.

The President with three of the seven joint authors of the paper which was adjudged the outstanding scientific contribution of the year and received the Clerk Maxwell Premium. Left to right: Dr Tom Blaney, Dr Walford Stone and Dr Gareth Jones.

'The nett result of this major management effort, even after taking this opportunity to write off some £10,000 against old and slow moving stocks of conference and other publications and long standing debts of conference fees, is a surplus of £36,456. This, of course, has the important effect of reducing our General Fund adverse balance by the same amount—altogether a most gratifying result.

'Even with a continuance of the economies and tight financial control however, it would be naive to hope that this position will be maintained in future years without increases in the Institution's income.

'There are already signs that the continuing effects of inflation are once again catching up with us. The costs of "brought in" materials and services—particularly printing and postage—have shown quite frightening increases and there will inevitably have to be increases in staff costs if the Institution's services to members are to be maintained. We shall indeed be fortunate if this year's figures approach the "break even".

Mr Neil Gilchrist receives his Marconi Premium.

'Taking these facts into consideration therefore your Council has reluctantly agreed to a modest increase in members' subscriptions to take effect from 1st April 1981.

'Fellows' subscriptions will be raised by £6 per annum, Members' by £5 per annum, with *pro-rata* increases for other grades of which you will all be notified in due course.

'It is worth noting that these increases are well below the level needed to redress the effects of inflation during the last two years. Nevertheless (with a continuance of the tightest possible management controls and provided inflation does not exceed 10% per annum over the period) the Council expects to be able to hold these rates for at least two years during which time, hopefully, we will be able to show some small surpluses with which to reduce progressively the General Fund deficit.

'Mr President, fully detailed accounts have been circulated to all the members as part of the Annual Report, which are, I think, sufficiently explanatory. With the help of our auditors who are present this evening, I shall be pleased to answer any questions that members might care to ask and then, if you will permit me, I would like on behalf of the Council, to propose the adoption of the Accounts as published together with the Auditors' Report.'

There were no questions asked, and Mr John Powell (Fellow) seconded the Honorary Treasurer's proposal, which was carried unanimously.

Congratulations from the President to Dr Ralph Benjamin, winner of the Heinrich Hertz Premium.

ELECTION OF THE COUNCIL FOR 1980–81

Confirming that there had not been any opposing nominations to those made by Council and circulated to corporate members in a notice dated 5th June 1980 in the June issue of *The Radio and Electronic Engineer*, the President said:

'We are therefore honoured that we should have as our new President Mr John Powell.

'Mr H. E. Drew, Brigadier R. W. A. Lonsdale, Professor J. R. James, Dr P. K. Patwardhan and Mr S. J. H. Stevens are re-elected as Vice-Presidents; and Mr J. J. Jarrett is elected to fill a vacancy for a Member.

'Mr S. R. Wilkins is re-elected as Honorary Treasurer, and the remainder of Council will continue to serve in accordance with the period of office laid down in Bye-law 48.'

The joint authors of the paper awarded the Charles Babbage Premium, Dr Brian Davies and Mr Richard Davies, with the President.

APPOINTMENT OF AUDITORS AND SOLICITORS

Taking Items 5 and 6 of the agenda together, the President proposed that Gladstone, Jenkins and Company should be reappointed as the Institution's auditors, their remuneration to be at the discretion of Council, and that Bax, Gibb and Gallatlys (incorporating Braund and Hill) be appointed as Solicitors to the Institution. This motion was carried unamimously.

Professor Gosling's congratulations to Mr Philip Williams were especially hearty as this was the third occasion on which he had received the Brabazon Premium.

The Paul Adorian Premium was awarded to two co-authors and Mr Albin Zavody was present, representing also his colleague Dr Roger Emery who is now working abroad.

Mr Michael Judge was the recipient of the Sir Charles Wheatstone Premium.

A professor-to-professor handshake for Professor Douglas Lewin on being awarded the Eric Zepler Premium for an outstanding paper on the education of engineers.

PRESENTATION OF PREMIUMS

The President then called upon Mr F. W. Sharp, Editor of the Institution's Journal, to describe the awards and introduce the winners. The recipients of ten of the twelve Premiums awarded for 1979 were present and Mr Sharp referred especially to the first award being made of the Lord Mountbatten Premium. This had been recently established to perpetuate the memory of the Institution's Charter President and was for the outstanding paper on the engineering aspects of electronics or radio published during the year. (The list of Premium winners is published as an Appendix to the Annual Report.)

ANY OTHER BUSINESS

The President announced that notice of any other business had not been received. Mr John Powell then rose to express the appreciation of all members to Professor Gosling for his year of service in the Institution's highest office.

Mr Powell told the retiring President that there were two specific points which he would like especially to mention:

'Your Address at the beginning of your year of office which not only excited great interest at the time but has stimulated much thought since then, and your conduct of affairs throughout the period which has confirmed and enhanced your reputation as a dynamic electronic and radio engineer. I take pleasure in thanking you most warmly, on behalf of the Institution, for your leadership during the year and may I also add our best wishes for the success of your future endeavours.'

The meeting closed at 6.28 p.m. The Annual Meeting of subscribers to the IERE Benevolent Fund followed and at 6.35 p.m. Mr Powell gave his Presidential Address which precedes this Report.

Letter to the Editor

From: **D. Washington, C.Eng., M.I.E.R.E.**

Schools and Technology

The recent editorial 'Ploughshares from Swords'* drew attention to one particular scheme for providing schools with surplus industrial materials and equipment. As you rightly suggest, there are many benefits to be gained from wider adoption of such schemes. It may therefore interest readers to know of similar ventures which are operated by some of the Science and Technology Regional Organisations (SATROs).

SATROs have been, and are being, set up throughout the country under the auspices of the Standing Conference on Schools' Science and Technology. There are currently twenty-five, nine of which operate stores for teachers with several more showing an interest in starting similar ventures. As well as taking industrial surplus from both large and small firms, these stores also bulk-purchase goods which they can then offer at bargain prices.

Provision of resource material is not the only role of SATROs however, they are involved in a wide spectrum of industrial-educational interaction. SATROs share the following objectives—to encourage a modern approach to science and technology in schools, to improve understanding between schools, industry and commerce, and to provide practical help in developing co-operative activities between the world of education and the world of work. Through involvement with people of all levels from many sectors of the community, they combine the functions of agency and catalyst to encourage co-operation appropriate to the needs of their region. Hence they support the initiatives of others as well as initiating their own activities.

SATROs welcome help from anyone who is interested in the education of young people to acquire an understanding of the technology-dominated world in which they will live and work. Further information, including the location of existing and developing SATROs, may be obtained from Mr. P. Parsons, National Liaison Officer, SCSST, 1 Birdcage Walk, London SW1H 9JJ. (01-222 7899).

D. Washington
Chairman, SATROs' Panel

Philips Research Laboratories
Redhill
Surrey RH1 5HA
29th July 1980

The Radio and Electronic Engineer. **50**, No. 7, p. 323, July 1980.

Membership Subscriptions and Entrance/Transfer Fees for 1981

The Institution's membership subscriptions and entrance/transfer fees have been held at their present level for the past two years. Since these levels were agreed by Council in October 1978, however, inflation has reduced the purchasing power of the pound by some 27½% and the erosion continues at over 15% p.a. at the present time. As a result of the continued exercise of utmost economy in all areas of headquarters and Section expenditure, the Institution has returned a worthwhile surplus of income over expenditure in the year ended 31st March 1980 but there is no prospect of a better than break-even performance in the current year. It has thus not been possible to make as much progress as was hoped for in respect of the progressive reduction of the Institution's General Fund deficit which arose primarily as a result of the grossly excessive levels of cost inflation experienced in the mid-70s.

Council has consequently decided that the annual income from membership fees and subscriptions must be increased with effect from April 1981 if the Institution is to continue to cope with the current levels of inflation whilst dealing more vigorously with the General Fund deficit problem. Adequate provision for such increases remains available within the bracket provided for under Bye-laws 25 and 26 as formally approved by the Lords of Her Majesty's Most Honourable Privy Council on 26th September 1978. Accordingly, and as was announced in general terms by the Honorary Treasurer at the Annual General Meeting held on 23rd October 1980, the following rates will be payable by the various classes of membership with effect from 1st April 1981:

ANNUAL SUBSCRIPTIONS

Fellow	£36
Member	£30
Companion	£36
Associate	£28
Graduate* or Associate Member:	
35 years and over	£28
25–34 years	£20
Under 25 years	£14
Student*	
25 years and over	£12
Under 25 years	£7

*On production of a certificate of enrolment each year, the annual subscription of Graduate and Student members engaged in full-time courses of not less than 12 months' duration will be £8 and £4 respectively.

A Fellow, Member or Companion may compound his annual subscription by the payment to the Institution, in one sum, of £400.

ENTRANCE FEES

Fellow	£10
Member	£10
Companion	£10
Graduate	£6
Associate	£6
Associate Member	£6
Student	£2

Members who are aware of subscription increases recently imposed by other Institutions and Learned Societies of comparable size and scope to the IERE will readily appreciate that the increases now approved by Council are quite modest and that they fall well short of the levels needed to restore the original purchasing power of the current (1978) rates. Furthermore, barring unforeseen circumstances and on the general assumption that cost inflation does come down to the area of 10% in the immediate future, Council once again plans to hold subscriptions and fees at the April 1981 level for at least two years. In view of all this it is Council's hope that the 1981 fees and subscriptions will command the understanding support of the membership at large. To this end, all administrative action needed to revise the Institution's computerized subscription collection and accounting arrangements, including amendment of direct debiting and bankers order schemes, will be taken by the Membership Registrar during January and February 1981.

Income Tax Relief on Membership Subscriptions

Recent enquiries indicate that not all members are aware that they may claim relief from income tax on their annual subscriptions and they may like to know that the Commissioners of Inland Revenue have approved the Institution for the purpose of Section 16, Finance Act 1958. The whole of the annual subscription paid by a member in Great Britain and Northern Ireland who qualifies for relief under that Section will be allowable as a deduction from his emoluments assessable for income tax under Schedule 'E'. Members should apply to their Local Tax Office for Form P358 on which to make a claim for adjustment of 'Pay as you Earn' coding if they are not already enjoying the benefit of this entitlement.

Members' Appointments

CORPORATE MEMBERS

E. H. K. Dibden, M.A., B.Sc., A.K.C. (Fellow 1966, Member 1946) has joined the main board of The New Opportunity Press. From 1961 until his recent retirement Mr Dibden was director of the University of London Careers Advisory Service. His previous appointments included that of Secretary of the Cavendish Laboratory, Cambridge (1948–60), and from 1960 to 1961 he was Registrar of the Middle East Technical University.

Professor J. G. Simmons, D.Sc. (Fellow 1971) has been appointed to a Chair of Electrical Engineering at the University of Bradford. From 1969 to 1980 Professor Simmons occupied a Chair of Electrical Engineering at the University of Toronto. He was awarded the Clerk Maxwell Premium in 1978 for a paper on 'Switching phenomena in metal-insulator-n/p$^+$ structures'.

S. J. H. Stevens, B.Sc., (Fellow 1964, Member 1952) has retired as Director, Aeronautical Quality Assurance, Ministry of Defence, and has taken up an appointment as Quality Assurance Manager in the Underwater Weapons Division of Marconi Space and Defence Systems, Portsmouth. Mr Stevens has served on several Institution committees and at the recent annual general meeting he was re-elected a Vice President.

K. Ariyaratnam, B. Tech. (Member 1980, Graduate 1976) who has been with the Department of Telecommunications of Sri Lanka since 1976, has been promoted to Superintending Telecommunication Engineer (External Plant).

M. A. Aziz (Member 1974), formerly a Senior Research Engineer with Standard Telecommunication Laboratories, Harlow, is now a Senior Electronics Engineer in the Applied Electronics Laboratories of Marconi Space and Defence Systems, Portsmouth.

K. H. Barratt, B.Sc. (Member 1967, Graduate 1965), who has been Technical Director of Sony Broadcast since the formation of the company three years ago, has recently been appointed to the board. Mr Barratt was formerly with the Independent Broadcasting Authority, latterly as Project Manager of D.I.C.E. (Digital Inter-continental Conversion equipment).

T. E. Barritt, B.A., M.Sc. (Eng), D.I.C. (Member 1979) is now N.I.S. Programme Office Controller with Cossor Electronics. He was formerly with Marconi Space and Defence Systems as Divisional Quality Assurance Manager.

Sqn Ldr P. G. Claridge, B.Sc., RAF (Member 1973) has been posted to the Information Systems Division of SHAPE as Systems Analyst. He was formerly Officer Commanding Computer Systems Group at the Royal Air Force College, Cranwell.

R. C. Davey (Member 1964, Graduate 1963) has been elected President of the United Kingdom Association of Professional Engineers (UKAPE). Mr Davey who is now a Construction Engineer with I.C.I. Fibres, Tees-side, was formerly an Instrument/Control Design Engineer with British Nylon Spinners.

R. Filkins (Member 1965, Graduate 1962) has been appointed Managing Director of Anaren Limited of Frimley. He was formerly manager of Commercial E.W. Contracts with Decca Radar.

C. P. Fowler, M.B.A. (Member 1972, Graduate 1969) is an Assistant Divisional Director with the National Enterprise Board and in this capacity is Director of Burndept, Data Recording Instrument Company and Data Computer Corporation.

R. M. Innes, B.Sc., Ph.D. (Member 1978) who has been with the Philips concern since 1974, latterly in the Development Department of Mullard Hazel Grove, has been transferred to the Development Department of Philips Nijmegen.

B. G. Kennet (Member 1962) is now Technical Manager of Canatron Automation, Newbury.

A. J. Lawrence (Member 1971, Graduate 1968) has been appointed Deputy Controller of Works (Lines and Transmission) in the London Telecommunications Region of British Telecom.

Lieut. Cdr. K. A. Lowen, RN (Member 1971, Graduate 1963) has taken up the appointment of Man/Computer Research Officer in the Applied Psychology Unit of the Admiralty Marine Technical Establishment, Teddington. He was previously Closed Circuit Division Unit Officer with the Fleet Air Arm in H.M.S. *Daedalus*, Lee-on-Solent.

Sqn Ldr L. C. McNally, RAF (Member 1973) has recently been appointed to the UKAIR CCIS Project Team at RAF High Wycombe as the Communications Specialist. His previous posting was as Chief, NICS Network Control Section at HQ AFCENT.

Sqn Ldr A. F. P. Newns, RAF (Member 1972, Graduate 1968) has returned from a tour of duty on the staff on HQ RAF Germany and is now Officer Commanding RAF Oakhanger.

G. Pass (Member 1972, Graduate 1969) has been appointed Head of Postal Engineering Group, Eastern Postal Region of the Post Office at Colchester. He was formerly Executive Engineer in charge of Postal Engineering Group at Nottingham.

P. E. Scott (Member 1973, Graduate 1970) who is a Professional and Technical Officer Grade 1, is now with the Ministry of Defence at Bath. He was formerly at Helensburgh.

F/O P. J. Squires, B.Eng., M.Sc., RAF (Member 1980, Graduate 1979) has been commissioned in the Engineering Branch of the RAF and is at present at the RAF College, Cranwell. He was previously Chief of Test (Electronics) with GEC Mechanical Handling, Erith.

K. V. V. Stracchino (Member 1971, Graduate 1969) who was Design Assurance Manager with C.P.I. Data Peripherals, Stevenage, is now at the Valley Forge Corporate Centre of the parent company, Computer Peripherals Incorporated, in Norristown, Pennsylvania.

D. E. Tennant (Member 1969, Graduate 1966) has moved to Canada to join the Ontario Hydro as Assistant Technical Supervisor at the Nuclear Training Centre at Rolphton, Ontario. He was previously with the Fisheries Radiobiological Laboratory of the Ministry of Agriculture, Fisheries and Food, Lowestoft.

M. R. Walkden (Member 1972) who is with the Procurement Executive of British Telecom, has been promoted from the post of head of Quality Assurance Policy Section to that of Head of Quality Assurance Operations Branch.

P. Willatt (Member 1972, Graduate 1966) has been appointed Technical Manager for the Mediterranean and Middle East Region of the Plessey Company based at Tripoli. He previously held appointments with International Aeradio, lately as representative with Aeradio Libya in Benghazi.

NON-CORPORATE MEMBERS

M. J. Barker (Associate Member 1978) has left the Royal Navy where he was Radio Electrical Mechanician and has been appointed UK Service Manager with Technicane Imaging.

M. Bennett (Graduate 1970) has been appointed Manager of the Audio Department of Sony Broadcast at Basingstoke. He was formerly Manager, Broadcast Services with Alice (Stancoil), Windsor.

P. R. Blowe (Associate Member 1962), formerly Technical Manager of Gallo Africa, Johannesburg, has been appointed Managing Director of Radiolectric, Sandton, Transvaal.

Lieut Cdr M. W. Buggy RN (Graduate 1970) is now a Project Manager for In-Service and Post-Design Equipments at the Admiralty Surface Weapons Establishment. He was formerly an Instructor at the Naval Weapons and Radio School, H.M.S. *Collingwood*.

R. I. Fletcher, B.Sc. (Graduate 1978) has joined Vickers Design and Project Division, Eastleigh, Hants, as a Design Engineer. He was formerly a Senior Engineer with Sperry Gyroscope, Bracknell.

G. A. Minney (Associate Member 1978) has been appointed Telecommunications Manager with Glaxo Operations UK. He was formerly a Senior Telephone Consultant Engineer with the Telecommunication Projects Division of Burmah Engineering, Manchester.

Lieut Cdr M. F. Phillips, RN (Graduate 1967) has completed a period of duty in the Directorate of Airborne Radio at the Ministry of Defence Procurement Executive and is now Air Engineer Officer, 826 Naval Air Squadron RNAS Culdrose.

W/O B. A. Shoesmith (Associate Member 1974) is in charge of the Servicing Flight at Strike Command Avionic Development and Service Unit, RAF Scampton.

W. A. Taylor, B.Sc. (Graduate 1979) is now Training Adviser at the Engineering Industry Training Board Office in Northern Ireland. He was previously an Engineer (Telecommunications) with the Northern Ireland Electricity Service.

Obituary

The Council has learned with regret of the deaths of the following members:

Thomas Gordon Clark (Fellow 1965, Member 1955, Graduate 1954, Student 1950) died on 23rd September 1980, aged 54.

Gordon Clark started his professional career as an apprentice instrument mechanic in the radio department at the National Physical Laboratory in 1942. In 1944 he went into the Royal Electrical and Mechanical Engineers, eventually becoming a Warrant Officer in charge of wireless and radar workshops in India and the UK. In 1952 he joined Decca Radar as a Senior Development Engineer working mainly on marine and meteorological radar and initiating a number of patents for circuit improvements.

In 1965 he joined Astaron Electronics of Poole, Dorset as Technical Director. Three years later he went to Plessey Automation, Poole and in 1971 he spent an academic year on the lecturing staff of the School of Management Studies at Portsmouth Polytechnic. In that year he contributed an article on 'Finance for engineers' to the Institution's Proceedings and he spoke on this subject at Local Section meetings.

From 1971 to 1974 he was a Technical Manager with Mullard Limited and then he returned to the Plessey Group as Custom Support Manager concerned with navigational aids.

Gordon Clark was Chairman of the Institution's Southern Section in 1970 and he was also a member of the Management Techniques Committee.

Kenneth Walter Booth Fouweather (Fellow 1969, Member 1946) died on 7th May 1980 aged 66.

Born and educated in Newport, Monmouthshire, Kenneth Fouweather worked with radio companies in Newport up to the start of the war in which he served as Signals Officer in the Royal Air Force. In 1946 he joined the then Ministry of Civil Aviation as an Assistant Signals Officer and he remained with this department until 1949 when the inspection and approval functions with which he had been concerned were tranferred to the Air Registration Board. He was appointed Assistant Chief Radio Surveyor and in 1957 promoted to Chief Radio Surveyor. During his period of service with the ARB, with which he remained until his retirement, Mr Fouweather was concerned with the preparation and approval of standards of radio communication and radar for all types of aircraft, ranging from supersonic transports to light aircraft and hovercraft.

Norman Girvin Graves (Associate 1978, Graduate 1942, Student 1933) died 24th August 1980 aged 68.

Anthony Serle Pudner (Fellow 1961, Member 1943) died on 30th April 1980 aged 63.

The following tribute has been contributed by the President of the Institution, Mr John Powell, a former colleague:

Tony Pudner, as he was affectionately known, was educated at the Imperial Services College, Windsor, and then joined Cable and Wireless, a company he served for 40 years.

He had a varied career, a mixture of home and overseas appointments and an assignment to a cableship. His overseas postings included service in Bermuda, Athens, Haifa and roving commissions in Korea and the West Indies. In Korea where he was manager of the field telegraph unit providing press facilities during the war, his unit had to be where the news was generated. Travel for men and equipment, by land or sea, at short notice was a normal expectation and his work there was recognized by the award of the MBE in 1952. As Area Engineer (West Indies) he was based in Barbados but was frequently required to visit company installations in the Caribbean. In due course he became Engineer-in-Chief and retired as a Director in 1974.

His service to the Institution commenced in 1963 when he was appointed to the Membership Committee on which he served for three years. In 1968 he was elected to Council and the following year accepted appointment to the Finance Committee. He was a Vice-President from 1969 to 1972.

He contributed the paper on 'Fixed Communications' to the Golden Jubilee issue of the Institution's Journal in October 1975.

Always firm in his views he was, nevertheless, a gentle and kind man and all who knew him will share in the sorrow at his passing. He leaves a widow, son and daughter to whom sympathy is extended in their sad loss.

Daniel Rayburn Rogers (Member 1965, Student 1962) died September 1979 aged 58.

Daniel Rogers, born and educated in Montrose, Scotland, obtained his first technical training as an apprentice maintenance mechanic in a textile factory.

He joined the Royal Artillery during the war and continued to serve until 1961 when he retired as Warrant Officer Class 1. He then went to the National Cash Register Company as Engineer-in-Charge, Technical Field Support.

John Percival Titheradge (Member 1951, Student 1945) died on 6th September 1980 aged 60 after a long illness.

John Titheradge, who was born and educated in London, served in the Royal Electrical and Mechanical Engineers during the war, part of the time as an instructor at the Military College of Science, and later as a Warrant Officer at base workshops in India and Malaya. On demobilization in June 1946 he was appointed Senior Wireless Tehnician at the Home Office. Later he was promoted to be Chief Wireless Technician following open competition, and during this period he was involved in design and development of communication equipment and systems with the police.

In 1951 Mr Titheradge moved to the then Ministry of Civil Aviation with whom he remained for some 16 years; he was principally occupied with the design and development of air-to-ground communications including those for the new terminal building at London Heathrow.

In 1970 he returned to the Home Office Directorate of Communications as Chief Wireless Engineer and was concerned with design, development and specifications of communication systems for the fire and ambulance services and civil defence. In 1977 he was awarded the Queen's Jubilee Medal and in June of that year resigned from the Civil Service hoping to take up consultancy work but the onset of a progressive illness prevented this.

During the '50s Mr Titheradge took an active part in seeking recognition of Institution qualifications within the government service.

John Titheradge was widely known in the communications field, and former friends and colleagues may like to know there is a memorial fund which is to be devoted to the installation of sound amplification equipment in the Dormansland Baptist Church.

UDC

Indexing Terms: Telecommunication cables, coaxial, Electric measurements, gain

Coaxial telephone cable testing using a c.w. burst method

P. M. BUTCHER, B.Sc. (Hons)*

SUMMARY

The measurement of impedance irregularities in wideband coaxial telephone cables in the factory or in the field poses serious problems to the instrument engineer. This paper reviews some current measurement techniques and proposes a c.w. burst test method as an effective solution to some of the problems encountered. The c.w. burst method is explained and a commercial test set described. The advantages of this method over conventional swept frequency measurements are described, and its limitations in the cable test field noted. Results of measurements made on a length of wideband coaxial telephone cable are presented to illustrate the advantages claimed for adopting the technique for swept frequency measurements, especially on drum lengths of cable.

1 Introduction

Coaxial cables, operating over wide frequency bands, have become an important part of communications in common antenna television and telephone systems. Even in radio systems, the connection to the antenna may require the use of high-quality coaxial cables. Measurement of their principal transmission characteristics has attracted much thought and design effort since, inevitably, the user must reach a compromise between an acceptable performance and a realistic cost for his cable. Nowhere, perhaps, has this compromise been more fully investigated than by the telephone authorities who employ multipair coaxial cables for trunk routes.

Almost all telephone authorities have existing, installed, coaxial trunk routes, equipped with analogue (frequency division multiplex) systems. In general, two grades of coaxial pair cables are in use—typically, small bore (1·2 mm inner and 4·4 mm diameter outer conductors) and large bore (2·6 mm and 9·5 mm diameter). Typical system operating frequencies for these cables are 12 MHz and 60 MHz respectively. In the United Kingdom the smaller cable accounts for about 85% of the British Post Office coaxial cable network.

In recent years there has been a trend towards digital transmission, and the introduction of high-bit-rate digital line systems. These systems have made it necessary to investigate and specify cable performance over considerably greater bandwidths than for the original analogue use. As an example, the small bore cable will be used for 140 Mbit/s digital transmission requiring approximately 100 MHz bandwidth. In a telephone network, this change-over to digital working will mean testing cables designed and installed many years ago for relatively low frequency analogue systems in order to ensure that they can carry wideband digital traffic. The careful assessment of any new cable, as it is manufactured and installed, is also very important, since the highest bandwidths are likely to be required from the most recently installed systems.

Considering the characteristics of coaxial trunk cables, it is probably true to say that many of them exceed the performance for which they were originally installed, and it is this margin which is of importance to the new digital systems. The many different tests which have been, are now, and may be applied in the future to coaxial trunk cables are beyond the scope of this paper. An excellent summary of the various tests was given in 1977 at the U.R.S.I. Conference in Lannion, and in particular, the current methods employed by the United Kingdom Post Office were reviewed.[1] However, the international telephone network embraces a wide spectrum of different systems, cable manufacturers, installation procedures and levels of development. Thus the measurements adopted by one authority will not necessarily be optimum for a different authority,

---

* *Racal (Slough) Limited, Lyon Road, Walton-on-Thames, Surrey.*

The Radio and Electronic Engineer, Vol. 51, No. 1, pp. 21–30, January 1981

0033–7722/81/010021 +10 $1.50/0

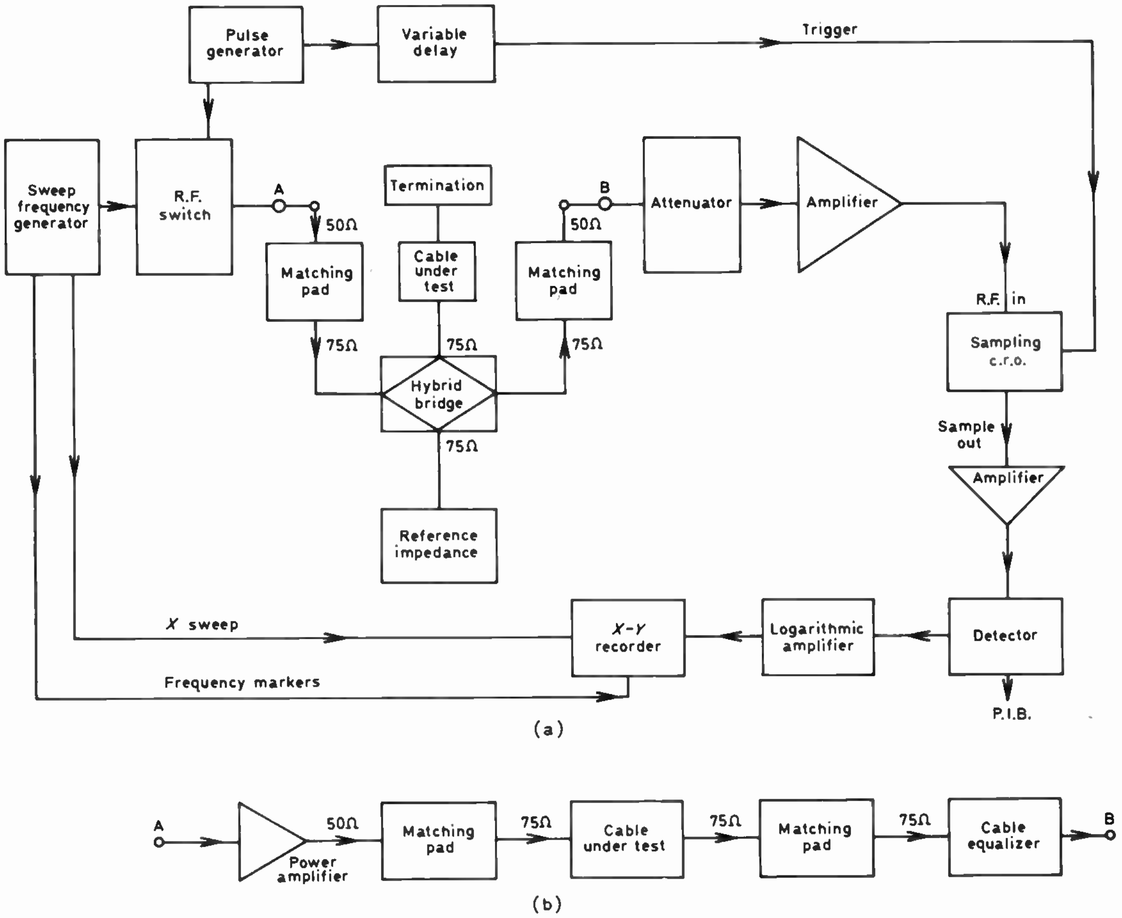


Fig. 1. C.w. burst testing. (a) General arrangement return loss. (b) Forward echo arrangement.

however technically advanced they may be. The cost of a measurement, related to the performance required from the cable, and the availability of apparatus, may both play a part in the final test methods adopted.

One important characteristic which must be measured is impedance regularity. Impedance is a function of the cable construction and all practical cables contain small construction irregularities distributed along their length. These irregularities may be sub-divided into two broad groups: those whose distribution is random, and those whose distribution is periodic, due to the repetitive nature of the manufacturing processes. Echoes from the random irregularities arrive at the transmitting and receiving ends of the cable in a random manner and manifest themselves as noise. It is the periodic irregularities which are more serious. At frequencies at which the periodic irregularities are spaced half a wavelength apart (or multiples thereof), the individual echo signals are in phase and thus additive. This effect gives rise to magnified return and forward echo signals at discrete resonant frequencies. Unlike signal-to-thermal-noise level, the signal-to-echo ratio cannot be compensated for by increasing the signal level. The forward echoes, coherent in the time domain, follow the signal from the cable to the receiver and, if of sufficient amplitude, can induce errors in the received signal. Impedance irregularities may be investigated in the time domain or in the frequency domain.

1.1 Impedance Irregularities in the Time Domain

The use of pulse echo methods for the measurement of impedance irregularities in coaxial cables is well established. As systems bandwidths have increased pulse widths have decreased, to provide frequency spectra appropriate to the system bandwidth. Many commercial pulse echo test sets are available, one at least with a pulse width as low as 1 ns. However, the attenuation of a 1 ns pulse in coaxial cables makes such an instrument capable of measurements over a very restricted length of cable. Typically a 10 ns pulse width has been specified for tests on cables expected to carry 140 Mbit/s digital transmission in the United Kingdom, with a 2 ns pulse width for higher bit rate developments.[2] With the standard pulse echo tests the attenuation within the cable limits the length of cable which can be measured, and, with amplitude equalization, the basic sensitivity remains about 75 dB on transmitted power, for the shorter pulses.

An important development in impedance irregularity measurement in the time domain came with the development by the British Post Office of the through pulse echo technique.[3] This test method offered the sensitivity to measure full repeater lengths of coaxial cables for their through and return impedance irregularities—a significant step forward in cable testing. However, the system was, of necessity, complex and to date no commercial version is available or advertised as being under development.

1.2 Impedance Irregularities in the Frequency Domain

For investigating periodic impedance irregularities over wide bandwidths, a swept frequency sinewave return loss measurement may be used. A levelled power input to a hybrid bridge† is swept over the required frequency range and the cable impedance irregularities are compared with the bridge reference impedance. The resulting signals are amplified, detected and recorded as a return loss ratio in decibels. The calibration or reference is the measure arm of the bridge open or short circuit. The resulting characteristics show all types of impedance irregularity, but significant periodic ones are distinguished by their sharp spikes at resonant frequencies. This method has shortcomings which become serious if, as is often the case with high quality cables (for high bandwidth systems), the expected return loss is high. The disadvantages may be summarized as follows:

(a) The balance of the hybrid bridge becomes difficult to maintain in that the cable should be compared with its correct mean impedance on the reference arm.

(b) The test lead to the cable, the connections on the cable and the cable far end termination may give rise to larger impedance mismatches than the cable, thus masking its true performance.

Great care is necessary in making and interpreting the measurements which, in commercial terms, is expensive. In order to overcome these limitations, the United Kingdom Post Office introduced a swept frequency c.w. burst testing technique.[4]

2 C.W. Burst Techniques

The essential difference between the sine wave return loss equipment and the c.w. burst technique is the inclusion of an r.f. switch in the output of the sweep frequency generator—see Fig. 1. The swept r.f. is gated into 'bursts' and signals returned from the bridge are examined in the time domain. The technique is thus a combination of swept frequency and time domain techniques, the swept frequency part presenting the impedance irregularities as a function of frequency, and the time domain part enabling the trigger delay of the sampling detector to be adjusted to discriminate against reflections from the hybrid bridge, test leads and connectors.

2.1 Regularity Return Loss Signals

Consider a burst of constant frequency carrier applied to a cable via a hybrid bridge as shown in Fig. 1, and the reflections examined as a function of time. A response of the form shown in Fig. 2(a) will be obtained. Section A represents the reflection of the transmitted burst from the input end of the cable, and section C the reflection from the termination at the far end of the cable. Section B represents the reflections from the cable alone. Notice the attenuation of the signal with time (and therefore distance along the cable). It should also be noted that if the cable had a perfectly uniform impedance, whatever the value, no reflections would occur between sections A and C.

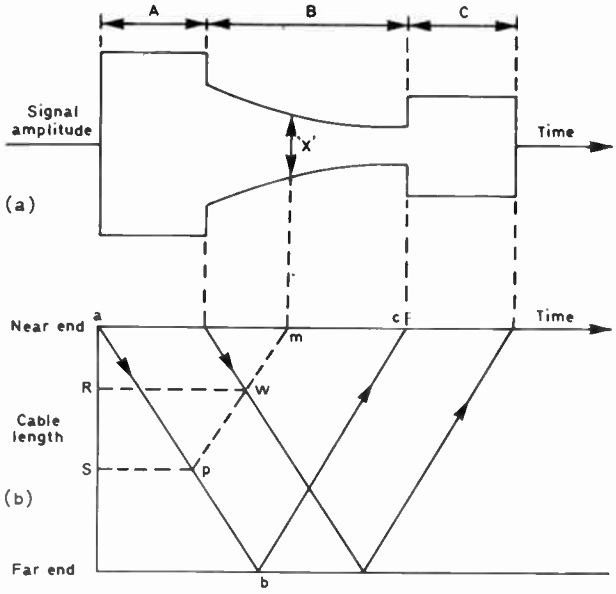


Fig. 2. (a) C.w. burst reflected signal.
(b) Time-cable length diagram.

Figure 2(b) shows the outward passage of the burst plotted in time against a length of cable co-ordinate. A line representing the passage of the burst leading edge slopes downward to the right, **ab** the slope being determined by the propagation velocity of the burst. The leading edge reaches the end of the cable and is reflected back **bc**. Similar lines show the burst trailing edge. Consider now point X; working back from the display amplitude to the line **mwp** one finds the signal at X comes from a summation of all signal returns from the cable length R to S as it is passed through by the burst. If the carrier burst length is increased until sections A and C almost meet, the sample X represents the summation of reflections from virtually the whole cable and the burst time then approximates the 'two-way trip' time of the cable. The second variable, the delay time of the sampling point, is used to ensure that no measurement is

---

† See Appendix 1

made until the trailing edge of the burst has entered the cable under test. Conversely, by a suitable choice of burst time and sample point delay, a particular section of cable may be examined.

To obtain the regularity return loss (r.r.l.) of a cable as a function of frequency, the r.f. source may be swept over the required frequency band at a rate slow compared with the burst repetition. Each burst then becomes essentially a discrete frequency package.

2.2 Forward Echo Signals

A re-arrangement of the test equipment as shown in Fig. 1(b) sends the bursts of r.f. through the cable under test. If the output from the cable is displayed on an oscilloscope, the response shown in Fig. 3 will be seen. Point A represents the leading edge of the burst leaving the cable, B the trailing edge. Each double or higher even-order reflection in the cable gives rise to forward echo signals (f.e.) which arrive at the receiving end after the incident signal, due to the time required to travel the extra distance in the cable. Energy is lost during the burst to the reflections in the cable (echo loss) and the forward echoes appear as an exponential tail (B to C) on the received burst. The forward echo signal is measured by sampling the received signal with a time delay after the end of the burst. A detailed analysis of the effects of burst length and time delay shows that the influence of the test leads cannot be eliminated and a good match between leads, connectors, and cable is required. Practically, a burst length equal to the 'round trip time' for the cable and a time delay longer than that from both test leads gives optimum results. The radio frequency is swept to obtain the f.e. response as a function of frequency. However, in swept frequency measurements, the increase in attenuation of the cable with frequency must be compensated for, and an equalizer network is inserted at the far end of the cable, having a frequency/attenuation characteristic the inverse of that of the cable. The receiver thus sees a constant loss, usually about 7 dB greater than the cable attenuation at maximum frequency, due to a non-perfect equalizer network, and its dynamic range remains unchanged by the frequency sweep. The equalizer must be designed for each particular length, type of cable, and frequency range swept. To compensate for the equalized cable attenuation, the burst power may be increased with a power amplifier, but the possible dynamic range of measurement is limited by the on/off ratio of the r.f. switch.

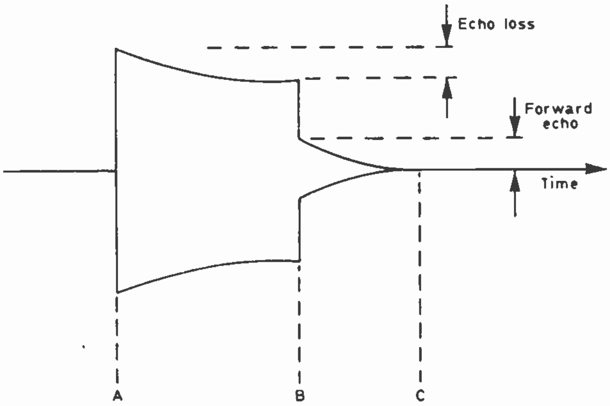


Fig. 3. C.w. burst forward echo signal.

2.3 Returned Power In Band Signals

The complexity of information received from swept frequency measurements often makes interpretation difficult in terms of a simple cable specification. By measuring the power in discrete frequency bands, an appreciation of spike width and total reflected signal power may be obtained. The additional circuitry is readily fitted within the receiving system.

The detected r.r.l. information is passed to a squarer, thence to an integrator and a sample-and-hold circuit. The integrator and sample-and-hold circuits are reset every 10 MHz (or other suitable interval) by frequency marks derived from the sweep generator. The sampled output passes through a logarithmic amplifier to the chart recorder. A histogram of the mean power returned in each 10 MHz band is plotted. The reset time of the integrator is made small compared with the integration time, thus minimum information is lost.

2.4 Comparison of Techniques

Just as limitations occur with the pulse echo testing techniques, largely overcome by the through pulse echo methods, limitations are present in the c.w. burst method. The r.r.l. information is biased towards the near end of the cable in a manner dependent on the instantaneous frequency and the attenuation variation with frequency characteristic of the cable. The maximum length of cable from which echoes can be received is also limited by transmitted power, cable attenuation, and the receiver sensitivity. In the case of f.e. measurements a serious limitation occurs on the length of cable which can be tested. Considering a practical system, with a commercial sampling oscilloscope as the detector, the sampling noise sets the overall system noise level, even with a high quality r.f. preamplifier. Then, using a power amplifier to raise the burst level to approximately 3 watts, a f.e. dynamic range of 55 dB is obtained with a total equalized cable loss of 37 dB. This limits the cable measurement length to 650 metres of the large bore cable or about 290 metres of the small bore, more lossy, cable. To double the length of cable which could be measured would demand an increase either in the power transmitted or in the receiver sensitivity of about 37 dB. Neither solution is practical. For the investigation of f.e. responses in the frequency domain, on repeater lengths of cable, a technique has been developed by the British Post Office of measuring excess attenuation, and calculating the forward echo.[5] Although longer cable lengths may be measured, the cost and complexity of the measurement is considerable, only justified where no other method exists.

In the overall field of cable measurement the c.w. burst method has a place where a swept frequency test is preferred and moderate cable lengths are available, notably in the cable factory.

3 C.W. Burst Test Set

Although the c.w. burst technique has been known for some time, commercially-produced instruments have not been available. Early attempts to assemble an instrument used a number of commercially-available equipments, each one having numerous controls, and not necessarily being an optimum match with the others. Frequent calibration checks and adjustments were often required, and the instruments were not always easy to use.

Given the limitations of the c.w. burst method outlined above, a commercial instrument had to appeal to the potential user on the grounds of cost-effective measurements. The instrument had to be relatively simple to use, make measurements swiftly, yet with an acceptable accuracy, require little calibration or adjustment, whilst the cost had to be reasonable. Some of these requirements may be seen to be mutually contradictory, and compromises were made in the design.

(a) A proprietary r.f. sweep generator was used on economic grounds, which gave more controls and functions than were strictly needed.

(b) A sampling oscilloscope was used as the detector, again on economic grounds. The problem of an operator mis-setting the controls was, to a large extent, overcome by making the sampling point delay time totally controlled on the test set.

(c) A single preset sweep time was chosen, as fast as possible for currently available chart recorders, with a fixed integrator time constant for the p.i.b. measurement. Simultaneous outputs were provided for r.r.l., frequency markers, and p.i.b. so that a multi-pen chart recorder could be used.

(d) A fast warm-up time with excellent stability was achieved, so that pre-recorded calibrated charts could be used without time-consuming calibration before each measurement.

(e) Simple reconfiguration of the set for f.e. measurements was achieved by changing test leads and sub-units. A considerable emphasis was placed on push-button operation, the buttons being illuminated when selected. Figure 4 shows the front panel of the instrument in its production form.

An abridged specification for a typical c.w. burst test set is given in Appendix 2.

4 Cable Measurements and Discussion

A series of measurements was obtained (Figs. 5 to 9) on a laboratory test cable, which illustrate the advantages of the c.w. burst method previously described. The measurements (except Fig. 6) were obtained using a standard c.w. burst test set with a 3 metre test lead. The tests were performed on a 440-metre length of single tube 2·6 mm/9·5 mm test cable. Each end of the cable was permanently fitted with N type connectors, giving a connection to the cable superior to that normally encountered during factory or field testing. In two tests detailed in the following text, a different connector was fitted to the near end of the cable. Since a single tube cable was used, it should be noted that the cyclic

Fig. 4. Commercial c.w. burst test set.

impedance irregularities normally associated with the stranding process, whereby a number of coaxial tubes (or pairs) are twisted to form a multiway cable, were absent. In practice, these irregularities often form the major difficulties in cable manufacture, and thus this cable was not representative of any currently manufactured cable.

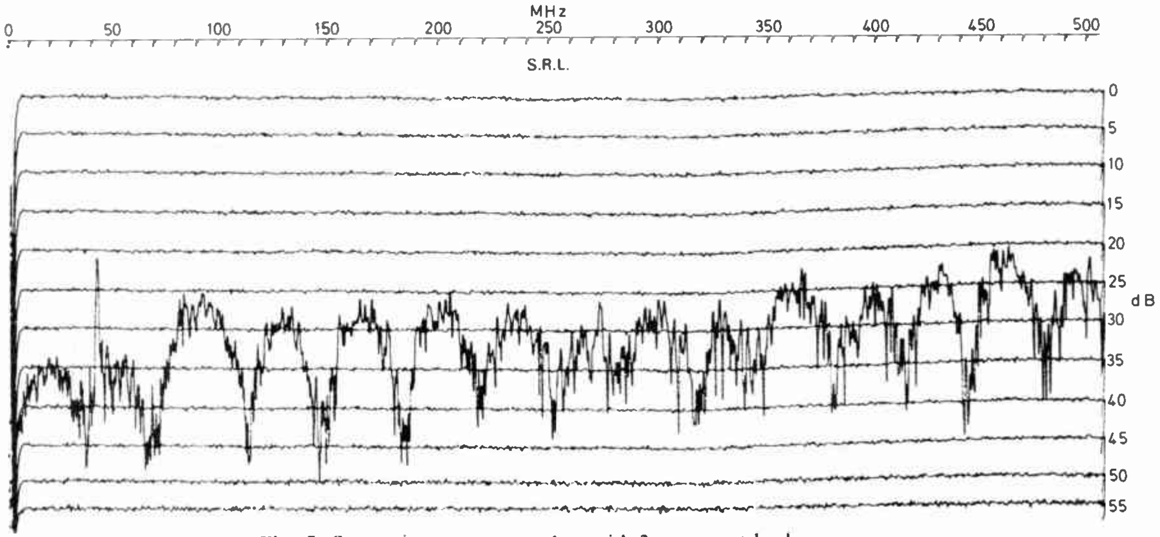


Fig. 5. Swept sine wave return loss with 3 metre test lead.

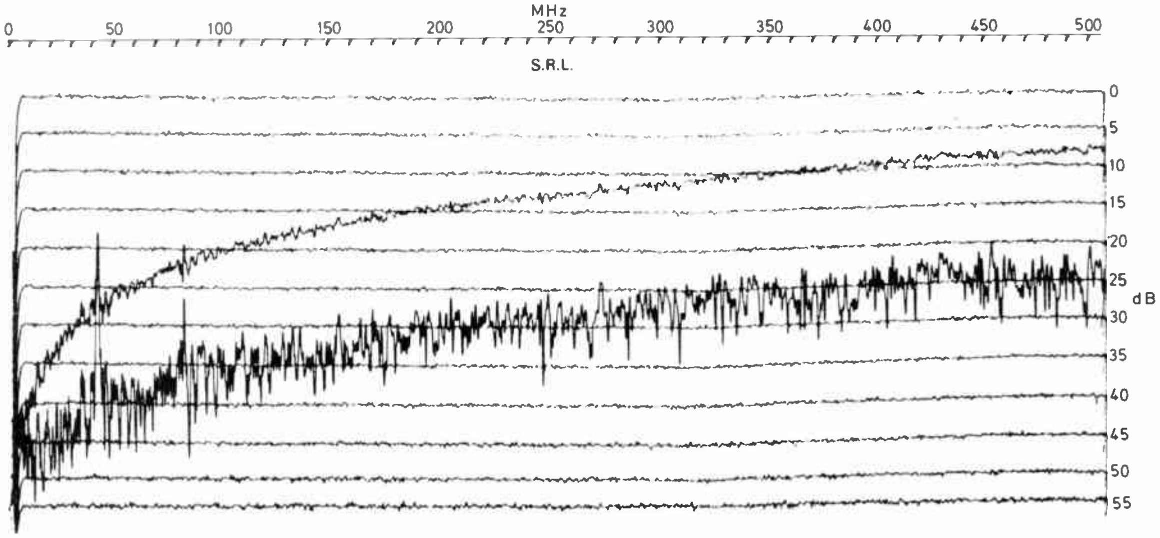


Fig. 6. Swept sine wave return loss, bridge directly on cable. Lower trace: N type permanent cable connector. Upper trace: Temporary cable connector.

4.1 Structural Return Loss Measurements

Conventional c.w. sine wave measurements of return loss are shown in Figs. 5 and 6. In Fig. 5 the standard 3-metre test lead was used to connect the bridge measure arm to the cable, whilst in Fig. 6 the bridge was connected directly to the cable. In each case, the 10 MHz interval markers are seen along the top of the chart (0 to 500 MHz) and the vertical calibration lines are at 5 dB intervals.

Comparing the results in Fig. 5 with the lower trace in Fig. 6, the effect of the test lead may be seen. In Fig. 5 the measured return loss characteristic has a cyclic variation superimposed on it with a repetition frequency of approximately 50 MHz, as well as a degradation in the mean value. The cyclic variation has the classic shape of a finite length of transmission line terminated in a non-characteristic impedance, i.e. the test lead impedance does not match that of the cable under test. The change in mean value of return loss cannot be accounted for purely by the test lead attenuation. At best, the structural return loss (s.r.l.) measurement can only compare the cable impedance (directly connected to the bridge) with a reference termination on the hybrid bridge. In this case the reference was a precision wideband 75 Ω termination, and two such terminations directly on the bridge arms gave an absolute balance of 48 dB from 10 to 500 MHz. The lower trace in Fig. 6 is the best case s.r.l. measurement, whilst Fig. 5 shows the degradation introduced by only a 3 metre long, high-quality, 8 mm, double-screened test lead. The effect of longer leads or inferior-quality tail cables in the field can readily be imagined.

The upper trace in Fig. 6 was obtained by substituting a temporary connector for the N type at the near-end only of the cable, and no test lead was used. The two traces in Fig. 6 show dramatically how a poor connector on the cable under test can effectively mask off the following cable in a conventional s.r.l. test. The connector used was a proprietary device designed for robustness, and push fitting into the unprepared cut end of 2·6/9·5 mm cable; consequently, it had a calculated mean impedance of 54 Ω and a measured loss of 1·5 dB at 500 MHz.

4.2 C.W. Burst Measurements

Figure 7 shows the same measurement repeated using the c.w. burst technique. The sampling delay was 50 ns after the end of the burst left the test lead, and the burst width was set to be 50 ns shorter than the full cable length, i.e. 7·5 m from both ends of the cable was removed from the measurement. The simultaneous output of mean power in 10 MHz bands (p.i.b.) is plotted on the chart recorder second channel, below the r.r.l.

Comparing the r.r.l. in Fig. 7 with the s.r.l. in Fig. 6 (lower), the cable appears to have 5 dB greater return loss at low frequency, rising to 10 dB at 500 MHz. Clearly, a better product is evidenced when one can measure only the cable. The impedance variations are plotted against the cable mean impedance, not the artificial standard of a bridge and termination. Note that the larger excursions in return loss at 42 and 84 MHz are very similar for both methods of measurement; it is the true measurement of a high return loss which is shown so clearly by the c.w. burst method.

For the p.i.b. presentation, the intervals (10 MHz) are self-evident, but they are offset from the frequency of the r.r.l. by a combination of two factors. These factors are the mechanical offset between the two pens on a dual pen recorder to allow pen overlap, and the inherent 10 MHz delay in the p.i.b. signal derivation. The mean power is integrated for 10 MHz before being sampled, held and output whilst the next 10 MHz interval is being swept. The recording shows a vertical start line at 0 MHz, followed by a small fall in each calibration line at 10 MHz which identifies the commencement of the measurement. The advantage of having a simultaneously available p.i.b. characteristic is mostly when large, narrow in-frequency excursions occur. Often, the p.i.b. trace shows their effect to be far less serious, against the whole general cable characteristic, than their immediate peak value might suggest.

Figure 8 shows the effect of using the same temporary connector at the cable near end as used in Fig. 6 (upper). Careful comparison with Fig. 7 shows no discernible

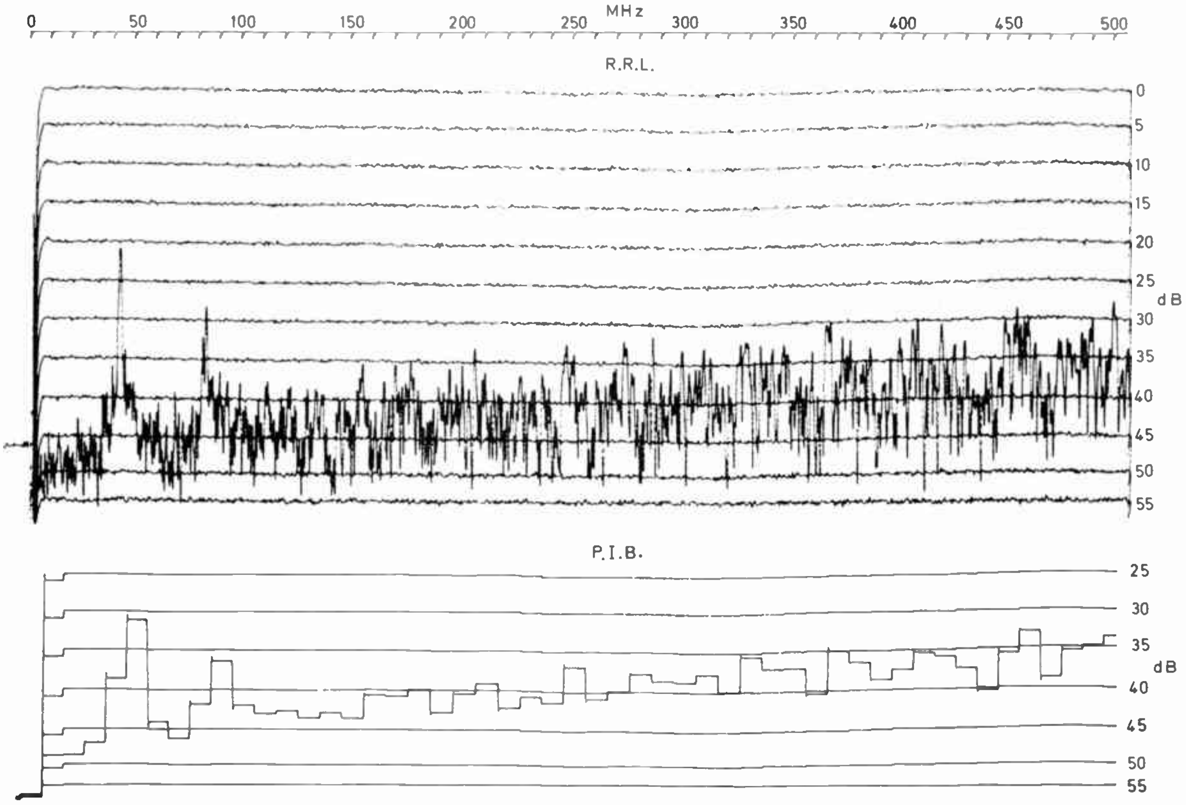


Fig. 7. C.w. burst. R.R.L. and P.I.B. (10 MHz Interval) via N type connector.

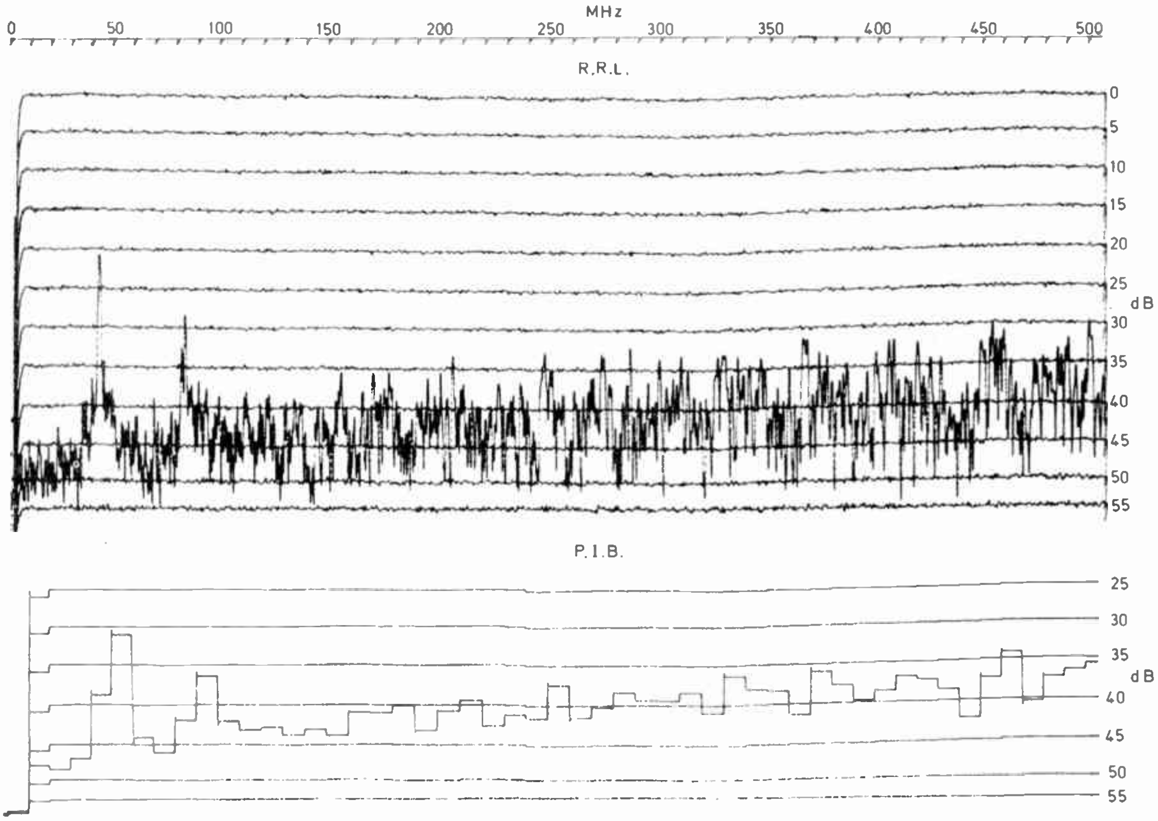


Fig. 8. C.w. burst. R.R.L. and P.I.B. (10 MHz Interval) via temporary connector.

difference up to 170 MHz. Above this point, a steady change in return loss appears, reaching 1·5 dB, on a return loss of approximately 40 dB at 500 MHz. Contrasting this with a change of 17 dB on 25 dB at 500 MHz shown between Fig. 6 upper and lower traces, the power of the c.w. burst method becomes obvious.

4.3 Forward Echo Measurements

Figure 9 shows the forward echo (f.e.) characteristics of the same length of cable. The use of the correct cable equalizer is shown by the almost flat calibration lines and a full 50 dB dynamic range for the measurement with less than 2 dB compression. The sampling delay was set to be 150 ns after the end of the burst left the cable, and the burst length was set to be approximately that which filled the cable. Since the cable tested was only 440 metres long, the 0 dB calibration corresponded with 15 dB remaining in the signal attenuators (to avoid receiver overload). The frequency range of the f.e. measurement is limited at the low frequency end to 20 MHz and this is

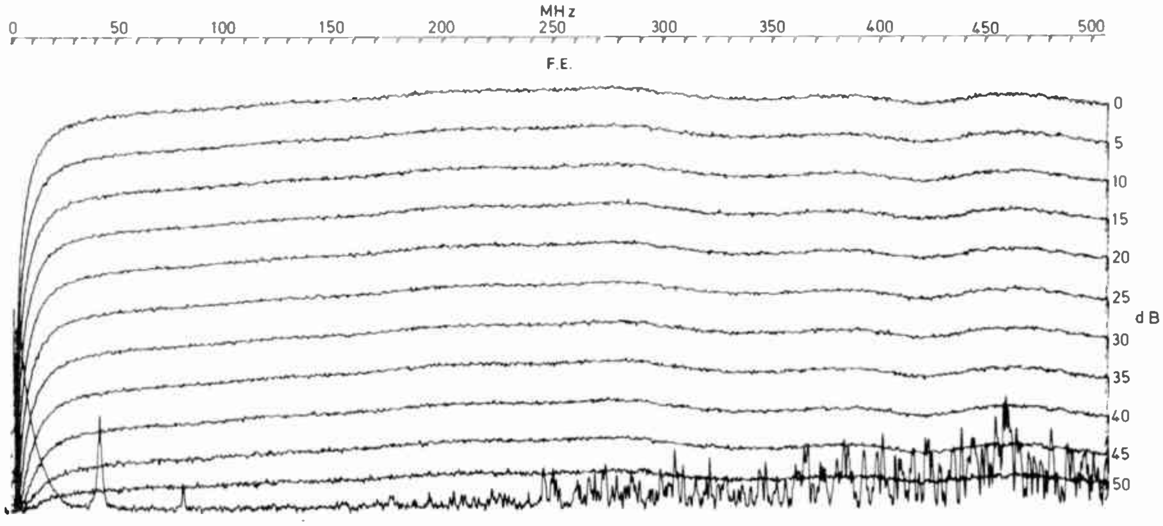


Fig. 9. C.w. burst forward echo.

evident in Fig. 9. In f.e. measurements, the presence of cross-modulation products between direct 72 kHz breakthrough and the sidebands on low r.f. affects the measurement. These products occur for a significant time after each burst at low r.f. and, at 10 MHz, have power which is only about 30 dB less than the fundamental. In r.r.l. measurements, most cables have a good match at low frequency and a typical return loss will be 50 dB for the 10 MHz fundamental, and for the adjacent cross-modulation products. Thus, the return from the cross-modulation products will be a 50 dB loss on power which is already 30 dB lower than the 10 MHz fundamental and the signal from the products will be below receiver noise. In the f.e. case, the cross-modulation products will still be present after the end of the burst, 30 dB below fundamental. When the detector sampling point is reached, 150 ns after the end of the burst, the gain has been set to measure f.e. signals typically 55 dB below fundamental and the cross-modulation products are still present only 30 dB down. In Fig. 9 this effect accounts for the rapid rise in the apparent f.e. characteristic below 20 MHz. This effect has been minimized by increasing the r.f. switch fall time to 40 ns, for f.e. measurements, from its normal 10 ns and by the introduction of a high-pass filter at the input of the power amplifier in Fig. 1(b). The influence of the filter on the general transmission characteristic is apparent from the calibration lines in Fig. 9 which show a 3 dB loss at 20 MHz. As the r.f. increases beyond about 30 MHz, the level of cross-modulation product falls below the receiver noise level and ceases to affect the measurements.

Comparison of Fig. 7 with Fig. 9 shows a clear correlation between sections of the r.r.l. characteristic, where large cyclic variations occur, and the presence of forward echoes. Forward-echo testing, unlike the r.r.l. and p.i.b. results, is not biased toward the testing end and is not therefore subject to bad sections of cable being masked by the attenuation of an earlier good section.

5 Conclusion

The c.w. burst method offers very substantial improvements in the testing of drum lengths of coaxial cables, especially where wideband sweep testing is required and the cables have high return loss values. The technique does not suffer the limitations of conventional sweep sine wave testing, the interpretation of results is simplified by the power-in-band presentation and, furthermore, it makes possible the direct measurement of forward echo. The original complexity of implementing the technique has, to a large extent, been overcome in a production instrument by careful design based on factory testing requirements. Speed and simplicity in operation have been achieved for routine measurements and, in fact, more complex measurements can also be performed with this test set.

Using pre-calibrated charts, reproduced on a standard copying machine from a master chart produced on the test set, the author and a colleague have demonstrated that the speed of testing is limited primarily by the rate at which an operator can change the test lead and termination between pairs to be tested. These demonstrations took place during a year, at seven different sites in Europe with widely differing facilities, and are felt to be a representative sample of users. One 50-second sweep suffices to plot regularity return loss and power-in-band for each cable pair, using the simplest temporary coaxial connection to the cable that can be devised (both for the test lead and termination). Inspection of results shows that, in many cases, only below 20 MHz can any difference in the regularity return loss be seen even with the cable far-end open circuit. The bridge may be connected via a test lead without affecting the measurement, often a vital consideration in multi-pair cable testing, although a practical length limit of 10 metres exists for this lead.

Although the c.w. burst technique has limitations on sensitivity, which makes it impractical to use on repeater sections of cable at 500 MHz, it nevertheless offers a cost-effective method of characterizing drum lengths of coaxial cables, especially during production.

6 Acknowledgments

The development of this test set was carried out in the laboratories of Decca Radar Limited, Hersham, from original information disclosed by the British Post Office. The author wishes to acknowledge with thanks to the Directors of the Company permission to publish this paper, and also the many helpful discussions with members of the Post Office Research Centre Martlesham. He wishes to acknowledge the work of colleagues which made a production instrument possible.

7 References

1 Crank, G. J., 'High frequency characteristics and measurement techniques for wide-band coaxial cables', Proceedings of the URSI International Symposium on Measurements in Telecommunications, Lannion, France, 3rd–7th October 1977, Session G, pp. 356–62.

2 Monro, D. I., 'A 2/10 ns pulse echo set for the measurement of impedance irregularities', Post Office Symposium on Coaxial Cable Measurement and Test Equipment, 4th July 1972, Session 4.2. (Joint Technical Committee for Trunk, Junction and Local Telecommunication Cables).

3 Brooks, R. M. and Cochrane, P., 'A through pulse echo technique for assessing the forward echo characteristics of telecommunications coaxial cable', Proceedings of the URSI International Symposium on Measurements in Telecommunications, Lannion, France, 3rd–7th October 1977, Session G, pp. 379–84.

4 Rossman, G., 'Assessment of coaxial cable for frequency division multiplex transmission by means of a c.w. burst test signal', *Proc. Instn Elect. Engrs*, **117**, p. 45, 1970.

5 Ahmad, S. and Stephens, W. J. B., 'The measurement of excess attenuation on cables installed in the telecommunications network of the British Post Office', Proceedings of the URSI International Symposium on Measurements in Telecommunications, Lannion, France, 3rd–7th October 1977, Session G, pp. 373–8.

8 Appendix 1: Hybrid Bridge

A four-port a.c. bridge having one side of each port connected to a common circuit point, usually ground. It has the property that when the impedance on the measure port is matched by that on the reference port there is no coupling between the input and output ports. One form of hybrid bridge has the circuit shown in Fig. 10 where a 'balun' transformer is used to couple the output port.

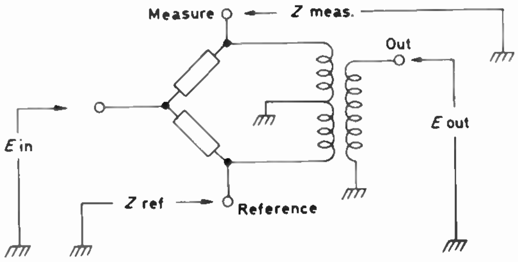


Fig. 10. Hybrid bridge—typical connection.

9 Appendix 2: Abridged Specification of C.W. Burst Test Set Type M85556

Regularity Return Loss and Returned Power in Band

Frequency Range	10 MHz to 500 MHz	
Sensitivity	> 50 dB	
Dynamic Range	regularity return loss	50 dB
	power in band	25 dB
Calibration Stability	< ± 1 dB	

Forward Echo

Frequency Range	20 MHz to 500 MHz
Dynamic Range	50 dB
Sensitivity for full dynamic range	37 dB equalized cable loss.

General

Frequency Markers	1, 10, 50 MHz
Measurement sweep time	50 s
Burst p.r.f.	72 kHz nominal
Burst Width range	0·4 to 12 μs
Outputs (simultaneous)	regularity return loss returned power in band frequency markers
Power Supply	110 or 240 V a.c. 40 to 60 Hz

Manuscript first received by the Institution on 24th January 1980 and in final form on 16th June 1980.
(Paper No. 1967/MI 16)

The Author

Peter Butcher received his B.Sc. (Honours) degree in physics from the University of Nottingham in 1958 and joined Decca Radar Research Laboratories at Hersham, now Racal (Slough). Since then he has worked on a varied range of projects including airborne Doppler radar, ultrasonics, radio frequency sources, electron spin resonance spectroscopy and nuclear quadrupole resonance spectroscopy. In 1970 he became chief engineer of the Instrument Division, adding to his experience waveguide switches and solar radiometers. In 1971 he became involved in a development contract with the British Post Office for a Coaxial cable loss and gain measuring set. Other cable test equipment developments followed, in close collaboration with the Post Office Research Station at Martlesham, including the c.w. burst test set. He is currently developing a 2 M bit/s digital crosstalk analyser and an optical fibre loss measuring set.

UDC 621.37/9: 851: 681.3

Indexing Terms: Communications, Office equipment, Computers

Viewdata in the electronic office

A. S. GILES, B.A.,*
S. R. LAURENSON, B.Sc.(Eng.)*
A. J. CHRISTIAN, B.A.*
and
K. L. JONES, B.Sc.*

Based on papers presented at the IERE Conference on The Electronic Office, held in London in April 1980.

SUMMARY

Viewdata brings together computer, telecommunications and microprocessor technology to provide the electronic office with a cheap, user-orientated information distribution and processing service.

This paper describes two aspects of viewdata. The first of these is that of private viewdata systems, which are mainly applicable for larger organizations. The second aspect is that of intelligent terminals which may be used in smaller organizations singly or grouped for distributed processing applications.

1 Private Viewdata Systems

The British Post Office's viewdata system 'Prestel' is now making an impact on the office environment by providing a new method of distributing information quickly and economically over the telephone network. This system has led to the development of a wide range of terminal equipment which has advantages in some applications over more conventional business computer terminal equipment. Foremost among these advantages are economically-priced full colour displays and easy connection to the telephone network using in-built modems and dialling capability. Complete private viewdata systems can also take advantage of terminals offering the business user the possibility of a complementary, more specialized version of the public viewdata systems. The first part of this paper describes the concept of private viewdata systems, outlining hardware and software considerations as well as identifying areas of application in future office environments.

1.1 Hardware

The basic requirements of a private viewdata system are those of any conventional computerized information distribution system. The central installation is based on a standard mini or larger computer together with magnetic disk drives for storing the information, a printer to provide centralized hard copy, and a multiplexer to provide connection to a number of distributed viewdata receivers. An outline of such an installation is given in Fig. 1, which shows the layout of central equipment and indicates the links that will generally exist with the telephone network and other local or remote computers.

Viewdata equipment has to achieve a low total system

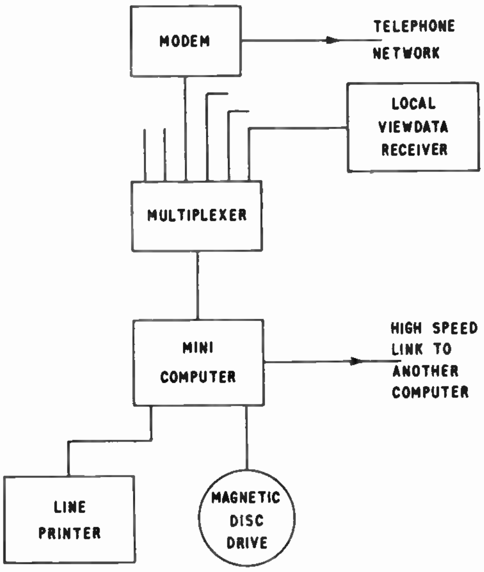


Fig. 1. Central installation hardware

---

* *GEC Hirst Research Centre, Wembley, Middlesex HA9 7PP.*

The Radio and Electronic Engineer, Vol. 51, No. 1, pp. 31–36, January 1981

0033–7722/81/010031 +06 $1.50/0

cost per terminal and also must carry a very heavy work load. For these reasons, viewdata central installations are frequently operated near their limits. The central computers come from near the top of their particular range and require a relatively large amount of memory. The disk drives may be specially tuned mechanically to provide the quickest possible access to pages, since this is usually what limits the size of any viewdata system. Then, as many multiplexer ports as possible, compatible with reasonable speed of access to pages, are connected to the computer.

Two private viewdata systems which we have developed, for example, are:

(1) A small system providing for a 25 000 to 50 000 page database capable of serving simultaneously 32 viewing only or 8 editing terminals, or a mixture of these on a *pro-rata* basis. This system uses either 10 or 20 Mbyte disk subsystems.

(2) A larger system providing for a 250 000 up to several million page database, capable of serving simultaneously 200 viewing only or 50 editing terminals, or a mixture on a *pro-rata* basis. This system can use disk capacities from 10 to more than 300 Mbyte.

The communications network for a private viewdata system spreads out from the multiplexer ports to all the distributed terminals. A variety of communication types are possible:

- Direct wired connections—here the terminals communicate over dedicated cables to the ports of the central viewdata computer. Communication can be either by direct data transmissions at V24 levels† or 20 mA loop drive; alternatively a baseband modem can be used. These direct connections, while requiring new cabling within the building, allow much faster operation than over standard telephone networks. Typically we use 9600 baud, which is more suitable for editors and users requiring rapid display of information.
- Dial-up access—users who are situated at some distance from the central computer can access the system over dial-up lines through the internal telephone exchange, communicating via the terminal's own internal viewdata modem. This has the disadvantage of restricting the user to the standard viewdata transmission rates of 1200 baud (equivalent to 120 characters per second) from the computer for display, and 75 baud ($7\frac{1}{2}$ characters per second) to the computer for instructions entered by the user. However, it has the advantages that the existing telephone system is utilized and the same terminal can also access Prestel and other private systems. By these means the office user can access a wide range of information services.

A variety of viewdata terminals is now available: black and white or colour, small or large screen, for business or domestic use, and controlled by simple numeric remote ultrasonic keypads, standard 'QWERTY' keyboards, or full expanded viewdata editing keyboards with up to 120 keys. Even in simple terminals all the information on the private system is readily accessible to the unskilled user, together with the ability to enter simple numeric data into the system in response, for example, to multiple choice questions. Substantially more intelligent terminals with extensive computing power in their own right, are under development and these are described later.

All the terminals use large-scale integrated circuits specially developed for teletext and viewdata, which in mass production allow a cost reduction compared with normal computer v.d.u.s. This will mean that most viewdata terminals based around television receivers could also be capable of receiving teletext signals, thus providing additional news and information services from the broadcast authorities.

1.2 Software

A typical multi-terminal and hence 'multi-tasking' or 'multi-process' viewdata computer program is shown in the block diagram of Fig. 2. The diagram summarizes the functions which the program has to perform: reading input from the terminals, deciding which pages are required, finding the pages on disk and transmitting them to the terminals.

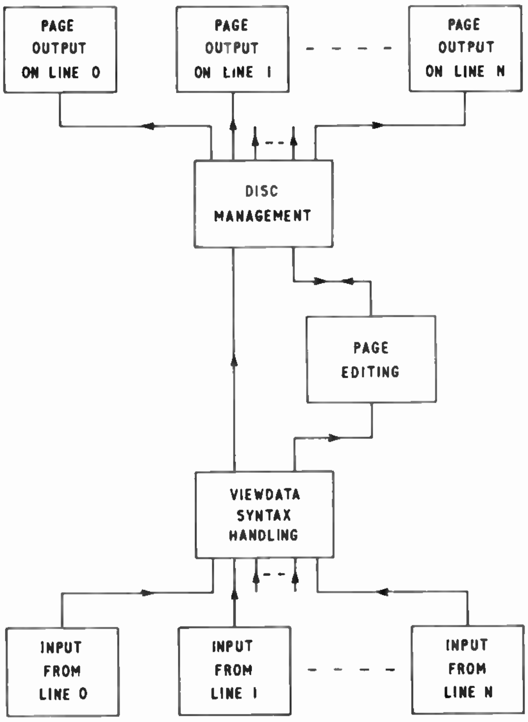


Fig. 2. Possible viewdata program modules

---

† Refer to CCITT Recommendation V24 for specification

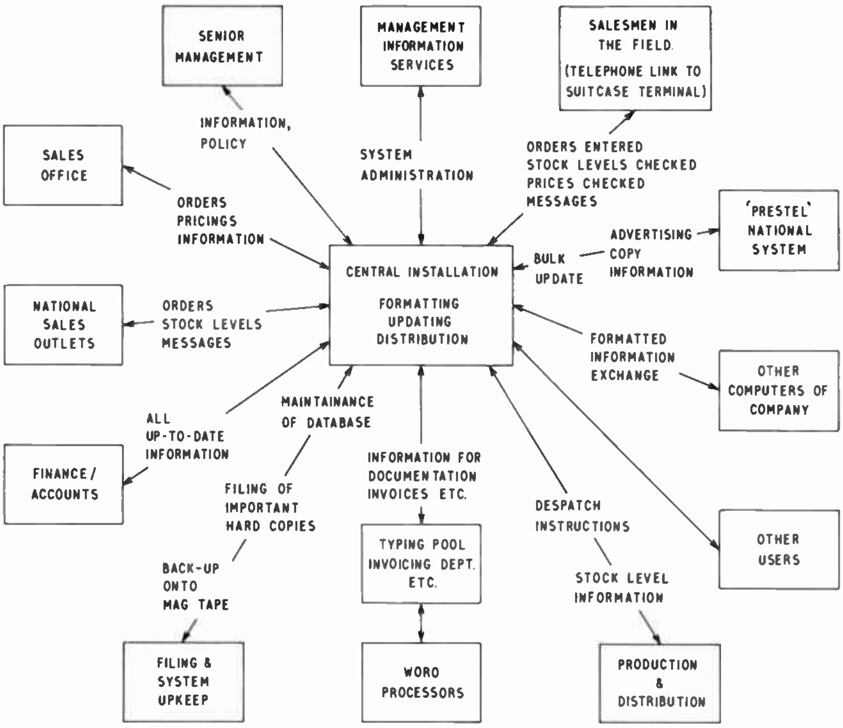


Fig. 3. Private viewdata system within the electronic office

The blocks requiring major effort are those concerning page editing and disk management. In particular the ease with which pages can be edited makes major differences to the suitability of the program to particular uses.

At present the Prestel approach is to make page editing as simple as possible, the editor moving a cursor around on the screen to overwrite the previous contents of a page. An alternative approach gives the editor access to a number of commands to achieve complicated editing manoeuvres quickly and simply. Commands can be used to search through the page and, for example, change everything in green to red. They can also be used to move part of the page up a line, redisplay the page as it would be seen on different types of receiver, or repeat a series of previously learned commands, and so on. Anything the private viewdata system owner requires, within the power of the computer, can be built into the program to help his editors produce the required pages. All these commands are designed to augment the basic editing program, which must, like everything else in viewdata, be as simple as possible to use.

The program's disk management routines are less directly visible to the viewdata user, but these are the routines which determine the system's speed of response. Research into the behaviour of viewdata systems has shown that with current technology the limiting factor in the speed of operation is the disk drive subsystem.† Various techniques can be used within the disk management routines to optimize disk access strategy and to minimize the number of disk transfers required to find a page. This latter feature is a function of the system's internal page indexing procedures and the program's ability to realize when requiring a page that another user of the system is already looking at the same page, so that the associated disk transfer can be saved.

The private viewdata program also allows for the addition of routines to handle extra tasks, such as sending messages from a user to a supplier of pages or to another user. Bills can be calculated for each user, based on his usage of the computer; each page can carry a separate charge, or the charge can be based on number of pages seen or connection time. Pages of important information can be printed out centrally, as permanent records for editors or other interested users. Transactional routines can transform a viewdata system from a simple information distribution system to a combined information collection, processing and distributing system.

1.3 Applications

Some typical applications of a private viewdata system within the electronic office are shown in Fig. 3, which shows how a private viewdata structure would fit into the office environment of an organization. The diagram does not show the non-viewdata cross links, which exist between the departments, but demonstrates the system's usefulness to the various departments. Some departments would use the system to extract information only, while others would be active in entering information into

---

† Fedida, S., 'Optimizing viewdata', *Wireless World*, **84**, no. 1510, pp. 75–7, June 1978.

the system. By use of system security, levels information can be released to certain people only or to all departments simultaneously; for example, completely up-to-date directories can be made instantly available to everyone.

Conventional computer systems are now an essential part of modern business, but normal output media can restrict the use to which the computer is put. The image is all too common of a computer user analysing reams of line printer paper in his office, in order to extract some relatively simple piece of information. Viewdata can frequently provide a more efficient way of presenting computerized information to the user. Information can readily be put into the viewdata system and can easily be accessed without the need for hard copy of all the non-essential information. The user can select which pages to look at, and these can be presented as full colour graphical representations of the information required. Viewdata can therefore be regarded as an enhancement to any data processing normally handled by computer.

The low price, familiarity and generality of a viewdata receiver will also make it an important computer input device, replacing 'data prep forms', punched cards or more expensive v.d.u.s.

Additionally viewdata can be used for the computerization of material previously issued as printed directories. Here, viewdata has the advantage that updating the master copy of the directory immediately changes the directory entry which users see. The time delay and randomness associated with conventional means of issuing updates are completely removed.

2 Intelligent Viewdata Terminals

Viewdata terminals, giving access to a national telephone network for data communication, can form an important part of an integrated electronic office system.

The intelligent viewdata terminal is an enhanced version of the viewdata terminals currently being produced, but has a substantially wider range of application. The most significant feature of the terminal is in its ability to run programs locally, the programs having been loaded down a telephone line from a central computer or stored on an optional floppy disk unit.

The aim of this Section of the paper is threefold. First, following a description of existing viewdata terminals, to define the concept of an 'intelligent viewdata terminal'. Secondly, to describe the features of an advanced intelligent terminal from the point of view of the hardware structure and the interrelation of the firmware, user r.o.m., and software which control its operation. Thirdly, to illustrate by several applications the use of such a terminal in a business office environment.

2.1 Current Viewdata Terminals

Figure 4 shows a block diagram of the relevant section of a currently produced viewdata terminal which uses a common bus design. The terminal is centred around a microprocessor which runs a program stored in memory, the memory being r.o.m. (read only memory) or e.p.r.o.m. (eraseable programmable read only memory), with the program fixed when the set is manufactured. This program controls the terminal and will obey commands such as 'connect viewdata' from the keypad. Telephone numbers, user number and password of the set, all of which must be preserved when the set is turned off, are stored in battery-backed r.a.m. (random access memory). A serial data interface enables communication with the viewdata computer via a line interface unit and telephone line. The information received from this serial interface is decoded by the microprocessor and stored in an area of memory.

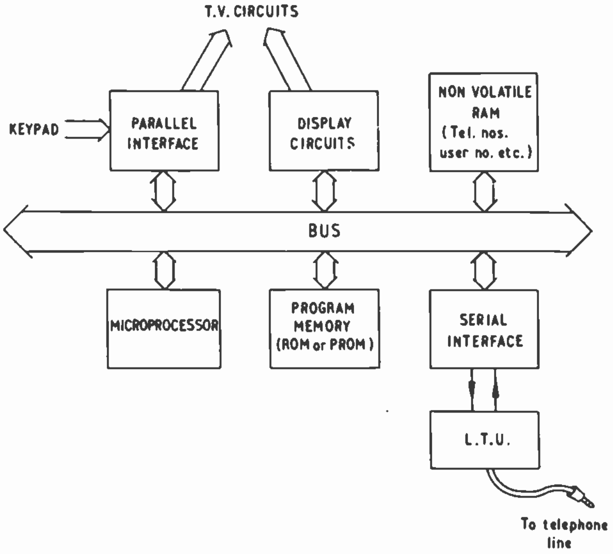


Fig. 4. Structure of a viewdata terminal

Display circuits then map the data on to a display screen in the form of alphanumeric characters and viewdata graphic symbols. A currently produced terminal would typically contain 2 K bytes of e.p.r.o.m., 256 bytes of battery backed r.a.m. and 1 K bytes of screen memory.

2.2 The Intelligent Viewdata Terminal

The main drawback of the present form of viewdata terminal is its inflexibility: it will perform a limited range of functions which cannot be extended without dismantling the terminal to change the program memory. However, the microprocessor system itself is in essence a general-purpose processor, capable of carrying out a wide range of data processing and communication tasks. It is the harnessing of this versatility by enabling the microprocessor to run programs other than its built-in r.o.m. firmware which defines the intelligent terminal. There are two main ways in which other programs can be run. One possibility is to make part of the r.o.m. in the form of a plug-in box which can be changed: this has the advantage of being simple and not requiring complicated loading, but has the disadvantages of needing a separate box for each program to be run, being limited to small programs, and not allowing for programs to be changed while the machine is in operation. The other possibility is to have a larger area of r.a.m. in which programs can be loaded and run: this is more versatile but needs some kind of loading procedure and also a source for the programs. In the present intelligent terminal design these features are combined to give the advantages of both.

2.2.1 *Hardware*

A block diagram of the terminal is shown in Fig. 5 and from this it may be seen that the following additions to the normal terminal have been included:

(1) A large array of r.a.m. (at present up to 48 K bytes) to enable the running of very large programs and/or storage for a large amount of temporary data (data retained while the set is turned on).

(2) A facility for r.o.m. to be plugged in. This r.o.m. can contain small user programs or a loader for larger programs.

(3) A second serial interface to control input/output to auxiliary devices such as printers, serial keyboards, cassette recorders or links to other computers.

(4) A disk controller to control up to two 8 inch floppy disk drives for back-up storage of programs and data.

(5) Extended firmware (presently up to 8 K bytes) which, as well as containing all the program necessary to function as a viewdata terminal, also controls all the devices through interrupt handling software, and provides simple I/O subroutines for any other software to use plus links for handing over control to other software.

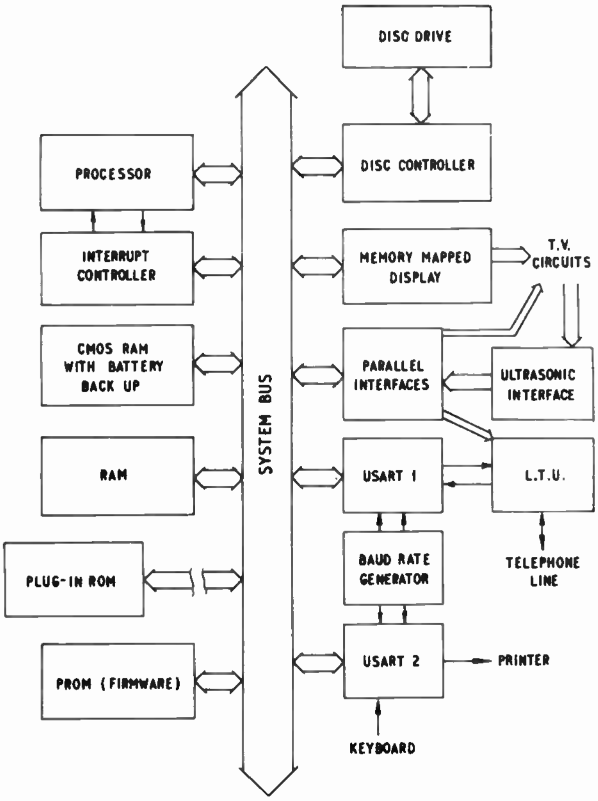


Fig. 5. Block diagram of intelligent viewdata terminal

2.2.2 *Software*

The design of the intelligent terminal allows for many different ways of loading and storing programs, the method used offering many advantages in terms of ease of use, versatility, and ease of distribution of programs. Programs are stored, not on the terminal, but centrally on the viewdata computer in exactly the same way as ordinary viewdata pages. If viewed as pages they appear as meaningless strings of letters and numbers, but they can be translated by a simple 'loader' program in the terminal and stored in the terminal's r.a.m., ready to be run as programs. The concept of storing programs centrally, which can later be retrieved by intelligent terminals and run without any further reference to the viewdata computer, is called 'Telesoftware'.

2.3 Interrelation between Firmware and Applications Software

When the terminal is activated, the firmware assumes control of the terminal and enables the user to make calls to a viewdata computer in the usual way. This firmware controls the basic operation of the terminal and resides in r.o.m. which is permanently installed within the set. However, on command from the user, the firmware hands over control to the program found in the plug-in unit. This program can call user subroutines provided in the firmware, which enable it to carry out the following:

(i) Send messages to the user via the display screen.

(ii) Accept data from the user via the keyboard or keypad.

(iii) Initiate a viewdata computer call.

(iv) Send and receive data to and from a viewdata computer.

(v) Enable or disable firmware routines which automatically echo keyboard data, or viewdata characters, to the screen and echo data to the the viewdata line. The result is that the terminal appears to the user as a normal viewdata terminal while simultaneously running a different program.

(vi) Define a user routine to be executed by the terminal every 20 ms. This is useful for book keeping operations such as maintaining a real-time clock.

Typically, the plug-in program would use the subroutines to make a call to a viewdata computer, request a page or pages containing an application program in coded form (a 'Telesoftware' program), and process the characters as they are received by the interrupt routine in the firmware. It would then reconstitute the program from these characters and store the program in r.a.m. ready to be run. Having checked that the received data is free of errors from noise on the telephone lines, control would be handed over to the program that had been loaded. This program again could make full use of the firmware user subroutines in the course of its execution, and finally return control to the firmware on completion.

2.4 Applications

One of the greatest needs in the electronic office is for an integrated data handling system. For example, if stock information has to be retyped into a word processor and reformatted before it can be printed as a letter to a distributor, much of the advantage of an electronic office is lost. A versatile intelligent terminal can, with suitable software, retrieve the data (automatically dialling a viewdata computer perhaps), reformat it, and then print it. If required, it could run word processor software for the user to reformat documents, or, given a standard letter format, it could do this automatically. The software can also make use of the floppy disk stores: for example, a list of names and addresses to whom the letter must be sent can be stored on disk and multiple copies of the letter sent with appropriate names and addresses. For a small business, the local storage will accommodate payroll information, stock levels or accounts information. The software needed to handle, format and print this data, and the software to interface the terminal to other electronic office equipment such as word processors, can be obtained from, and maintained through a link to a private viewdata system of the type described or a national viewdata network such as Prestel.

3 Conclusions

This paper has described a private viewdata system with a capacity extending to about 500 000 pages of information and about 200 simultaneous viewing terminals, using current technology. Also an intelligent terminal which has the capability to execute a wide variety of programs, including a large microprocessor business operating system, has been described.

The terminal and viewdata system are designed to operate separately or together. The viewdata system offers the electronic office the possibility of cheap information display, whilst the intelligent terminal offers the possibility of convenient and inexpensive processing of the information retrieved.

Manuscript received by the Institution in final form on 8th September 1980.
(Paper No. 1968/Comm 219)

The Authors


A. Giles


S. Laurenson


A. Christian


K. Jones

After graduating from Cambridge University with a degree in mathematics, **Alan Giles** worked at the GEC Hirst Research Centre, where he was actively involved in the system design and programming of a number of viewdata systems, including the GEC Viewdata 4000 system. He is now promoting Prestel applications in Yorkshire.

Steve Laurenson gained an honours degree in physics and electronic engineering at the University of Manchester in 1977 and since then has been working in the Telecommunications Research Laboratories of the GEC Hirst Research Centre. He has been actively involved in the design and implementation of various items of viewdata technology, in particular modems and viewdata terminal equipment.

Arthur Christian graduated in 1978 from Clare College, Cambridge, with an honours degree in electrical science and joined the GEC Hirst Research Centre, working in the design of advanced viewdata terminals and developing the concept of telesoftware.

Keith Jones went to the Telecommunications Research Laboratories of the GEC Hirst Research Centre in 1971 after graduating in mathematics and electronics from the University of Salford in 1967 and working in the defence industry on radar and guided weapon systems. After early work on digital telephone exchanges and digital telephones, more recently he has been involved in the development of advanced terminals for viewdata related applications, and the design of integrated circuits for telecommunications applications.

UDC 621.3.049.75/77: 621.317.33
Indexing terms: Integrated circuit testing, Printed circuits

Signature analysis for board testing

JOHN R. HUMPHREY, M.S., B.S.E.E.*

and

KAMRAN FIROOZ, B.S.E.E.*

Based on a paper presented at the Network/IERE Conference on 'Automatic Testing 79' at Brighton in December 1979

SUMMARY

A signature analyser detects and displays the unique digital signatures associated with the data nodes in a circuit under text. By comparing these actual signatures with the correct ones, faulty nodes can be detected. The technical details of a practical signature analyser for use in production are presented and its application to the testing of complex printed circuit boards incorporating l.s.i. devices, such as memories and microprocessors, is described.

1 Introduction

When Hewlett-Packard developed the Model 5004A Signature Analyzer[1], the objective was to provide a way to substantially reduce repair costs on microprocessor and r.o.m.-based products. The board-exchange approach commonly adopted for field service support of such products has a number of economic drawbacks. Signature analysis was viewed to be a viable, component level repair alternative for l.s.i. circuit-based equipment that could stand a few hours of repair downtime. During the past three years, Hewlett-Packard has introduced more than 50 major products which include provision for testing with signature analysis. Furthermore, by early 1979, nearly 70% of the top US electronic companies (by sales volume) had invested in signature analysis as a measurement tool.

Implementation of signature analysis (s.a.) capability into an automated test system with bed-of-nails circuit visibility extends the practicality and power of the technique from the realm of field service of l.s.i.-based products to that of production testing of individual circuit boards. The stimulation, measurement, and fault-isolation aspects of s.a. within an automated test system environment are discussed. Examples of s.a. testing of representative memory and microprocessor boards are presented with sample stimulus approaches, tester interconnection and programming requirements, and troubleshooting strategies.

2 L.S.I. Board Testing—Problems and Solutions

Considerable space has been allocated within the spectrum of literature directed toward test problems to the challenges posed by boards designed around l.s.i. technology.[2-6]

Chip complexity has reached the point that a single microprocessor may contain more gates than a 50 to 100 i.c. board of m.s.i. devices. The board on which the processor is placed may contain several other chips of l.s.i. complexity as well as the original 50 m.s.i. devices. Such complexity makes the task of generating effective test sequences more difficult. The simulator-aided programming techniques which have been successfully applied to m.s.i. technology may also be used for l.s.i. boards. However, modelling l.s.i. devices may be very difficult and time consuming.

For simulators which utilize algorithmic pattern generation, complex circuits modelled in terms of NAND gate equivalence can easily exceed the 4K to 20K gate capacity of the simulator—even if the detailed, gate level specifications of the l.s.i. chips in question are available from the manufacturer. An approach which reduces the severity of the chip complexity problem is to employ a simulator which works with a functional rather than gate level model of complex l.s.i. devices. Functional modelling reflects overall data transfer within the device based upon operational data published by manufacturers. In any case, modelling of l.s.i. devices is

---

* Hewlett Packard Corporation, Loveland Division, P.O. Box 307, Loveland, Colorado 80537.

0033–7722/81/010037+14 $1.50/0

not a trivial task and tester manufacturers have not updated libraries in pace with the development of new l.s.i. chips.

After the modelling of the l.s.i. devices is complete, a simulator will model the board and help develop a pattern set for testing the board. The task of pattern development typically encompasses several steps involving both automatic and semi-automatic operations. Manually-generated inputs may be required to account, for example, for sequential functional requirements.

The next problem is stimulation and detection of digital activity on the board as specified by the simulator-generated data. Boards containing l.s.i. typically exhibit greater susceptibility to timing-related parameters. Furthermore, many such devices function only at dynamic conditions and cannot be statically exercised. This means that an l.s.i. board tester must work at rates corresponding to the sub-1-μs cycle level. Functional testers currently on the market may offer high-speed pin options to meet this requirement. Such options are generally configured around a specialized controller with r.a.m. at each (high speed) driver/sensor pin and software considerations for loading r.a.m. from and dumping r.a.m. data to mass storage between test sequences. Depending upon the degree of sophistication of both tester hardware and software, as well as cost, dynamic test capabilities of commercially available systems may include such features as:[6]

The capability to change pin function between driver/sensor modes during program execution without reducing system test rates.

Capability to synchronize the tester to different clock phases on the board.

The need for such tools must be considered in view of tester cost and programming requirements to achieve a level of fault coverage. The objective of testing is optimization of fault coverage and fault isolation based upon customer satisfaction and warranty cost parameters related to production throughput and production cost.

The question of fault coverage depends upon the adequacy of the functional stimulus in exciting fault modes and propagation of the effects of the faults to a measurement point. Simulators normally provide a calculation which relates faults detected by the test sequence to the total number of faults modelled for a particular board. Because l.s.i. devices are complex, board functions are more complex and it is more difficult to evaluate the quality of an l.s.i. board test program. Functional modelling techniques or the use of comparison chips in a reference-system tester[7] provide a hardware model, but they model the correct operation of the l.s.i. chip and do not predict faults. The use of other test tools, such as in-circuit inspection for shorts and opens in combination with digital functional tools may significantly enhance tester fault coverage capabilities. In the final analysis, test quality is measured and test approaches are tuned on the basis of customer feedback.

Fault isolation on many commercial testers is based upon guided probe and i.c. clip techniques. The structural characteristics of l.s.i. boards as related to bi-directional busses and specialized I/O devices can make diagnosis of faults to the component level difficult. Although a given node may be detected as faulty, the problem of determining which of five to ten i.c.s connected to the bad node is generating the fault is significant. For a bi-directional bus structure, inputs to one device become outputs for another and the probing problem becomes one of resolving a feedback loop condition. Furthermore, because a guided probe method must examine all inputs associated with several devices which are connected to a failing node, it generally takes longer to diagnose a fault on a l.s.i. board. L.s.i. boards feature extraordinary functional density. There are simply too many functions, too many states, and too much memory to test the entire spectrum of design operation. Furthermore, there is the problem of visibility. As chip complexity has increased, fault visibility has decreased.

Complexity, at-speed test requirements, visibility, effective fault coverage, fault isolation, tester cost effectiveness—these are the problems associated with testing today's l.s.i. boards. Yet circuit designs are already evolving from l.s.i. to v.l.s.i. technology. Testing may very well become the major cost associated with the use of these technologies. In line with the emphasis on programming support and peripheral chip development which were required to make circuit design with l.s.i. practical, designed-in testability will have to be seriously addressed both by the chip manufacturers and end-product designers.

Signature analysis is one proven method to help solve these problems in a cost-effective manner and it offers alternatives to simulation, r.a.m. backed test pins and dynamic reference test systems.

3 Signature Analysis—Technical Details and Characteristics

Signature analysis is conceptually simple. It is a synchronous process, whereby activity at an electrical node, referenced to a clock signal, is monitored for a particular stimulus condition during a measurement time period. The result of the s.a. nodal monitoring process is based upon a unique data compression technique which reduces long, complex data stream patterns into a 16-bit, 4-digit 'signature.' Correct signatures for a particular circuit are determined empirically from a known good product. Testing is performed by probing interdependent nodes to determine the functional origin of bad signatures.

3.1 Stimulus Considerations

The original Signature Analyzer manufactured by Hewlett-Packard requires that the stimulus for s.a. testing be generated by the product being tested. For many boards, the most effective stimulus is indeed derived internally, within the framework of 'designed-in' s.a. testability. However, when considering s.a. with respect to board rather than full product testing and in conjunction with an automated test system rather than a portable field service capability, .it may be desirable, practical, and even necessary that stimulus be generated as part of the test environment.

Signature analysis testing relies upon the principle of 'exercising' circuit nodes—changing logic nodes from one state to the other—stimulating the various fault conditions (stuck-low, stuck-high, pin faults, etc.) that may exist for a particular circuit. For combinational circuits it may not even matter 'what' specifically causes a node to be exercised to provide useful diagnostic information. In fact, pseudo-random pattern stimulation may be effectively applied in conjunction with s.a. testing of combinational logic. However, for circuits such as microprocessor-based controllers, sequential operational characteristics may reduce the validity and effectiveness of random stimulation.

One approach to l.s.i. board stimulation for s.a. testing is to 'free-run' the board. Free-running, for purposes of s.a., involves getting the circuit to run in a repetitive loop with only a minimum number of the circuits logic elements required to control the process and causing the maximum number of logic nodes to be exercised. In the case of microprocessors, controllers, sequencers and algorithmic state machines, free-running is often accomplished by opening the data (or instruction) input bus and forcing in an instruction or control that causes a continuous cycling through the entire address or control field. The circuitry performing this cycling function is referred to as the kernel and is functionally the 'heart' of the system. Taking signatures while in the free-running mode can verify the processor's capability to execute one instruction (such as NOP) as well as the operation of circuitry which functions from the data and address busses (address decoders, r.o.m.s, etc.). Further stimulation may be required to functionally test the processor and other circuitry not stimulated directly by the address and data busses.

To test board functions not exercised by free-running, specific test algorithms must be generated to emulate the functional modes of the board's applications environment. The algorithms applied must also be designed to make fault isolation as effective as possible. Often the test algorithm may incorporate subroutines used in normal application of the product or as part of a self-test procedure. In the case of a microprocessor board, the s.a. stimulus algorithms are written into a portion of on-board or externally connected r.o.m. (as part of the auto test fixture, for example). Stimulus for the test is thus generated internally which is easier than trying to stimulate devices surrounding a processor from the board's edge connector I/O ports. Furthermore, the intrinsic data manipulative capabilities of microprocessors make this a powerful stimulus control approach, yet a relatively straightforward task to implement in the design.

Consider, for example, the stimulation of peripheral I/O devices that accept inputs from a processor and output data to another board. A short program can be written to increment an accumulator in the processor and output the data to all devices. Signatures can be taken on each output line to test not only the devices that are connected to the processor but also the processor itself for several specific instructions (increment accumulator, test accumulator, jump, etc.).

3.2 Signature Measurement

The process by which the signature of a data stream is measured is controlled by three signals. A START signal is used to trigger the beginning of a signature measurement time interval. The CLOCK signal synchronizes the s.a. data sampling circuitry to signals to be monitored on a test node. The STOP signal is used to trigger the end of a signature measurement time interval.

The START and STOP signals which define the data sampling interval can be taken from address lines, state pointers, software controlled output ports, direct I/O ports, or any other signals that identify the presence of a unique data stream. A sophisticated tester may allow the measurement to be made on the basis of a START signal and a specific number of clock pulses following START. Special circuitry may also be designed into the production test fixture to generate measurement window signals, on the basis of decoded address lines, for example.

As with s.a. stimulus discussed previously, s.a. was originally designed to allow the unit under test to run at speed by its own clock with the tester synchronized to that clock. In the production test environment, it is likely that some boards will be tested independently of other boards which normally supply such signals as a clock. In such a case, the tester may be utilized to generate the clock required to make the board function. The s.a. measurement process is likewise synchronized to the tester-generated clock. The test fixture can be designed to furnish such signals as a clock as well.

When utilizing s.a. for field service, both the CLOCK and START/STOP signals are generally derived from circuit test points which are not changed through many or all signature data probings. In such a case, with the START/STOP and stimulus running repetitively, the fault isolation process is a matter of physically moving the signature analyser input probe from node to node on

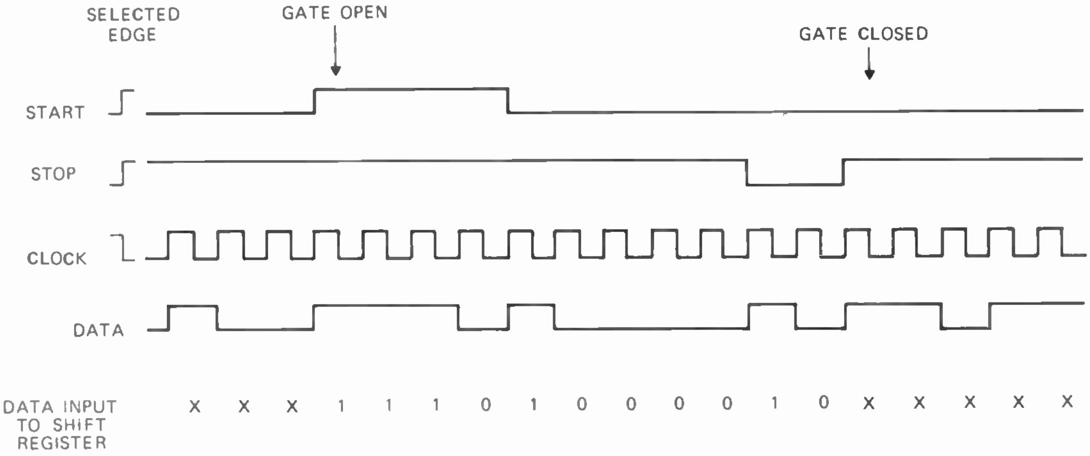


Fig. 1. Typical data input to the signature analyser illustrating the timing relationship between the control signals and the measured data stream.

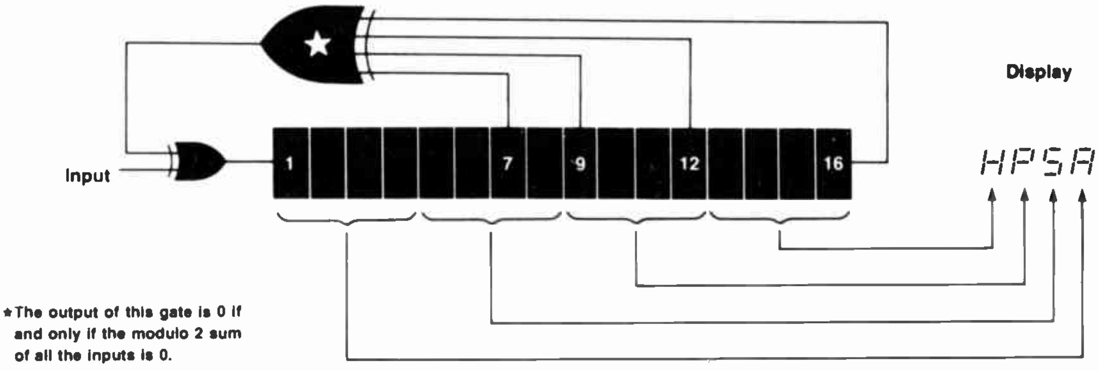
the circuit under test—searching for components with good signatures on the input but bad signatures on the output. The test system implementation of s.a. can provide not only automated multiplexing of the data input connections but also of START, STOP, and CLOCK connections. This capability in conjunction with properly designed stimulus signals can simplify the fault isolation process since specific measurement windows can help isolate devices functionally. Figure 1 illustrates the timing involved in a signature measurement window.

Processing of the nodal activity measured by s.a. is accomplished using a compression technique known as cyclic redundancy check (c.r.c.) which has been commonly used in the communications industry for error checking.[8] Compression of potentially long streams of data into a unique 16-bit result (the signature) obviates the need for r.a.m. and mass storage for performing dynamic tests. This reduces usage complexity and tester cost.

Signatures are captured using an n-bit linear shift register with multiple feedback taps that are modulo-2 summed with the input data as shown in Fig. 2. Feedback is selected so that the shift register produces deterministic and maximal length bit sequences. The deterministic characteristic refers to the fact that if the shift register is initialized with a particular word and shifted using a particular bit sequence, the remaining residual word (signature) is always the same. For a shift register with feedback that is characterized by the maximal length property, any bit stream that is shifted into the register will exhibit all $2^n - 1$ possible states before repeating a state. (See Ref. 9 for a discussion of shift register properties.)

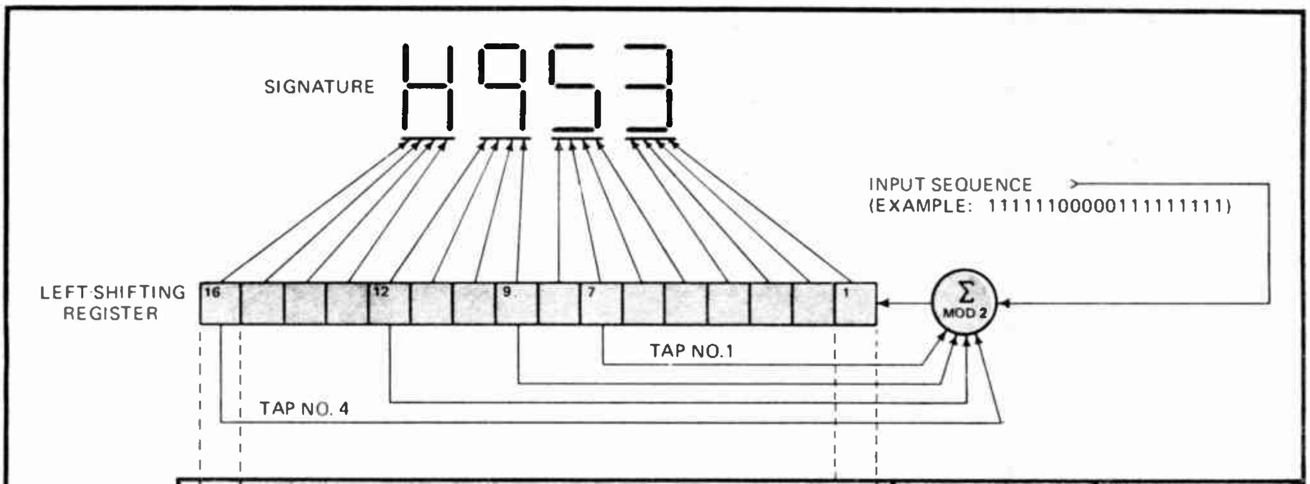
The selection of shift register feedback taps to establish these properties is not unique and various choices for different length shift registers are described in Reference 9. For s.a. as implemented by Hewlett-Packard, a 16-bit register with feedback from the 7th, 9th, 12th, and the 16th bits has been selected.

This c.r.c. implementation yields a 100% detection of all single-bit errors in a bit stream and 99·998% detection of multiple faults in a data stream regardless of length.[9] Note that these percentages indicate probabilities of detecting faults that may exist in the data under test. The effectiveness of the fault coverage is a function of the stimulus pattern and propagation of faults to a measurement node.



★The output of this gate is 0 if and only if the modulo 2 sum of all the inputs is 0.

Fig. 2. A linear shift register with feedback is utilized to measure the signature of a data stream.



TIME	CONTENTS OF SHIFT REGISTER																NEXT INPUT TO SHIFT REGISTER	NEXT INPUT SEQUENCE BIT
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0
7	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0
8	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0
9	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0
10	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0	0
11	0	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0	1	1
12	0	0	0	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1
13	0	0	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1
14	0	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	0	1
15	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	0	1	1
16	1	1	1	1	1	1	0	1	1	0	0	1	0	1	0	1	0	1
17	1	1	1	1	1	0	1	1	0	0	1	0	1	0	1	0	0	1
18	1	1	1	1	0	1	1	0	0	1	0	1	0	1	0	0	1	1
19	1	1	1	0	1	1	0	0	1	0	1	0	1	0	0	1	1	1
20	1	1	0	1	1	0	0	1	0	1	0	1	0	0	1	1	—	—

Fig. 3. The table shows how a 20-bit input sequence is processed to a four digit (modified) hexadecimal signature.

The 16-bit shift register residue from a data stream measurement is displayed and processed in a hexadecimal format. This representation of the result is what is referred to as the 'signature' of the measured bit stream. HP signature analysis products utilize a nonstandard hexadecimal character set (0123456789ACFHPU) which was chosen for easy readability and compatibility with 7-segment displays.

The table in Fig. 3 shows how a signature is generated from the 20-bit sequence 11111100000111111111. Initially (time 0 through 7) the register acts merely as a shift register. At time 7, the first 1 of the input sequence has reached the first feedback tap (tap 1, Fig. 3). It is fed back and mixed with the input 0, with the result that a 1, not a 0, is next clocked into the register (time 8). This behaviour continues until the end of the measurement when a residue of 16 bits, 1101100101010011 (time 20), is all that is left from the 20-bit input sequence. (Note the total dissimilarity in appearance between this residue and the original 11111100000111111111 input sequence.) This residue is displayed in hexadecimal format as H953, the signature of the 20-bit sequence.[10]

In general, a faulty signature provides no information regarding the exact nature of a node fault (i.e., the content of a signature cannot be analysed to determine that a specific bit was in error). There are, however, two important signatures which do relate to specific activity at a node. First, consider the signature for a node held at the low reference voltage. Because the s.a. shift register is initialized to zero when a measurement sequence is started, if no 'ones' are shifted in, the register will remain at zero. Thus, a signature of '0000' will be measured for a node held low. Next, consider the case of a signature taken on a node held high. All 'ones' are shifted into the s.a. processor and the signature is a function not of the transitions of the measured data stream but of the number of times (clock pulses) the data is shifted. Thus, each stimulation/measurement period has a particular signature which characterizes the 'stuck high' state for that period. The occurrence of any signature other than '0000' or the signature associated with the constant high condition is an indication that the node is being exercised and that 'stuck-at' faults are being excited by the stimulus. Furthermore, the signature of the high reference condition can be used to check the number of clock pulses associated with a stimulation sequence.

3.3 Fault Isolation with Signature Analysis

Signature analysis is a nodal analysis technique. As such, it is very effective at yielding pass/fail decisions. In fact, s.a. can help minimize the cost of testing good circuitry. This is due to the fact that a single signature measurement at one node can accurately reflect the correct or incorrect operation of a logic structure consisting of a large number of devices and many nodes. This is dependent upon effective fault stimulation of the various nodes feeding the cardinal measurement nodes. Examples will be presented later to show how this may often be accomplished in a straightforward manner.

In the event of a nodal signature fault, the effectiveness of using s.a. to isolate the device(s) causing the fault is dependent upon the logic structure of the node itself related to testability features designed into the board. In the a.t.e. system test environment, fault isolation effectiveness also depends upon test system hardware and software tools.

For combinational logic, without feedback, fault isolation is largely a simple comparison of the measured and known good signatures for the board. If a bad signature is found, the signatures of lower-order nodes are checked until a component can be located with good signatures on the input but bad signatures on the output. For an a.t.e. system, with either bed-of-nails or guided probe visibility, the tracing algorithm may be easily built into look-up tables which reflect circuit topology. Tracing may be based upon binary half-splitting, inside-out checking of all signatures, or by straight back-tracing. These methods of fault probing are illustrated in Fig. 4.

Isolation of faults to the component level on circuit boards which employ feedback connections is dependent upon hardware and software capabilities for breaking the feedback paths. This consideration applies both to the test system and the board under test. For example, the most common loop associated with microprocessor-based boards consisting of the processor, address bus, memory elements, and data bus may be broken by including a data bus jumper plug capability within the design. During production test, the board may be tested before the jumper is installed. After the kernel is tested using a free-run stimulus as described earlier, test system relays can be closed to emulate the normal 'jumper-in' data bus connections. Then, additional test cycles in which typical operations of the board are verified may be run.

Feedback could also be disabled electrically by designing the board with buffers to tristate selected paths upon command from the test system. This approach may dictate extra hardware cost for the product and the need to test the states of the devices in question. However, significant return may be realized on such testability investments.

Feedback loop failures may also be analysed by measuring signatures during periods when the feedback signal(s) take on constant zero or one states. This may be accomplished by designing stimulation software so as to provide sequences in which feedback signals are constant. In some cases, i.c.s may permit shorting to ground for the brief period in which signatures are measured in order to set feedback paths to zero.

Within a bed-of-nails test environment, the capability to select START, STOP, and CLOCK signals automatically from anywhere on the board and to perform measurements using START and CLOCK pulse count can contribute significantly to effective fault isolation. Use of such tools is illustrated with the examples in the following Section.

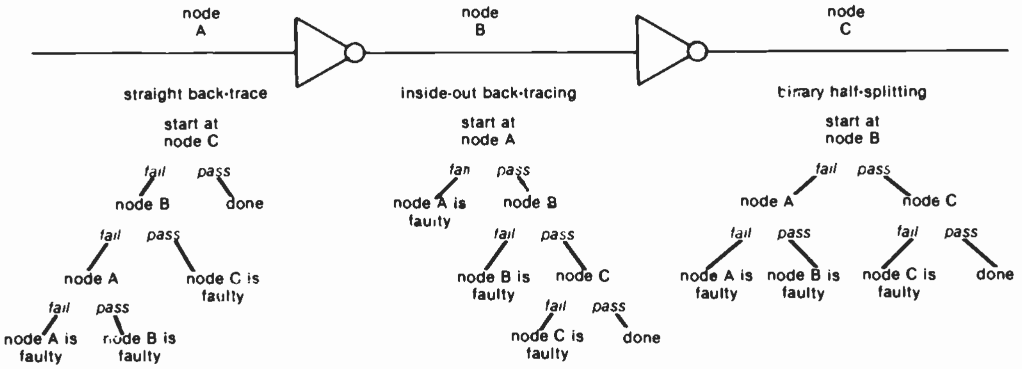


Fig. 4. Methods of fault probing using signature analysis.

4 S.A. in Production Test A.T.E.

In this Section, the general concepts of s.a. testing which have been presented will be related to specific test problems and their solutions. To accomplish this, hardware and software capabilities of an automated test system currently on the market will be described. These capabilities will then be applied to two representative l.s.i. board test problems.

On the sample test system, s.a. is featured as an at-speed digital functional test technique.[11] The system is utilized in conjunction with bed-of-nails type fixing and provides a full spectrum of test capability. Shorts/opens, in-circuit component tests, static digital tests, and considerable general-purpose analogue hybrid functional test in addition to s.a. may be performed with this a.t.e. It is important to note that the objective of thorough test of a board is, in general, best accomplished by taking advantage of all of these capabilities in an integrated test sequence. It is best to resolve passive short/open conditions prior to application of power for functional testing. Discrete component fault and loading errors are best diagnosed using passive state in-circuit testing. Static digital test tools are useful for checking for simple active logic faults and for controlling signals during s.a.-based dynamic functional testing.

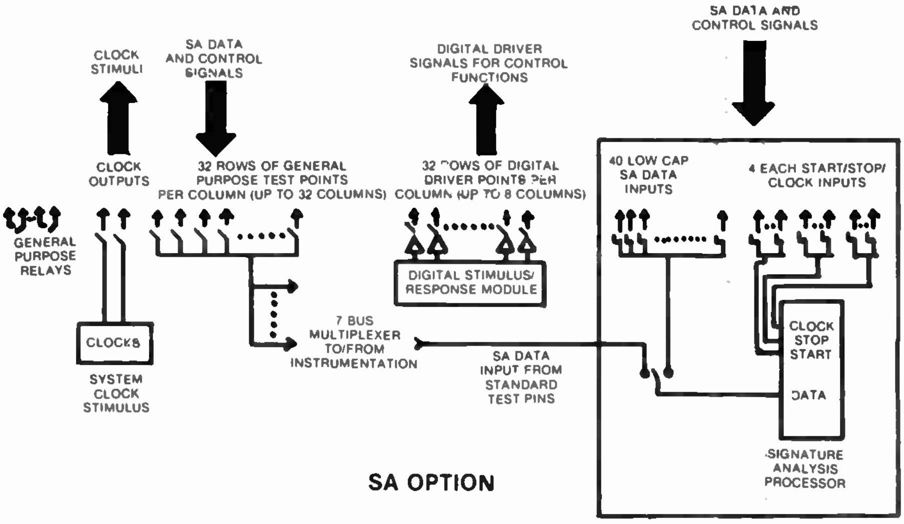


Fig. 5. One example of the hardware implementation of signature analysis test capability in a commercially available a.t.e. system.

The hardware components of the sample test system typically utilized for s.a. testing are represented by the simplified block diagram of Fig. 5. General system multiplexing is implemented in a row-column matrix configuration in which any individual test point may be switched to none, one, or any combination of signal busses in a seven-bus multiplexing scheme. These busses may be programmed for use with both in-circuit and functional testing as required. For example, the bus structure can be configured to route any one of up to approximately 500 nodes into the s.a. data stream processor. In addition, columns or individual relays may be configured to multiplex START, STOP, and CLOCK signals.

The signature analysis hardware option for the system includes additional multiplexing dedicated to s.a. as represented in the large block of Fig. 5. Forty low capacitance test pins and four each START, STOP, and CLOCK inputs are provided. Note that the cost of the s.a. option is in the order of $100 per pin for the dedicated pins with no additional cost for utilizing standard in-circuit test pins for s.a. testing.

With respect to software, the sample test system features a BASIC-like interpreter structure enhanced by approximately 40 programming statements designed especially for board test programming. Loops, variable manipulation and branching typical of BASIC and FORTRAN processor-based systems may be applied freely with the special board test language (BTL). For s.a. testing, six of the BTL statements are commonly used. Of the six, two are statements dedicated to s.a. processing while the remaining four are useful in several of the available system test modes and are general purpose in nature.

The first of the two s.a. statements 'saset', is used to select input pins for START, STOP, and CLOCK, and to set up processing on the basis of rising or falling edge conditions of these signals. The second s.a. statement, 'sig', is used to measure signatures and its parameters include provision for learning signatures (from the reference assembly) or for measurement of signatures from the board under test with or without automatic fault message print out. Whether a signature is measured on the basis of a START/STOP combination or START and a specified number of clock pulses is also controlled by 'sig' statement parameters. The s.a. processor can be set up to test on the basis of a repetitive stimulus or a single-cycle stimulus sequence with 'sig'.

The remaining four BTL statements which will be

Table 1

An a.t.e. system with software designed for the particular problem of circuit testing can make the test programming job easier. The statements shown are used to program s.a. functional testing in one commercially available a.t.e. system

Statement	Purpose/Description
saset	Select START, STOP, CLOCK input connections and whether signatures are to be taken on rising or falling edges of these control signals. Initializes SA processor. saset 1, 'R', 3, 'F', 4, 'F' — CLOCK input #1—rising edge START input #3—falling edge STOP input #4—falling edge
sig	Measure a signature. sig 'U1-pin 6', — Fault message '3961', — Expected signature 32767, — Number of clocks after START. S, — Variable to which measurement code is returned. S$[7] — Alphanumeric variable to which measured signature is returned.
mcon	Close multiplexer test point relay. mcon N, M Close relays N and M where N, M are row/column positions given by $X.R_1R_2C_1C_2$ X = Node; R_1R_2 = Row Number; C_1C_2 = Column Number
apply	Set digital driver patterns. apply 'INTRPT' 3, 0, 3 or apply 'INTRPT', '11', '00', '11' — Set the two-bit digital control signal named 'INTRPT' high, low, then high again.
rcv ref	Set SA or static digital reference voltage levels. rcv ref 1, 0·2, 2, 3·2 — Set SA reference voltages for: ⩽ 0·2V for low; ⩾ 3·2V for high
clock	Set up digital clock stimulus. clock 1, — clock output 1e6, — frequency 1e5 — Number of pulses or free-run Set up clock number 1 to output a 1 MHz signal for 10,000 pulses.

utilized to illustrate automated s.a. testing include a test pin multiplex statement (mcon), a statement for generating a clock signal (clock), a statement for setting digital levels (apply), and a statement (rcv ref) for programming the logic '1' and '0' reference voltage levels used for s.a. signal processing. All of the BTL statements used in following illustrations appear in Table 1 with a description of their programmable functional parameters.

4.1 Testing a Memory Board

Consider the problem of testing the memory board shown in Fig. 6. The board consists of both r.o.m.s and r.a.m.s and the data and address busses are accessible via an edge connector. Each memory element is selected via a chip enable line which is decoded from address bus data. Two control lines are used to direct data flow. Read/write (R/W) determines the direction of data flow while enable (ENA) controls timing—specifying when each device is to drive the data bus.

In this case, there is no source of internal stimulus for the board. An external stimulus is to be designed into the test fixture. Consider first, test of only the r.o.m. portion of the board. The decoder logic is stimulated by the various combinations of address lines A 11 through A 15 Particular addresses of the decoded r.o.m. are selected by the address lines A0 through A10. An externally applied 16-bit counter may be conveniently utilized to stimulate the address lines. The counter itself will be driven a via test system clock. This clock signal is also supplied to the CLOCK input of the s.a. processor. The R/W control line will be controlled via a static digital drive signal from the test system.

The r.a.m.s will also be exercised by the counter. However, before taking meaningful signatures involving r.a.m. output data, the r.a.m.s must be initialized. One way to accomplish this is to fill each location in r.a.m. memory with its own address. Figure 6 illustrates how this may be implemented with the same counter stimulus as described above. The R/W line is set to the write state, the buffers are enabled and address data, bits A0 through A7, is applied to the data bus. As the counter is cycled through all possible addresses, each writable location is initialized with its particular address. With the r.a.m.s so initialized, they are treated like r.o.m.s for signature tests.

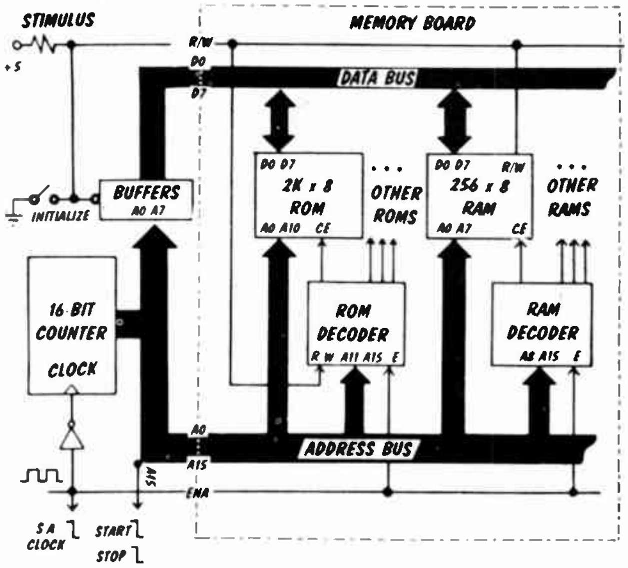


Fig. 6. A memory board consisting of both r.o.m.s. and r.a.m.s can be tested using signature analysis. An external stimulus is applied using a 16-bit counter to drive the address lines and to initialize r.a.m.

A GO/NO-GO test may be performed on the board by collecting just the eight data bus signatures. The counter is set up to cycle continuously and the s.a. measurement window is set to monitor all 2^{16} possible states.

The most significant bit of the counter is connected to both the s.a. START and STOP inputs. In less than one second all decode and data functions may be checked as reflected in the eight data bus signatures. Figure 7 shows both the hardware connections and software required to perform this test.

Suppose one or more faulty signatures are measured during the GO/NO-GO test described above. Fault isolation may be easily performed using inside-out tracing. First, the 16 address lines driven by the counter are verified over the entire count cycle. If a bad signature is measured, there is a problem with the stimulus circuitry which must be corrected. If the stimulus is verified to be working properly (at 1 MHz clock rate, 16 signatures in approximately two seconds), the decoder logic outputs are checked. In the event of a bad decoder signature, back tracing is performed through the decoder

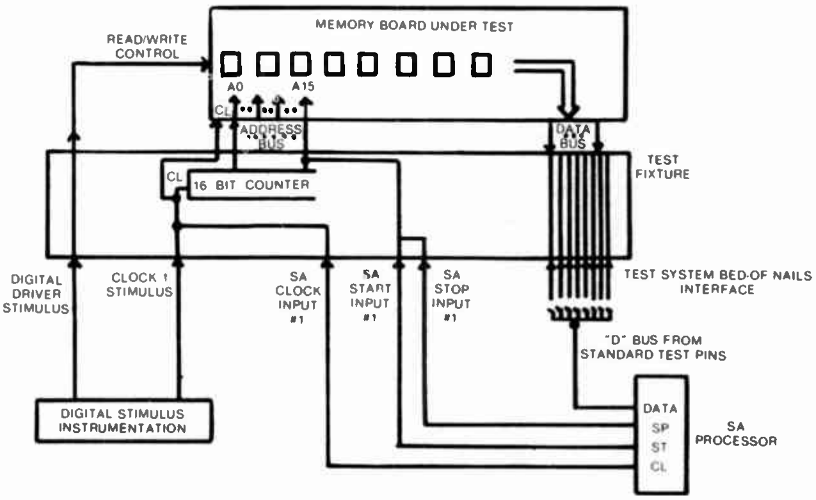


Fig. 7. Example of hardware connections and software required to perform a GO/NO-GO test for a memory board using signature analysis.

Test Program for GO/NO-Go Test

Line #	*Program Statement*	*Description*
1:	‘GO/NO-GO test for memory board’:	Comments for Documentation
2:	‘Tests signatures of 8 data bus’:	
3:	‘Lines for all possible addresses’:	
4:	‘RAM’s have been initialized’:	
5:	rcv ref 1,0.4,2,3.2	Set s.a. low, high reference voltages
6:	saset 1,‘R’,1,‘F’,1,‘F’	Set s.a. to process clock 1
7:		input, rising edge, start 1,
8:		stop 1, falling edges initializes s.a. processor
9:	clock 1,1e6,1e7	Set clock to 1 MHz, free run
10:	apply ‘R/W’, 1	Set r.a.m.s to Read
11:	for I = 1 to 8	Start of loop for 8 signature measurements
12:	mcon N [I]	Close test node relay specified by variable N[I]
13:	sig “ ”, S$[1]	Measure and check signature against stored reference signature S$[1]
14:	if flg11; gto ‘DEBUG’	Test pass/fail flag; if fail, branch to debug subroutine
15:	next I	End of measurement loop
16:	dsp ‘BOARD PASSED’; gto ‘START’	Display PASS message
17:	‘DEBUG’:	Start of debug procedure
18:		

logic until a circuit element with good input signatures but bad output signature(s) is implicated as the faulty device.

Correct signatures at the decoder outputs imply a faulty memory device. Individual memory device functions may be isolated by varying the source of the START signal, broadening the address range for successive measurements of the data bus line where the faulty node was found during GO/NO-GO testing. The faulty device is easily determined on the basis of the START signal being used when the failure occurs. Another possibility is to continue using a START/STOP which encompasses the entire range of addresses but to select the enable pulses of individual memory elements for use as the CLOCK signal. In such a case, only data bus output for the single device will be monitored by the s.a. processor. A third possibility for isolating the faulty memory element is to take signatures on specified clock counts with or without varying the START signal source. The count parameter may be set to the number of addresses of the device(s) being tested with the START signal derived from the counter bit representing the first address to be monitored.

Figure 8 illustrates sample test system software to isolate a faulty memory device in a 32K memory system consisting of eight 4K devices. Variable arrays are used to tabulate test node locations, expected signatures and to set the order of the fault isolation sequence.

In summary, it has been shown that a typical memory board can be fully tested at speed with s.a. Fixturing requirements include a simple counter circuit for s.a. measurement stimulation and provision for writing r.a.m. data. A GO/NO-GO test can be conducted in less than one second by monitoring data bus signatures and fault isolation can be performed, typically in 5 to 15 seconds to the component level.

4.2 Testing a Microprocessor Board

The second s.a. test example is the board represented by the diagram of Fig. 9. It consists of a Motorola 6800

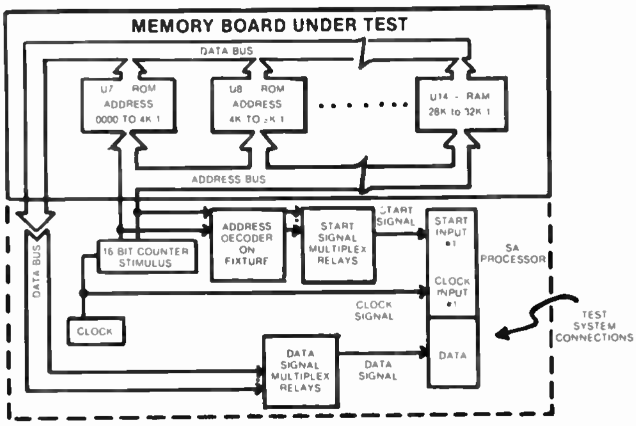


Fig. 8. Sample a.t.e. software for isolating faulty memory elements on a memory board using signatures taken only over the span of memory addressed for each 4K memory device.

Data relays set to monitor node where data bus failure occurred during GO/NO-GO test encompassing all addresses.
Array S[ ] holds relay data corresponding to address line which indicates first address of each device.
Array U$[ ] holds designators for each memory element; S$[ ] holds good signature data from reference device.
RAM previously initialized.

	Program Statement	*Description*
151:	for J = 1 to 8	Set up loop to test 8 devices
152:	mcon S[J], N[I]	Close start signal relay and data node relay
153:	sig '', S$[J], 4096	Take signatures for 4096 clock pulses
154:		(total memory of current device), compare
155:		to reference signature S$[J].
156:	if flg11; gsb 'PRINT FAULT'	Test flag to see if signature test passed.
157:		If not, go to subroutine to print fault message.
158:	next J	End of fault isolation loop
159:	gto 'RESTART'	After all tests, start new board test.
160:		
161:	'PRINT FAULT':	Entry point of subroutine to print fault message
162:	wrt 'PRINTER', 'REPLACE', U$[J]	Write device replacement message.
163:	ret	Return from fault message subroutine.

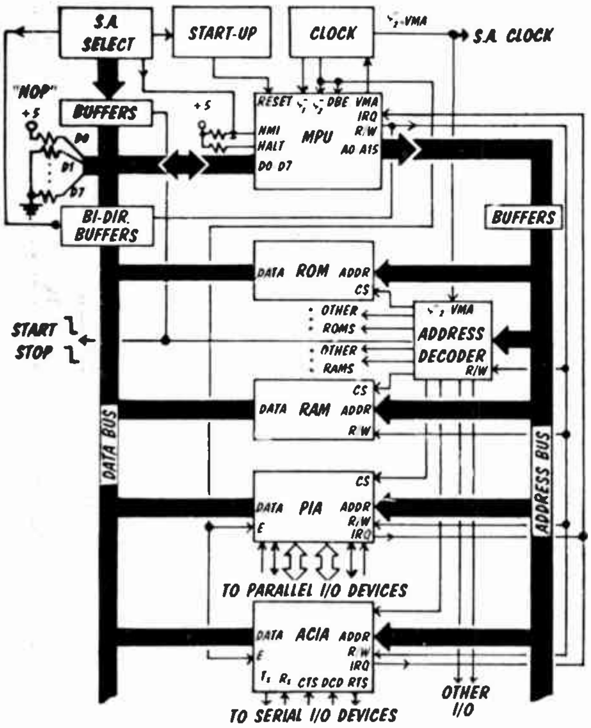


Fig. 9. A board with microprocessor and specialized peripheral chips can be effectively tested using s.a. Hardware and firmware designed into the board can enhance s.a. testability and aid in fault isolation to the component level.

microprocessor, an on-board clock, power-up support circuitry and various I/O circuitry. On-board memory elements include both r.o.m. and r.a.m. There are both hardware and software elements included to enhance signature analysis testability.

Architecturally, the board utilizes a 16-bit address bus and an 8-bit data bus. There are buffers on the address bus lines and bi-directional buffers on the data bus lines. Control lines employed by the board include read/write (R/W), valid memory address (VMA), data bus enable (DBE), and interrupt request (IRQ). R.o.m. and r.a.m. elements are driven by combinatorial address decoder logic.

The I/O circuits include a peripheral interface adapter (PIA) for parallel I/O devices such as printers, displays and keyboards, and an asynchronous communication interface adapter (ACIA) for serial I/O devices such as a terminal.

Provisions which have been made within the design requirements for s.a. testability include:

Signal lines which may be programmed via switches or a.t.e. system digital drivers to select vectors to run particular programs in r.o.m. Used in conjunction with a non-maskable interrupt (NMI) to cause the microprocessor to jump to a firmware test sequence.

Special firmware included in on-board r.o.m. and accessible as described above for exercising board elements during signature measurements.

A signal line which may be driven by the a.t.e. system to disable the data bus buffers and break the feedback path to the microprocessor for 'free-run' testing.

Pull-up and pull-down resistors which may be applied to the microprocessor input to provide a no-operation (NOP) instruction during 'free-run' testing.

The test strategy for the board includes first in-circuit shorts/opens and discrete component testing, followed by a functional test sequence including both free-run and internal stimulus driven tests:

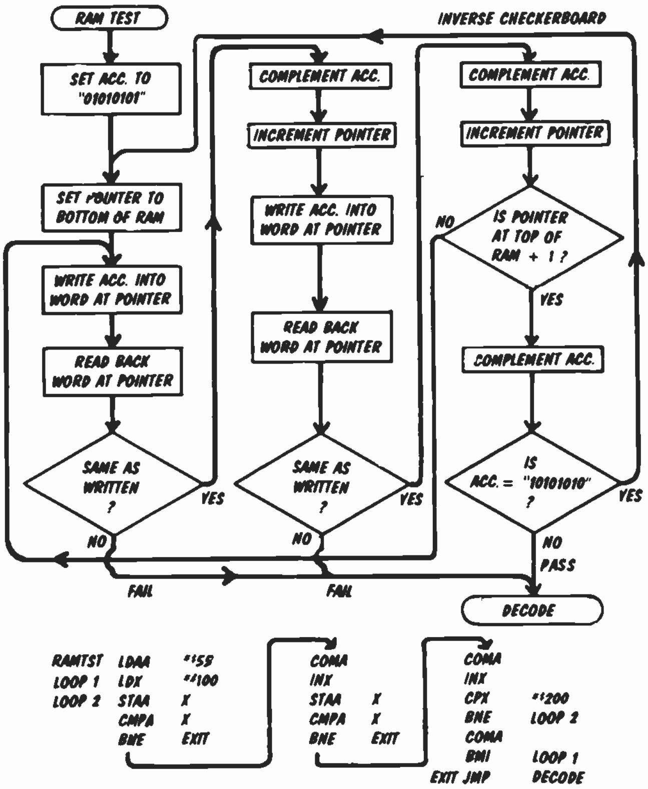
Free-run tests
  Verify that microprocessor can address memory properly
  Verify contents of r.o.m. which contains s.a. stimulus firmware
Internal s.a. stimulus tests
  Verify contents of all r.o.m.s
  Test r.a.m.s
  Test PIA
  Test ACIA

The free-run tests are initiated by electrically disabling the data bus buffers and applying a NOP instruction to the microprocessor via the pull-up/pull-down resistors. This has the same effect as applying a 16-bit counter to the address bus—the program counter of the processor will cycle through all possible addresses. S.a. CLOCK is derived from memory access control functions (ϕ_2 clock and valid memory address signals) while START/STOP signals are derived from address lines or signals decoded from address functions. As in the previous example, all addressing functions and all data storage functions except r.a.m. functions (which must be initialized) may be verified by checking the eight data bus lines during free run. In this case, a different approach will be taken to illustrate alternative SA test procedures.

First, address functions including the address bus buffers and decoder logic are verified by taking signatures on the address bus on both sides of the buffer and at the output nodes of the address decoder logic. Then, the content of r.o.m.s is verified by selecting START and STOP lines from the address bus corresponding to the low and high addresses of the r.o.m.s and monitoring signatures on the eight data bus lines. All of this is accomplished in the free-run mode and would require on the order of five seconds to run at a 1 MHz test rate. Any failures which occur are handled as discussed in the previous example. One exception to this might be a test of the board clock in the event of an apparent microprocessor failure as reflected in a faulty signature on the address bus. The clock into the processor could be checked with amplitude/frequency measurements or by measuring a constant high condition signature over the free-run window. Such a signature is a function of the number of clock pulses in the measurement window only as previously described.

Given that the r.o.m. containing the s.a. stimulus tests 'good', then that stimulus may be used for further tests on the board. The firmware for a particular test sequence is executed by controlling interrupt and vector address data to the processor as described previously. The firmware may be written to perform individual tests or to string individual tests together in any desirable sequence—all controlled by vectoring to the appropriate location in the r.o.m.

To perform r.a.m. tests, a firmware-based sequence such as that shown in Fig. 10 may be effectively utilized. First, the processor writes alternating ones and zeros into each word of r.a.m. Complementary patterns are used in even/odd locations. These are well-established patterns for testing r.a.m.s for adjacent bit and adjacent address shorts. Each word is read back and tested by the processor. After all addresses are checked, the patterns in each address are complemented and the procedure is repeated. If any cell fails, a flag is set (not explicitly represented in Fig. 10) to register the failure. At the end of each r.a.m. test, the flag will be checked and the firmware will take one of two different paths depending upon whether a PASS or FAIL condition occurs. If the signature of a constant high condition is monitored during this r.a.m. write/read procedure, a different signature will be registered for each pass/fail condition (since the test signature will reflect the number of clock pulses required to execute the firmware-based procedure).



```
RAMTST  LDAA   #$55
LOOP 1  LDX    #$100
LOOP 2  STAA   X
        CMPA   X
        BNE    EXIT
        COMA
        INX
        STAA   X
        CMPA   X
        BNE    EXIT
        COMA
        INX
        CPX    #$200
        BNE    LOOP 2
        COMA
        BMI    LOOP 1
EXIT    JMP    DECODE
```

Fig. 10. Sample algorithm executed from on-board firmware while signatures are collected by a.t.e. for r.a.m. tests. Firmware can be designed so that a single signature in conjunction with microprocessor data processing capability can indicate faulty or correct r.a.m. operation and which, if any, r.a.m. is faulty.

A table of signatures for all pass/fail conditions may be established within the a.t.e. test program. The r.a.m.s can also be checked by monitoring the data bus during the read/write sequence. This would require eight signature measurements over eight identical stimulation cycles. By monitoring the high-level signal and having the microprocessor perform the data check function, the same test is executed on the basis of one signature, one stimulation cycle. In the event of a r.a.m. failure, a troubleshooting procedure may be executed as described for the memory board example to isolate to the faulty device.

The PIA provides two eight-bit ports which may be programmed for either input or output functions. The two ports act like latches. Control lines define the data direction and handshaking schemes for passing data. The PIA is effectively stimulated via 'PIA' routines in the s.a. stimulus r.o.m. Test system relays can be used to connect the two I/O ports together at the board edge connector. Then, one port can be programmed to output while the other is configured as input. Signatures may be taken directly on data bus lines to verify proper activity for virtually all possible combinations of the data and control signals, or the processor itself can be programmed to perform data check functions while the high line signature is monitored as for the r.a.m. tests. After tests are completed for one combination, the input/output functions can be reversed and the test procedure repeated. The PIA test firmware can be written to stimulate the device as it is used in the final application.

The ACIA is similar in nature to the PIA except that data transfer may be asynchronous to the processor clock and one port is dedicated for the transmit functions and a second port is dedicated to receive functions. Again, if the two ports are connected together, firmware in the s.a. r.o.m. may be used to exercise the device. However, it will be necessary to make the test synchronous to some reference clock in order to use the normal s.a. test mode. If this is not possible, then nodal activity may be characterized by taking a high level signal signature while using the test node signal as s.a. CLOCK. The signature will thus test that the correct number of transitions occur on the test node.

The a.t.e. test program can be written to perform an efficient GO/NO-GO test on the board by using a free-run test to verify the board kernel and r.o.m.s. Then r.a.m. and peripheral firmware may be executed while monitoring the high level signature as described to quickly verify correct or incorrect operation. If faulty signatures occur, some faults will be directly specified by the high line signature. In other cases, tracing algorithms will be required to isolate to the faulty component level.

Signature analysis can be effectively applied at normal operating speeds to test a board with a microprocessor and auxiliary peripheral chips. Typically, a few hundred bytes of firmware or less (depending upon board complexity), in conjunction with the processing capabilities of the microprocessor, can be used to verify normal operating modes without knowledge of the internal logic structure of the devices used in the board design.

5 S.A. for L.S.I. Board Testing—Summary

Signature Analysis is an effective method for a.t.e.-based testing of printed circuit assemblies which include l.s.i. devices. When using s.a., the tester is synchronized to the device under test and the testing is typically performed at megahertz rates. A large number of microprocessor instructions can be tested using a short a.t.e. test program and the entire contents of r.a.m./r.o.m. verified in relatively short test times. L.s.i. devices may, thus, be thoroughly exercised to achieve high operational confidence—encompassing at speed, timing related faults which are often more difficult and costly to detect in the production test flow.

Signature analysis imposes no pattern length limitations. Since a compression technique is used, the measurement unit performs no comparisons on the input data stream until the end of the test sequence. This obviates the need for r.a.m.-backed receivers and minimizes both tester memory requirements and the processing time in achieving pass/fail decisions. Thus, s.a. may help minimize both tester and test time costs. In an a.t.e. environment, test stimulation may be effectively generated either internally or externally to the device under test. Test patterns are often directly related to the application software. With the measurement capabilities of a.t.e., the stimulus may be either a repetitive or single-cycle signal.

The measurement technique of s.a. is not dependent upon the logic structure of the circuit being tested. Although the stimulus may vary somewhat depending, for example, upon the processor type (one processor test may generate START/STOP on the basis of address decoding whereas a test for another processor may use an I/O line for the same purpose), the a.t.e. software, the measurement approach, and fault isolation processes are largely the same for all types of a generic class of circuits.

In general, s.a. can be most effectively utilized when the designer of the board is knowledgeable of the technique and plans for the fact that s.a. production testing is to be employed. Considerations for accomplishing this objective and examples of s.a. designed-in testability may be found in References 11, 12, and 13. Designing s.a. into a microprocessor-based board may require dedicating a small portion of the on-board memory for the 's.a. r.o.m.'. This memory space can be utilized by the processor to exercise itself and other devices on the board.

'Designed-in' s.a. testability, such as on-board stimulus, can make s.a. an effective test technique for both production test and field service test applications. With stimulus generated by the unit under test itself or a simply-connected external r.o.m., s.a. lends itself to use with portable field service instrumentation. The compatability of s.a. in production and field service can minimize the cost of developing product test approaches. S.a. can often reduce warranty costs by eliminating the need for board exchange with its inherent service-module inventory and typically high administrative and handling costs.

Signature analysis is not, however, without its limitations. Designing-in s.a. testability may add to product cost, although this cost may well be recovered in reduced testing cost. S.a. is a synchronous technique. Any bit stream that is examined during a measurement period has to be synchronized to a clock. Hazards which exist in the board or logic races generated by the stimulus could cause unstable signatures. Obviously, it is far preferable to eliminate such hazards and races from the board before testing. If this is not possible, the user must choose the measurement window in a way that will exclude these uncertain data from entering the measurement cycle. 'Don't care' conditions on data or address busses may be handled by choosing a clock that is gated by a data valid signal. Asynchronous signals can also be measured using s.a. processor hardware by monitoring the high line signal while the test node signal is used to drive the s.a. clock input.

As in any other technique of testing, signature analysis requires a set of stimulus patterns that functionally test various components and propagate any possible faults to a measurement point. For devices that are directly connected or are readily accessible to the stimulus, it is usually quite simple to generate a high-confidence test pattern. For devices that are not readily accessible to the stimulus or are a part of a deep sequential circuit, it requires careful effort to generate a high confidence test pattern. However, by using test sequences directly related to the applications environment, a high confidence level can usually be obtained.

Signature analysis is being effectively employed as an a.t.e.-based test tool for l.s.i.-based board testing by a variety of users. It offers unique alternatives to other test methods and can provide high test confidence at reasonable cost for both production and field testing.

6 References

1 '5004A Signature Analyzer', Technical Data, Hewlett-Packard Publication Number 02-5952-7464D, April 1977.

2 LeBoss, B., 'L.s.i.-board test bedevils users', *Electronics*, **51**, pp 81–2, 26th October 1978.

3 'Automated systems for l.s.i. device testing,' *Electronics Test*, May 1979, pp. 14–30.

4 DeSena, A., 'Automated board testing', *Electronics Test*, March 1979, pp. 32–40.

5 Francis, R., 'Real time test methods for m.p.u.-based products', *Electronics Test*, March 1979, pp. 42–6.

6 Sheldon, C., 'Understanding and solving the problems of l.s.i.-based boards', *J. ATE*, Spring 1978, pp. 4–5.

7 Bisset, S., 'L.s.i. tester gets microprocessors to generate their own test patterns', *Electronics*, **51**, pp. 141–5, 25th October 1978.

8 Peterson, W. W. and Weldon, E. J., 'Error Correcting Codes', (MIT Press, Cambridge, Mass., 1972.)

9 Frohwerk, R., 'Signature analysis: a new digital field service method', *Hewlett-Packard J.* **28**, no. 5, pp. 2–8, May 1977.

10 Gordon, G. and Nadig, H., 'Hexadecimal signatures identify trouble spots in microprocessor systems', *Electronics*, **50**, pp. 89–96, 3rd March 1977.

11 'Designers guide to Signature Analysis', Application Note 222, Hewlett-Packard Publication Number 02-5952-7465, April 1977.

12 'Application Articles on Signature Analysis', Application Note 222–2, Hewlett-Packard Publication Number 02-5952-7542, May 1979.

13 'Implementing Signature Analysis for Production Testing', Application Note 222-1, Hewlett-Packard Publication Number 5952–8785.

14 Firooz, K., 'Signature analysis—a technique for board test and field service applications', presented at Boston ATE Show, June 1979.

Manuscript in final form received by the Institution on 29th August 1980
(Paper No. 1969/MI 17)

The Authors

Rick Humphrey is a 1970 B.S.E.E. graduate of the University of Louisville and a 1971 M.S. graduate of the same university. He was employed by Texas Instruments in Dallas for five years working on Automation Projects for Microwave Instrumentation Systems before joining Hewlett Packard in November 1977. He now works as an Application Engineer on circuit test products.

A native of Iran, **Kamran Firooz** is a 1972 B.S.E.E. graduate of Louisiana State University and a 1974 M.S.E.E. graduate of Ohio State University. With Hewlett Packard since 1974, he has contributed to the design of the digital section of the 3060A Board Test System and has also worked as R&D project manager for this equipment.