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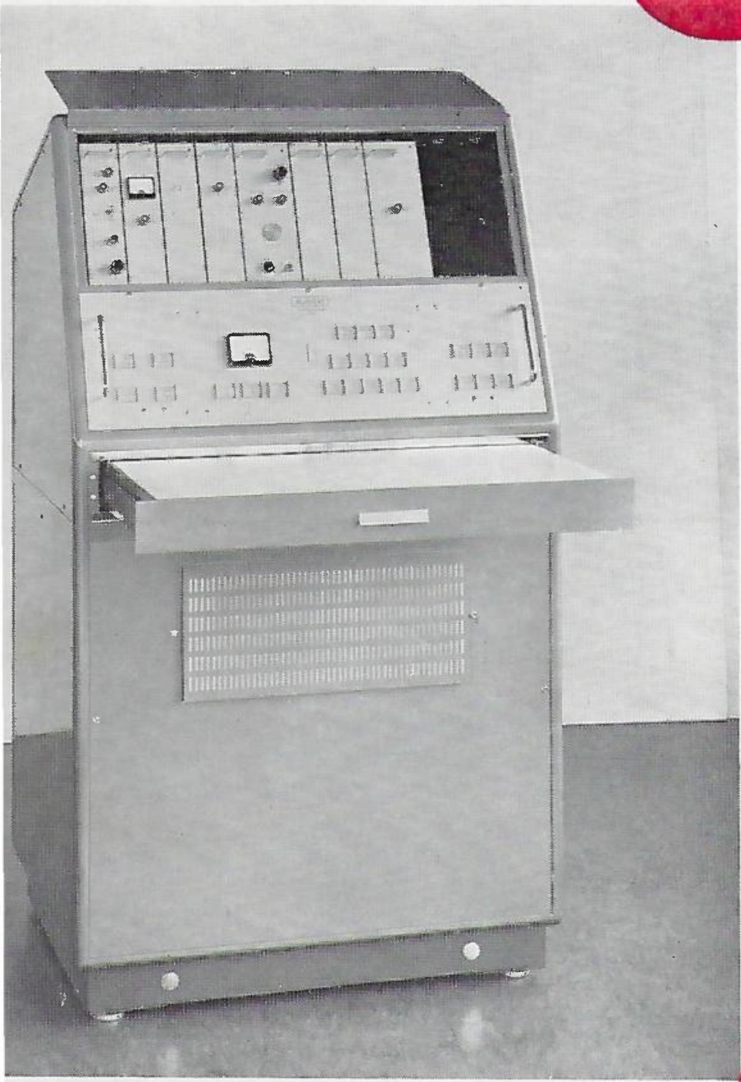
IN THIS ISSUE



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The
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of Australia

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BOARD OF EDITORS

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*For addresses see page 229.

TECHNICAL SUB-PROFESSIONAL WORK IN THE COMMONWEALTH SERVICE

Editorial Note: This address was presented by Sir Fredrick Wheeler, C.B.E., Chairman of the Public Service Board, to the Canberra Division of the Institution of Engineers, Australia on the occasion of its Fortieth Annual General Meeting on 26th April, 1967. It is published with the kind permission of the Institution.

Mr. Chairman, gentlemen. I am grateful for your kind invitation to me to attend this your Fortieth Annual General Meeting, and to have the opportunity to address you. I have chosen a subject which is, I think, of interest to those engaged in professional work, particularly to professional engineers.

About twelve months ago the Public Service Board established a committee comprising a research scientist from the Australian Defence Scientific Service and an engineer from the Post Office as well as a member of the Board's own staff to undertake a comprehensive review of the technical and drafting grades structure within the Commonwealth Service. It became evident in the course of this review that it was desirable to extend the exercise to embrace a study of the concept of the whole technical sub-professional area and this in fact has been done.

It is perhaps appropriate for me at this stage to indicate a little more clearly what I mean by the term technical sub-professional. As we in the Board see it he is a person qualified by technical training and practical experience in a technical area who works largely according to established techniques at a level generally between that of a skilled tradesman and a professionally qualified technologist. The tradesman boundary may be absent in some scientific disciplines. In some circumstances he may be required to supervise the work of subordinate sub-professional, tradesman or other technical groups, but his work is separate and distinct from a foreman tradesman. The technical areas involved include most branches of engineering, the physical and biological sciences, and medical science in the medical laboratory environment.

This definition is in fact very close to definitions of technicians promulgated by various other bodies. (While these people are frequently referred to as "technicians" both overseas and in industry, in the Commonwealth Service this could lead to confusion with the large group of officers designated as Technician in the Post Office and a few other departments.) For example, in 1965, your Federal Council pointed to the existence of a group —

> "operating in the area between the professional engineers and the tradesmen whose members have separate and distinct but complementary functions . . . It is recommended that 'Engineering Technician' be adopted as the general term to describe the members of this group".

The Association of Professional Engineers of Australia expressed its view on the place of the "Technician" in November, 1965 in these terms —

> "The general vocational relationship of engineering technicians to professional engineers and to the trades is becoming understood. The employment of engineering technicians must complement and confirm this relationship. The employment of tradesmen has been established reasonably for many years. The employment of professional engineers has been evaluated more recently and a general standard of salary levels presented. General 'upper' and 'lower' boundary conditions to the employment of technicians are therefore indicated and the importance of both of these to the satisfactory employment of technicians must be recognised".

In another area the Royal Australian Chemical Institute, in the report of their Technicians Training Committee in 1964, accepted the term "Technician" as applying to any technical employee whose work required the application of technical knowledge and skill higher than that of a tradesman but below that of a professionally qualified engineer or scientist. The Institute also pointed out that the lower boundary of tradesmen present in engineering fields may be absent in science-based technician activities.

Turning to overseas developments we note that because of the need for reshaping the technical workforce to meet technological advances, the area between the tradesman — where this lower boundary exists — and the professionally qualified technologist has been the subject of much attention in recent years in industrialised nations such as Britain, the U.S.A. and so on.

In the United Kingdom, for example, a good deal of effort has been devoted to delineating more clearly the contribution which sub-professionals might be expected to make and also to assessing sub-professional training requirements. A number of White Papers encompassing these matters were published by the British Government between 1956 and 1962. The formation of the Institution of Electrical and Electronics Technician Engineers in 1965 was another significant development. At the Institution's inaugural meeting the Postmaster-General, the Right Hon. Anthony Wedgewood Benn, M.P., speaking for the Government referred to the —

> "enormous importance which (the Government) attach(es) to the setting up of the I.E.E.T.E."

He went on to say —

> "the formation of this new learned society and the contribution that it could make in raising the status, the efficiency and the qualifications of the technician engineer is something that will be of great value, and I can assure you that it is very much welcomed by the Government".

The development of the technician in the United States gained considerable stimulus from the National Defence Education Act 1958 and the Vocational Education Act of 1963. These Acts provided financial support from Federal funds for technical education related to defence requirements, and resulted in an expansion in the enrolment of full-time student technicians from 20,000 at 260 schools in 1958 to 90,000 at nearly 800 schools in 1964. Over the same period the number of students enrolled for sub-professional training in other than full time courses increased by 236% to a total of 220,000 students in 1964.

Perhaps the world-wide interest in the topic is best epitomised by the Expert Conference on the Education and Training of Technicians held in October 1966 under the auspices of the Commonwealth Education Liaison Committee. The conference was attended by representatives of twenty independent Commonwealth countries and four British Territories. Its report, which has recently become available, represents a valuable collection of the views and work of those expert in this field.

Coming back to Australia, I mention that some large employers have, for many years, been attempting, in a practical way, to develop their own effective sub-professional work forces. The major companies, if I may select examples, who have been actively engaged in the training of sub-professionals are The Broken Hill Proprietary Company Limited and the Electrolytic Zinc Company of Australasia Limited. A number of Government instrumentalities such as the Victorian State Electricity Commission have also been active in this area for quite a time. In addition efforts have been directed towards the establishment of common standards in technician training throughout Australia and in January last year an important conference on this topic took place under the sponsorship of the Department of Labour and National Service between technical education authorities and representatives of a number of interested learned societies.

I would not like you to think that the Commonwealth Service is only now beginning to take an interest in this field. In the early 50's the Board felt it desirable to encourage and formalise developments in the sub-professional area and following an enquiry and report by a joint working party a sub-professional structure covering the so-called technical grades was set up late in 1956. These grades established a common structure in which to absorb existing sub-professional positions such as experimental assistants and production planning officers and were designed to provide a medium for orderly recruitment and development to meet future needs as then foreseen.

The growth of the technical and drafting grades since then has been remarkable. By 1960 there were almost 4,900 positions established and by 1966 the numbers had grown to over 7,300. While the technical and drafting grades do not wholly represent the sub-professional component in the Service I think that this growth rate is strongly indicative of the need felt for sub-professional staff in many areas of Commonwleath Service employment.

Although the 1956 reorganisation of the technical and drafting grades gave the Service a basic structure within which to meet the demand for sub-professional effort, as I have just mentioned this stucture has never been completely synonymous with the sub-professional area. Substantial elements which seem to be of a genuinely technical sub-professional nature have developed outside the structure and some work of a lower order has been included in the structure. We are not alone in this situation of lack of definition — it is typical of industry as a whole that the need for a substantial sub-professional work force has outstripped the formalisation of organisational and training arrangements.

Flexibility in a developing situation often has advantages. There may come a time, however, when such advantages are outweighed by the concomitant lack of order. It is the Board's view that such a situation is now rapidly approaching in the Commonwealth Service and hence the extensive study of the sub-professional area to which I have referred has been put in hand. I have every reason to believe that as the study progresses it will contribute materially to a clarification of the existing situation and to the establishment of sound guidelines for future development within the Service.

It is interesting to note that the rate of growth of professional positions requiring full qualifications has been much less than for the sub-professional area, e.g. from 1960 to 1966 the number of professional positions in the Service increased from about 6,900 to 7,900, a growth of just less than 15% compared with the increase of almost 50% in the number of technical and drafting grades positions in the Service over the same period. It is my belief that the **ratio** of sub-professionals will continue to increase rapidly, at least over the next decade.

It would be an understandable reaction for a professional looking into the future to ask "What does this growth in sub-professionals mean for me?" First of all I am sure that it does **not** mean any decrease in opportunities for genuinely professional employment. You will have noted from the figures I have quoted that the professional area of Commonwealth Service employment, although not growing at the same rate as the sub-professional area, has nevertheless grown quite significantly. There is no evidence that has come to my attention of any limiting of professional employment opportunities as a result of the growth in sub-professional employment, nor do I see any such possibility in an expanding economy such as ours where one of our greater needs will continue to be that for professional expertise and highly trained manpower.

Rather, I see the effect of the developing use of sub-professionals to lie in another direction altogether. Professionally trained manpower is one of our scarcest resources and therefore it is essential that the most effective use be made of it. I think it is common knowledge that before the development of the technical grades in the Commonwealth Service over the past ten years not all professional officers were employed exclusively on work demanding the full use of their professional skills. The situation has, I believe, now improved. There may be very good reasons why on occasions a professional officer may need to undertake some duties which do not require his full professional training. Nevertheless it is, I think, an acceptable general proposition that the more this situation can be confined, the better.

The situation can only be confined by the full development of the possibilities inherent in the concept of the sub-professional. In this context I quote the views of the Association of Professional Engineers of Australia as they were expressed in 1965 —

> "The problem of qualified engineers being employed on technician duties is a lessening one since the advent of the Professional Engineers Award. However, professional engineers continuously must be self-critical of the level to which they are working and the level of working of engineering technicians must not be limited by the fact that engineers may, on occasions, perform tasks which are not professional engineering duties. The converse problem, the employment of engineering technicians for the attempted performance of professional engineering duties, is one which is serious for the Profession and also the community, which relies upon the Profession to regulate engineering performance and to achieve this with adequate efficiency and safety".

I am in full agreement with these views.

Lines of demarcation are not always easy to draw. It would be foolish for me to deny that there is a grey area where the work of the well experienced sub-professional shades into that of the qualified professional. It is the Board's experience however, that such grey areas do not constitute a major problem where satisfactory standards are established. It is certainly the Board's intention to ensure as far as it is practicable that qualified professional officers are employed on professional work.

This does not mean, however, that the Board believes that particular duties will always need to be performed by professional officers. We are dealing in many areas with a dynamic situation in which the professional duties of today tend to become the sub-professional duties of tomorrow. Perhaps I could quote to illustrate this point from a paper entitled "The Engineering Technician in Australia" presented to a number of Divisions of your Institution in 1965 by one of your members, Mr. B. E. Lloyd, in which the author says —

> "In a progressive situation of technological development such as that prevailing in Australia there is a continuous process of downward transfer of duties whereby the professional activities of today become the standard routine of tomorrow. If professional people can be relieved of the more routine tasks, they are then free to proceed to fields of higher creative effort. This process tends to increase rather than decrease the demand for professional people because the level of activity as a whole is stepped up. But such progression depends entirely upon the availability of appropriately educated sub-professional people upon whom the work can devolve."

Perhaps I could take up the final point made by Mr. Lloyd in that quotation, i.e. the importance of appropriate education for sub-professional people. Within the scientific and technological areas of the Commonwealth Service the level of academic qualifications required for professional officers is normally well defined and recruitment and training schemes for these officers are conducted on a clearly defined and systematic basis. Similarly, tradesmen are recruited and trained in a clearly defined way by means of apprenticeship.

No such clearly defined scheme has yet been introduced to cover the intermediate sub-professional group. The increasing significance of this group makes it imperative that due attention should be paid to the necessary training and education requirements. At the time of the introduction of the technical and drafting grades structure in 1956 the Board recognised the possible future need to introduce schemes of formal training in some areas and the allied possibility of introducing formal educational standards. There were difficulties in establishing such standards where in some cases what was required were special aptitude and experience rather than formal training, and where suitable technical training courses were not available. These difficulties may not now be as daunting as they appeared in 1956.

Because of the diversity of sub-professional work, the appropriate form of training naturally differs according to the needs of the various environments and disciplines in which sub-professionals are employed and must necessarily be devised to meet the needs of each individual area. At this stage it is possible only to say that in all probability distinctive patterns of training and education will evolve to cover both those who are recruited into sub-professional areas immediately from school and those who enter at a more mature age, e.g. those who complete a trades apprenticeship and obtain some practical experience in essentially manipulative functions before entering work of a sub-professional nature.

Many of the decisions which have to be taken in this regard will be influenced in a large measure by the availability of suitable courses in the technical education system. It is no criticism of this system which has contributed so greatly to this country's technological progress to say that in many areas the courses provided are as yet not fully reflective of the country's needs for sub-professional training. Rather it is the case that employers generally — and in fairness I must include the Commonwealth Service among them — have not been able to adequately define their needs to the technical education system. But as future trends have become clearer, so too has the responsibility of employers to define and make known their needs. I have mentioned earlier the study that the Board is currently undertaking of the whole sub-professional area of Commonwealth Service employment. If the only result of this review were a clarification of our training and education needs in this area I would regard the effort as well worth while.

The establishment of distinct education and training patterns will play an important part in according proper status to the sub-professional. In the Report of the Expert Conference on the Education and Training of Technicians held in October, 1966, under the auspices of the Commonwealth Education Liaison Committee, to which I have already referred, the point is made that —

> "There was unanimous agreement at the Conference that one of the key factors involved in the provision of proper education and training for technicians is the establishment of an understanding and appreciation of the status of the technician, both within industry and commerce, and within society. If the technician is to be accorded the recognition which he deserves, and desires, the public in general, and industry and commerce in particular, must be convinced of his quality and potential use to the community. This question of status, therefore, goes beyond the provision of proper salaries and other outward status symbols, important and necessary as these are. Again and again, delegates were concerned to emphasise the need to give technicians a recognisable career structure, adequately reflecting the importance of their position in the complex of industrial and commercial occupations. The technician is neither a 'failed' professional nor is he an up-graded craftsman. Training and education programmes for all types of technician must reflect this separate identity and the courses must be seen to exist in and for themselves; in words which run through the detailed discussions and detailed reports of the working groups 'technician courses must have their own integrity'."

In conclusion may I reiterate that I firmly believe that the full development of the potential of the sub-professional area of employment is a matter in which employers, professional institutions and indeed the community as a whole shares a very vital interest. My belief rests on the well recognised fact that the strength of a nation depends in large degree upon making maximum use of its human resources and on the fact that the sub-professional area of employment is becoming an increasingly more important element of the workforce.

TECHNICAL NEWS ITEM

AUTOMATIC DATA LOGGING FOR MONITORING TRANSMISSION LEVELS IN WIDE BAND CARRIER SYSTEMS

The Postmaster-General's Department has acquired a data logging system which is programmed to automatically measure and record the transmission levels of a number of selected communication circuits forming part of wide band carrier systems. The information is obtained in the form of a punched tape which can be used as an input to a computer for analysis.

To maintain a high standard of transmission quality in wide band carrier circuits used for the communication of speech telegraphy, facsimile, television and high speed data, it is necessary to ensure that the signal levels transmitted are maintained within close limits of magnitude irrespective of changes due to temperature and/or in the characteristics of the components.

Where fluctuations in level are excessive, automatic regulating equipment must be provided.

Since the cost of such regulating equipment is considerable (up to $100,000 for two ends of a fully equipped 12 kHz system), it is important that a decision as regards their application is arrived at only after thorough investigations have been made to justify the expenditure.

The data logging system is ideally suited for this purpose.

ENGINEERING ASPECTS OF SERVICE STANDARDS IN THE AUSTRALIAN TELEPHONE NETWORK

H. T. DAVIS, B.Sc., A.M.I.E. Aust., G. MOOT, A.M.I.E. Aust.,** and J. M. WALKER, A.M.I.E. Aust.****

Editorial Note: This article is reprinted from the Journal of Institution of Engineers, Australia, Volume 38, Number 7, September, 1966, with the kind permission of the Institution. The paper was presented at the 1966 Conference of the Institution at Newcastle, New South Wales.

The article and conference discussion will be of widespread interest to readers, integrating as they do, the service performance aspects of each of the major types of plant comprising a national telephone network.

INTRODUCTION

The telephone system exists to provide a service and the degree of satisfaction experienced by a subscriber is of the greatest importance to the telephone administration. Whilst the aim of a telephone administration is to make the service as good as possible, costs must be considered also; the problem is to strike an optimum balance between service performance and costs.

The following features of a telephone system affect the customers' satisfaction with the service provided —

(a) Availability of plant when required to provide the desired connection.
(b) Accuracy of setting up the connection.
(c) Reliability of service, i.e. freedom from faults and interruptions to the connection when established.
(d) Transmission quality, which determines the ease of conversation.

Overall performance of the telephone network is governed by the performance of the various components such as telephone instruments, subscriber's line to the exchange, exchange switching equipment and the links between exchanges, all of which are connected in tandem for the establishment of a call. Service reliability of each of these components is determined in part during the design and manufacturing stages, the aim being to achieve maximum reliability consistent with reasonable capital cost.

Advancing technology, the demand for more comprehensive facilities, and the need for reducing the capital costs have all resulted in a constant flow of improvements in the four main sections of the telephone networks, i.e., subscribers' equipment, line plant, exchange switching equipment, and long line equipment. A telephone network is built up over a period of years with plant purchased usually from different manufacturers throughout the world, and whilst designers and manufacturers in any one section must obviously take cognisance of developments in the other sections, it certainly does not follow that at any given time there is an optimum relative reliability of equipment in the different sections such as to give the best overall service performance at minimum operating cost. Indeed, a most important task of a telephone administration is to appraise the service reliability of the various components of a telephone network and advise designers and manufacturers of any new requirements in this field.

The service performance of the network is also determined by the level of maintenance applied to the plant and here again the operating administration seeks to distribute maintenance effort in the various sections of plant so as to achieve a satisfactory overall grade of service consistent with reasonable operating costs.

It can be said that service is improving continuously due to the improvement in facilities which occurs concurrently with expansion of the system and advancement in techniques. The need for improved performance is increased greatly by a number of developments which are taking place. These include the extension of subscriber dialling to the entire network and the likely extensive use of switched circuits for the transmission of digital data. The Australian telephone network, because of the geographic area covered and the concentration of population, presents some unique problems of maintaining standards.

This paper describes the current practice of the Australian Post Office in assessing service standards in the first instance and the maintenance and design techniques employed to provide the required service standards. First, there is a brief outline of the operation of a telephone network for a subscriber-dialled trunk call and this is followed by a discussion of the methods of assessing overall standards of service. In the next section is found an analysis of the trouble reports received from subscribers, a description of the method of handling these reports and an analysis of the faults in equipment at the subscribers' premises. The remaining sections contain an outline of the methods for maintaining service standards in automatic exchanges, the means of ensuring an adequate standard of transmission performance in the telephone network, a treatment of the service aspects of external plant, and a discussion of the maintenance of service standards in long line equipment.

OUTLINE OF A TELEPHONE SYSTEM

To appreciate those factors which influence the standard of service in a telephone network, an understanding of the essential features of a modern telephone network is essential. Fig. 1 illustrates the basic items of plant which are used in establishing a call from a subscriber in Newcastle to a subscriber in Sydney. Automatic dialling over this distance is known as S.T.D. (Subscriber Trunk Dialling) and the Australian Post Office plans that by 1975 some 65 per cent of trunk traffic will be handled entirely by the subscriber without the assistance of an operator.

The calling and called subscriber telephone instruments are connected

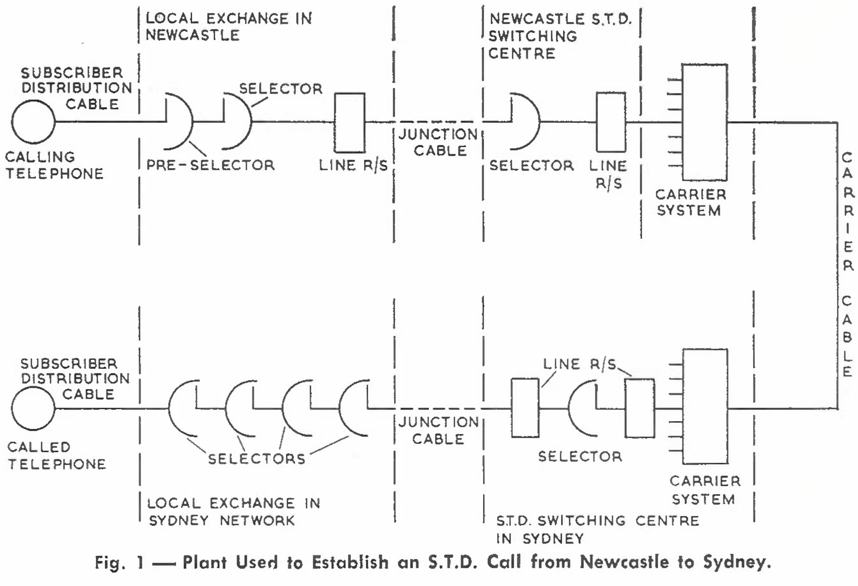

Fig. 1 — Plant Used to Establish an S.T.D. Call from Newcastle to Sydney.

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* Mr. Davis is Engineer Class 4, H.Q. Lines Section. See Vol. 13, No. 6, Page 502.
** Mr. Moot is Engineer Class 4, H.Q. Telephone Exchange Equipment Section. See Vol. 14, No. 4, Page 332.
*** Mr. Walker is Engineer Class 4, H.Q. Long Line Equipment Section. See Vol. 13, No. 3, Page 270.

to the respective local exchanges by means of a pair of wires, usually in underground cables. When the calling subscriber lifts the receiver, his line is connected to an automatic switch which responds to the electrical impulses generated by the dial. Thus, a Newcastle subscriber calling Sydney would first dial the digit "0" which causes the automatic switch in the originating exchange to select a junction line in an underground cable to the trunk exchange at Hamilton where a second switch is seized. The next digit dialled by the subscriber causes the switch at Hamilton to select a free trunk line to Sydney. Because of the long distance involved, the trunk lines between Sydney and Newcastle are derived by means of carrier systems operated over wires in an underground cable. The carrier system amplifies the speech currents and enables a number of telephone channels to be derived from one pair of wires. Further digits dialled by the subscriber set the switches in the Sydney exchanges to the subscriber's line being called.

The success of a telephone call depends on the reliable operation and proper interworking of telephone instruments, underground lines, telephone exchange switching equipment and long line equipment, connected in a complicated network extending over the whole country. Calls may fail due to faulty plant, or due to insufficient plant in telephone exchanges and the links between telephone exchanges to handle traffic under peak load conditions. If a satisfactory standard of service is to be provided, careful attention must be given to the following:—

(a) The basic reliability of the various items of plant. This is determined in the initial design stage, factory production techniques and procedures, and field installation techniques and procedures.
(b) The economic provision of sufficient switching plant and links between exchanges to meet peak traffic conditions.
(c) Adequate maintenance of the various items of plant.

The application of these principles to the various types of plant is described in the following sections. It is worth noting the following statistics on the value of Telecommunications plant in service throughout Australia.

Exchange equipment — $300 million
Exchange cables — $450 million
Ducts and conduits — $114 million
Aerial wires — $200 million
Subscribers' instruments and equipment — $136 million
Trunk equipment — $140 million.

The annual expenditure for maintaining this huge asset is of the order of $64 million.

OVERALL STANDARDS OF SERVICE

Introduction

There are three main methods of measurement used by telephone administrations for assessing the service performance of their telephone networks and the subscriber's satisfaction with the service:—

(a) Service assessment of live traffic.
(b) Statistics of subscriber trouble reports.
(c) Test calls set up by the administration.

The factors affecting telephone service performance are so complex that it cannot be adequately appraised by one of these alone. Methods (a) and (b) are described below and method (c) is discussed later.

Service Assessment of Live Traffic

The most fundamental method of assessing overall service performance given to the subscriber, and one used by practically every telephone administration, is the observation of live traffic. Selected Australian Post Office personnel are given remote access to some of the originating switches in each exchange so that the attempts to establish calls can be checked on a sampling basis. The observer is not aware of the calling subscriber's number and her function is to check that the correct number has been obtained, that speech transmission is satisfactory and that the metering is correct.

The percentages of calls, successful and unsuccessful for various reasons, for a typical network are as follows.—

Calls successful on first attempt	—70 per cent
Calls in which wanted subscriber is busy	—10 per cent
Calls on which wanted subscriber does not answer	— 8 per cent
Calls unsuccessful due to operating error	— 8 per cent
Calls encountering fault conditions and plant congestion	— 4 per cent

These statistics are representative of very large networks such as the Sydney network; for smaller networks up to 80 and 85 per cent of calls will be successful on the first attempt.

At least 18.0 per cent of call attempts fail for reasons beyond the control of the administration, i.e., the wanted party is busy or does not answer. Calls unsuccessful due to faults, i.e., calls on which a wrong number is obtained or the line "sounds dead" at the conclusion of dialling (i.e., no service tones are heard), must be kept to a practical minimum by proper design and adequate maintenance of the telephone plant.

Calls may also fail due to insufficient switching plant and junctions or trunks during busy hour periods. The caller receives Busy tone under this condition. An administration endeavours to keep these losses to a minimum consistent with reasonable capital cost.

Call failures due to subscriber operating error are also of concern to the administration. If the loss of calls due to subscriber error is high, it may be necessary to embark on a publicity campaign to correct this. Calls failing due to subscriber error unnecessarily occupy exchange switching plant and do not give any satisfaction to the subscriber, who is inclined to blame the administration for the failure. The more elaborate the facilities provided for the public, the greater is the risk of call failure due to mis-operation. An example is the correct dialling of 8- and 9-digit telephone numbers for S.T.D. operation.

Another factor not mentioned above is the transmission performance of the network. At present, observers make a subjective assessment of the ease with which the subscribers converse and they note any obviously bad instances of poor transmission. In the future, it is proposed to use speech volume meters to measure transmission performance.

As a general rule call failure rates due to subscriber operating error, plant congestion, and switching faults increase as the telephone networks increase in size. This is because more equipment, and frequently more complex equipment, is required to establish calls in the larger networks. Each additional exchange and junction or trunk line over which a call is switched increases the probability of a failure or defect of some type. One of the major problems of operating an S.T.D. network is to keep the overall call failure rate to a minimum. With manual switching of calls, the telephonist establishes the connection for the calling subscriber and thus shields him from any difficulties in establishing the connection. Also, she can check the transmission performance of the established connection and, if necessary, can re-establish the call. With purely automatic operation the subscriber does not have this direct assistance on each call and the administration must ensure that service performance is satisfactory by careful design and maintenance of the telephone system.

For S.T.D. traffic, the average call failure rate due to plant defects should not exceed 3.0 per cent. To this must be added losses due to plant congestion, which should not exceed 2.0 per cent.

Statistics of Subscriber Reports

A number of overseas administrations make extensive use of statistics of subscriber reports as a measure of service performance or subscriber satisfaction with the service, and the Australian Post Office is also about to use these statistics. Such statistics can, of course, be misleading in that a low reporting rate does not necessarily mean that subscribers are satisfied with service. It is a fact that subscribers can become tolerant of relatively poor service. Subscriber reports originate mainly from abrupt changes from the normal service performance.

An average of one trouble report or request for assistance from each subscriber during a year is a reasonably good achievement. This would apply to a residential service and would cover all reports due to obvious and sustained faults, and also requests for assistance when difficulty is encountered in obtaining a particular

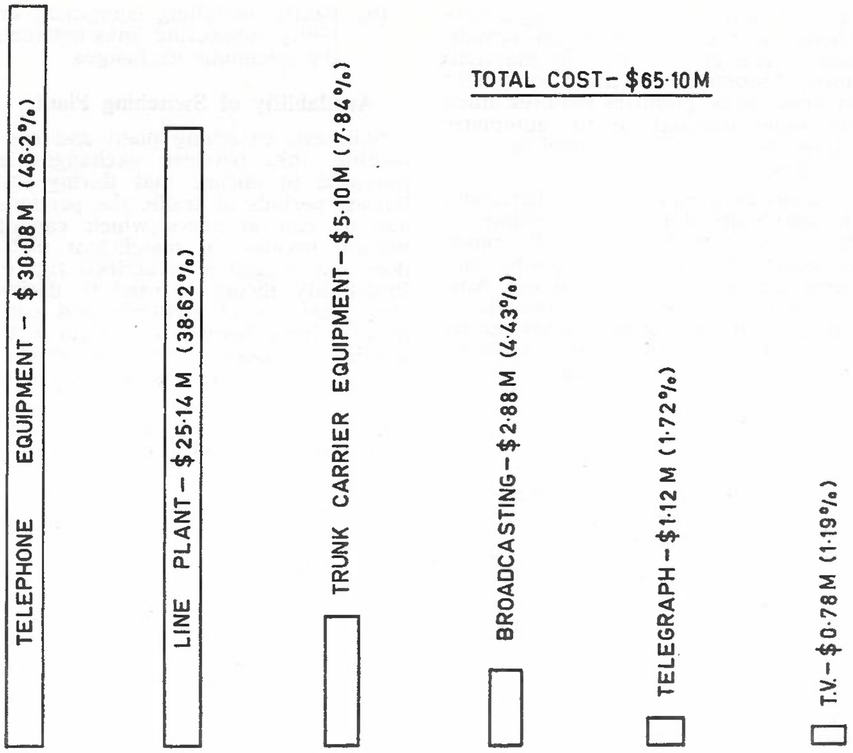


Fig. 2 — Maintenance Costs.

number, excluding cases where the number does not appear to answer or appears to be contiuously busy.

Service Performance Versus Maintenance Costs

Even with ample statistics of service performance in terms of service observation results and trouble report statistics, it is not easy to answer the question "What is a satisfactory standard of service?" The final decision is essentially subjective and a matter of personal opinion. Naturally, finance is a governing factor and the administration has to strike a compromise between service performance and the cost of providing it.

Fig. 2 sets out the major components of the maintenance costs incurred by the Australian Post Office for the year 1963/64. It will be seen that of the total of $65m., equipment in subscribers' premises and switching equipment in telephone exchanges accounted for just over $30m. Line plant accounted for $25.4m. There are considerable savings to be made by concentrated effort to improve productivity in the maintenance field, but any savings made must be balanced against the degradation of service which might result.

SUBSCRIBER TROUBLE REPORTS

Analysis of Trouble Reports

A subscriber may report trouble on his telephone service or seek assistance for the following reasons.—

(a) There is a definite fault evidently common to the telephone service and which affects all call attempts, e.g., a broken cord, faulty dial, noisy transmitter, etc.

(b) There is an intermittent fault which affects only a small percentage of calls, or the trouble may be of a temporary nature and only affecting calls to a given subscriber, e.g., the caller may encounter "no progress" or "wrong number" when calling a given number.

(c) A subscriber may seek assistance such as obtaining the details of a changed number or requesting a check of a subscriber who is not answering his 'phone or whose 'phone appears to be permanently busy.

Fig. 3 is an analysis of the subscriber reports during one month for one of our major networks. Thirty-three per cent of the reports were "repair", i.e., they required the attention of a technician to at least test the service, and if necessary remove a fault condition. The remaining 67 per cent of reports were requests for assistance under (b) and (c) above.

One may question whether it is part of the telephone administration's responsibility to check "wanted subscriber busy" and "wanted subscriber does not answer" conditions. Many administrations will not give this service to their customers.

When a subscriber "repair" report is received by the Service Centre, the particulars are passed on to an Engineering test desk for investigation. The testing technician obtains access to the subscriber's line by test access switches and conducts tests on the service to determine if in fact a fault does exist, and if it does, whether it is in the exchange equipment, the apparatus at the subscriber's premises, or the line plant. If a fault is proved to exist or suspected to exist, a faultman is despatched.

Fig. 4 is an analysis of the repair dockets for one month in a capital city network. Thirty-four per cent of the repairs are marked "Right When Tested", i.e., the testing technician could not find sufficient evidence of a fault condition.

Some of the faults proved by the initial testing to be in the exchange equipment, subscribers' equipment or line plant are subsequently classified as "Found O.K.", i.e., the faultman could not detect or discover a fault to cause the complaint. The reasons for this and the proportion of faults marked "Right When Tested" is simply that many fault conditions take a considerable time to develop to the stage of seriously interfering with service. In the initial stages the fault may cause intermittent and minor trouble only, and if it is reported at this stage it may not be detected by the test or by the subsequent inspections of the plant by the faultman.

Though public telephones are relatively few in number, they account for 13.6 per cent of all trouble reports and 15 per cent of all repairs. Vandalism, coin chutes blocked by bent coins and attempts to obtain free calls from the Service Positions account for this. The introduction of the single-coin 5-cent public telephone has considerably reduced the incidence of trouble from public telephones.

Speed of Attention to Faults

Prompt attention to subscribers' reports of service troubles will do much to recoup the loss of prestige the administration suffers because of the faults. This applies particularly to "no-service" troubles, i.e., the subscriber cannot make or receive calls. Whilst any subscriber would appreciate attention to a "no-service" fault within the hour, most would be content to wait till the next day for replacement of a frayed telephone instrument cord which is not affecting the actual service. The Australian Post Office is developing the so-called "no service time commitment" system whereby the subscriber is advised of the expected time of arrival of a faultman at the premises to investigate the fault. The aim is to attend to "no service" faults within 4 hours, but this is not practicable in remote areas.

Faults in subscribers' equipment and exchange equipment can usually be cleared with little effort but faults in line plant may require a day's work to remove.

Faults in Subscribers' Equipment

In telephone instruments the components which cause most trouble are transmitters, cords and dials. Carbon transmitters are used because of their high power output, but they have the disadvantage that, after a few years, noise may develop or the output may fall due to packing or deterioration of the carbon granules in the transmitter. The estimated average life for a transmitter is 6 years.

Although tensile conductors are used, telephone cords are just as much a maintenance problem as the cords used in domestic appliances. They become fractured and are subject to damage by accident and twisting. Braided cords are affected by moisture also, but this problem is being overcome with modern plastic sheathed cords.

The telephone dial also is a maintenance problem; with mechanical wear and tear, the shape and timing of the electrical pulses departs from the desired standards. In particular the speed of a dial changes with use. The type of telephone instrument which was standard up to 1960 would have a fault on it once every 3-4 years (national average) but the new standard instrument, the Color-Phone, will give a better performance.

More complicated items of subscribers' equipment such as switchboards, inter-communication units and special switching units, have a higher incidence of faults than has a single telephone. Cords and lamps on switchboards are major items in maintenance. Automatic switching equipment in subscribers' premises requires much the same approach as for automatic equipment in public telephone exchanges.

Subscribers' equipment is increasing in complexity due to the demand for more elaborate facilities. The range of equipment is also increasing and these trends have required the Australian Post Office to use more highly skilled staff. Whilst specialists can be employed for certain types of equipment, it is undesirable to have a faultman arrive at the subscriber's premises and then have to call for a specialist.

EXCHANGE SWITCHING EQUIPMENT

Causes of Service Failures in Telephone Exchanges

Calls many fail in the telephone switching network for the following reasons.—

(a) Insufficient plant to meet peak traffic loads.

(b) Faulty switching equipment or faulty connecting links between the telephone exchanges.

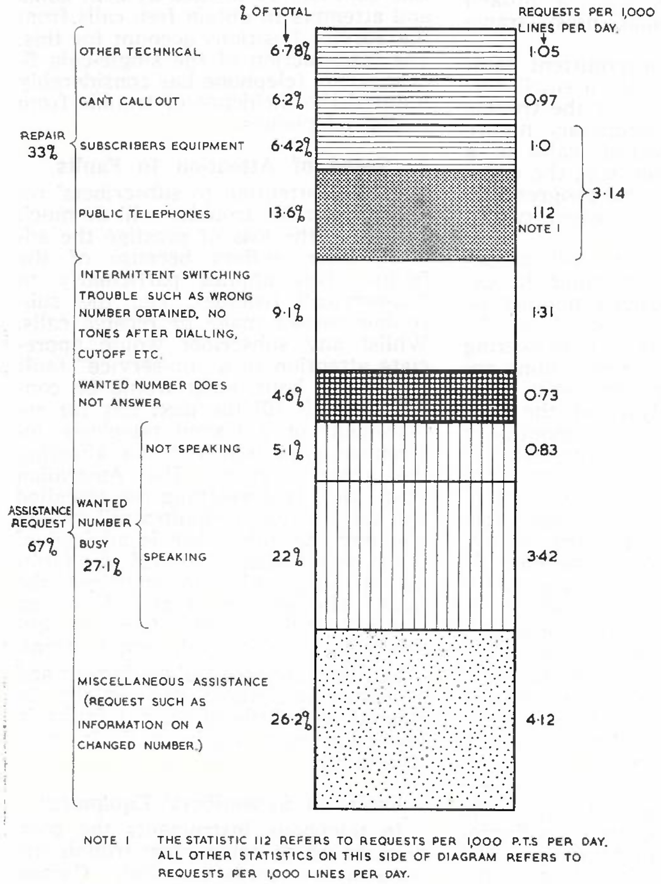
Availability of Switching Plant

Sufficient switching plant and connecting links between exchanges is provided to ensure that during the busiest periods of traffic the percentage of call attempts which cannot mature because of insufficient plant does not exceed a prescribed figure. Probability theory is used to derive the quantities of switches and connecting links betweeen exchanges to provide the desired grade of service.

The basic objective is that, for calls within a metropolitan network during the busy hour, the probability of a call failing due to insufficient plant shall not be worse than 1 chance in 100. The corresponding figure for S.T.D. traffic is 1 chance in 50.

Faults in Switching Plant

The great bulk of the switching plant in Australian telephone networks is known as step-by-step switching equipment in which a two-motion electro-mechanical switch is the basic switching mechanism. In



NOTE 1 THE STATISTIC 112 REFERS TO REQUESTS PER 1,000 P.T.S PER DAY. ALL OTHER STATISTICS ON THIS SIDE OF DIAGRAM REFERS TO REQUESTS PER 1,000 LINES PER DAY.

Fig. 3.

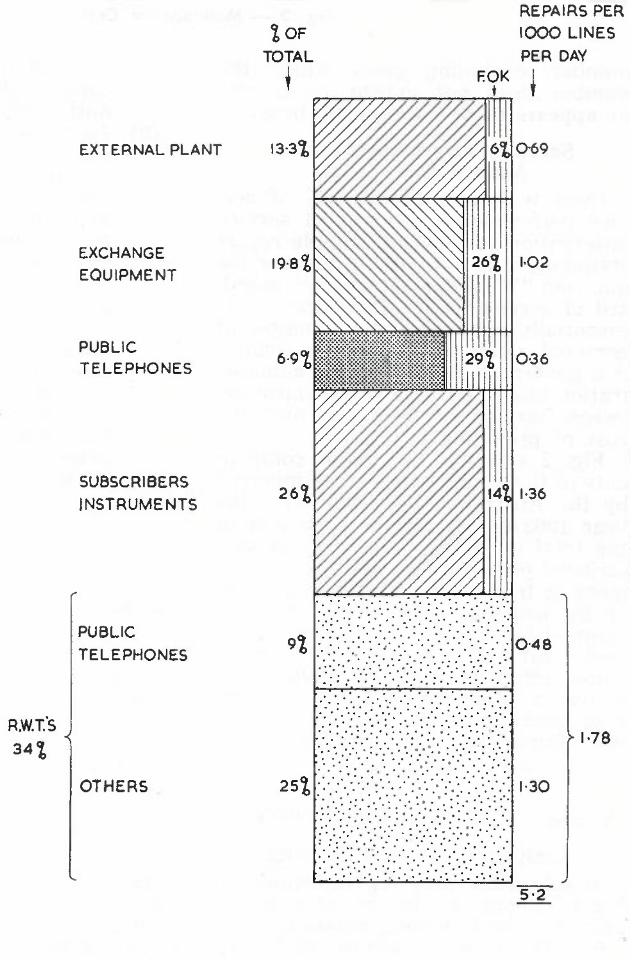


Fig. 4.

the simple 4-digit telephone exchange system shown in Fig. 5, the first digit vertically positions the switching wipers of the 1st selector which cuts in on the horizontal level and searches for a free outlet to the 2nd selectors. The 2nd selector is positioned vertically by the second digit and it searches for a free final selector. The 3rd digit positions the final selector vertically and the 4th digit positions it horizontally. The speech path is established between the calling and called subscribers through the wipers of the switches making contact with the outlets on the switch banks and also via the operated contacts of electro-mechanical relays in the switches.

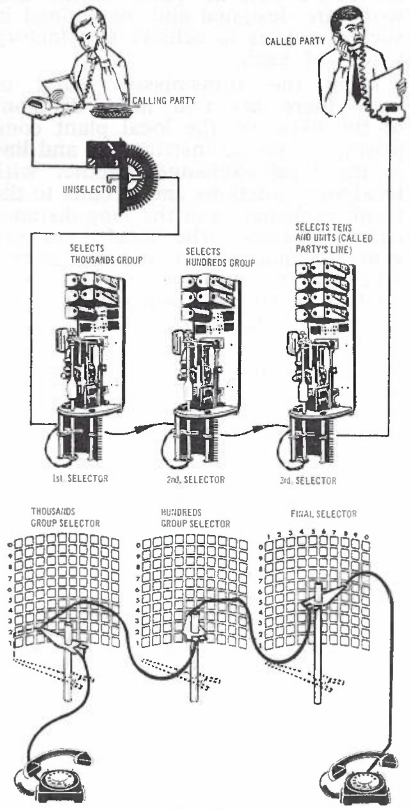


Fig. 5.

Some of the more common fault conditions in telephone exchanges are:

(a) The switching mechanism is complicated mechanically and after many thousands of operations, wear and tear can cause loss of mechanical adjustment and hence faulty operation, i.e., a switch may fail to operate or it may switch to an incorrect level or outlet.

(b) The switch is designed to respond to electrical pulses received from the telephone dial. These impulses may become distorted due to worn contacts on relays or defective relay coils, or the switching mechanism itself may develop marginal fault conditions which will cause it to fail to respond to the pulses.

(c) The relay contacts may go open-circuit either permanently or intermittently, due to dust, atmospheric contamination and corrosion brought about by arcing.

(d) The "wiper-to-bank" connections may become defective due to dirty or oxidised bank contacts or to worn wiper tips.

(e) The cords connecting the wipers to the selector proper may fracture and so cause switching faults and noise due to speech transmission.

In addition to the above, there are many thousands of soldered connections in an exchange and a percentage of these may be defective due to poor soldering at the time of installation or subsequent re-arrangement.

A significant percentage of faults in switching plant is directly or indirectly the result of poor workmanship either at the factory or by maintenance staff in their day-to-day duties. Modern techniques in exchange maintenance aim to reduce staff activity on the equipment to a minimum consistent with satisfactory performance, thus reducing the incidence of man-made faults.

Effect of Faults

The effect of a fault on the service performance varies according to the type of switching system and the traffic load at the time. In an ideal switching system, each unit of switching plant receives an equal share of the traffic offered and is brought into use either on a rotational or on a pure chance basis. Under this arrangement, the effect of a faulty piece of equipment is shared by all the subscribers who are using that particular traffic path. If a call attempt fails, the subscriber's repeated attempt goes through different switches and will be successful if there are no other faults present. This ideal exists to a large degree in the modern crossbar system but it does not apply to our existing step-by-step system. A faulty selector can, under certain conditions, very seriously affect a single subscriber or a group of subscribers. and repeated call attempts by a subscriber may fail due to the fault.

It will be appreciated that the call failure rate tends to increase as the amount of tandem switching increases. Thus to achieve a loss of no more than 2 per cent over 4 selector stages in the ideal system mentioned above would require a maximum loss of 0.5 per cent in each stage. This means that at any one time no more than 1 switch in 200 should be defective in each switching stage. An even smaller percentage of faulty switches can be tolerated in the step-by-step system because it does not have pure chance or rotational selection of switches and links at all-times.

The Approach to Exchange Maintenance

The Australian Post Office, along with most other telephone administrations, is developing a system of quality-controlled maintenance for its telephone networks. With this scheme the overall service performance of the switching network is gauged by the methods mentioned earlier i.e., service observation and, more recently, the incidence of subscriber trouble reports. These, together with the results of test calls and other statistics of plant performance, are analysed at a Service Co-ordination Centre established in each capital city. These statistics are known as Indicators and are analysed on a centralised basis for the whole telephone network and information on trouble spots is forwarded to individual exchanges for attention. Some of these Indicators are briefly described below.

Test Calls: Automatic test call generators, known as traffic route testers, set up test calls between spare telephone numbers. Test calls are established over individual traffic routes in a telephone network and the average, or "expected" call failure rate is established for each route. When this average value is exceeded, after making due allowance for statistical variations, the route is investigated to find the cause of the trouble. Test calls are set up in batches of 200 or 300 calls and the results are graphed in terms of percentage call failure rates, and action limits are set to indicate when maintenance attention is required. Traffic route testing is a valuable tool for quality control and also for fault finding.

Analysis of Subscriber Trouble Reports: Subscriber trouble reports are analysed at the Service Co-Ordination Centre (S.C.C.) for evidence of weaknesses in the telephone network. For example, a subscriber may complain of repeated difficulty in establishing a call to a particular number. As they are received, these reports are plotted on a grid chart depicting all traffic routes of the telephone network. A pattern may develop on the grid chart indicating that a particular traffic route or a particular section of an exchange has faulty equipment. The S.C.C. then requests the staff at the exchanges concerned to set up test calls or apply tests to the equipment concerned to locate the cause of the trouble.

Scheduled Testing of Equipment: Individual items of equipment in step networks, such as selectors and junction circuits, are given regular tests with the object of detecting troubles before they adversely affect service performance. Prior to the introduction of qualitative maintenance, these tests were performed at fixed frequencies set by the Headquarters Administration and uniform throughout Australia, irrespective of the service needs of the plant at any particular exchange. Under qualitative maintenance, the local field staff is required to set a frequency of testing for each section of the equipment in accordance with its individual service needs as revealed by the above Indicators.

Record of Switch Equipment Faults: Another indicator of plant performance is the incidence of faults on each type of equipment. Statistics are compiled on the number of faults per 100 units of each type of equipment per month or quarter. The Administration aims to set action levels for these statistics to guide maintenance staff as to when more maintenance attention is needed. In addition, in the case of bi-motional selectors, maintained for each switch. Should an individual fault history record is the number of faults on a switch in a given period be excessive, the switch is given a special inspection, and if necessary, a complete overhaul.

Selector Cleaning, Lubrication and Reconditioning: The earlier systems of inspections and reconditioning at standard fixed frequencies has been rationalised so that, as far as is practicable, all such work is done on an "as required" basis as revealed by the above Indicators. Some work, such as lubrication of mechanicals and cleaning of banks, is still performed at regular intervals; however, the frequency varies according to the needs of each particular section of plant.

Maintenance and Service Performance of Modern Crossbar Switching Equipment

The Australian Post Office has ceased purchasing step-by-step equipment and all new installations are of modern crossbar switching equipment. This system is fundamentally more reliable because it is essentially a relay switching system and does not possess the mechanical complications of bi-motional selectors and uniselectors. It requires practically no routine maintenance in the form of regular functional tests of individual items of plant and equipment inspection and overhauls. Service is supervised mainly by traffic route testing as described above, and also by inbuilt service aids.

These service aids work on the principle that the common control equipment in a crossbar system should switch a call through the connecting switches within a specified period of time and if this does not take place a so-called "time-out" is recorded on a meter. The time-out meters are read at frequent intervals, separate meters covering each section of the plant. An excessive number of time-outs may indicate a fault. In addition, these time-outs are also registered in an automatic alarm system so that, should there be an excessive number of time-outs in a given period, an alarm is given and the maintenance staff can investigate. This is a form of continuous supervision of the operation of the switching equipment and, as such, is most valuable in enabling a high standard of service to be obtained at relatively cheap cost. The Administration is currently investigating a system for recording time-out details in a form suitable for data processing.

Experience to date indicates that the crossbar system is capable of very reliable performance. The average call failure rate would be considerably less than for step-by-step plant in a comparable situation. However, it is subject to occasional failures in the common control equipments which set up the calls through the switches; a common control failure can cause complete blockage of traffic to a 1,000-line group of subscribers, but these are very infrequent and are usually cleared within a few minutes.

TRANSMISSION

An important aspect of telephone service is the transmission performance, which governs the ease with which subscribers can converse and transmit information. There is no absolute objective measure of the overall transmission performance of a telephone system because such a system necessarily includes human users. The final measure must therefor be made subjectively and expressed in statistical terms. A typical expression of performance of a practical telephone system could be that a large proportion of subscribers, say 95 per cent, should regard the service as good for a large proportion of the time and that it should be bad for a negligibly small part of the time. Such a standard varies as the users' expectations of service vary.

So far as the users of the system are concerned, the important criterion by which the connection is judged is the volume of received speech. There are a number of other factors which have an effect on articulation efficiency, e.g., noise, sidetone, and various forms of distortion of which the limitation of frequency bandwidth is the most important. With modern telephone instruments and transmission plant, it is the circuit loss which has a controlling effect on transmission. Nevertheless, the other factors are also important and it is necessary to ensure that all parts of the network are designed and maintained in such a way as to achieve satisfactory values of each.

From the transmission point of view there are two main divisions of the network, the local plant comprising telephone instruments and line to the local exchange together with local area junctions and circuits to the trunk exchange, and the long-distance trunk network. The local lines are generally unamplified, and it is in this area that the greater part of the overall loss is allocated since this factor determines the gauge of conductors used.

It is possible for as many as nine separate trunk circuits to be involved in a connection within Australia, with more on international connections. It is therefore necessary that the loss and other transmission impairments be kept as small as possible on these circuits. It is desirable to operate as many circuits as possible at "zero" loss. However, all circuits introduce some additional variability into the overall loss, and since reductions of loss tend to cause instability and tend to degrade echo conditions, it is arranged to operate some at a finite loss. The transmission plan provides for main trunk circuits shorter than 350 miles to have a nominal loss of zero with losses of longer circuits 0.5 db. or 1.0 db. Losses of local or circuits connecting terminal exchanges to the man low-loss trunks have nominal losses in the range 3 db. to 7 db. Design losses for a typical long-distance connection are shown in Fig. 6.

The accuracy with which the design losses are achieved in practice is a major problem in maintenance of the system since it is possible for an individual circuit to deteriorate gradually in such a way that the trouble would not be noticeable except in certain combinations of connections.

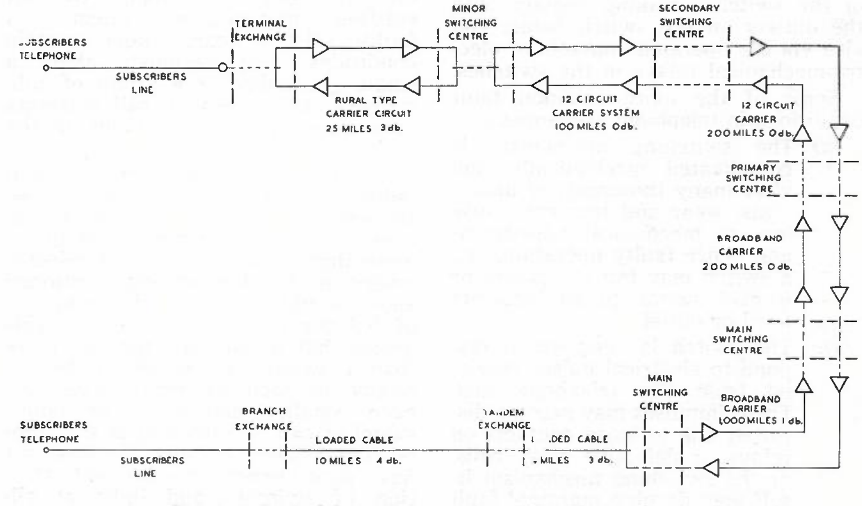


Fig. 6 — Typical Long-Distance Connection Design Losses.

For example, in the local network, marginal deterioration of transmission performance can occur due to such factors as the packing of carbon granules in a subscriber's transmitter (referred to previously), high-resistance joints in lines or equipment, errors in connecting equipment particularly during rearrangements, low insulation resistance in lines, etc. As a slight deterioration in transmission in a subscriber's service would in general affect only that service, reliance is placed mainly on trouble reports and service observations to detect this type of condition. On the other hand, the deterioration of transmission on a trunk circuit could affect a large percentage of connections and special measures are necessary to ensure that losses are maintained generally within the design limits. These measures are discussed later.

EXTERNAL PLANT PERFORMANCE AND MAINTENANCE.

Nature of the External Plant

A new telephone service can be required to be provided at any time in any part of an exchange area. The external plant, which consists of the electrical circuits and all structures associated with them required to link the subscriber with the exchange, is designed to provide this service with the minimum of arrangement and a high standard of reliability.

Flexibility is achieved in areas of high telephone density by dividing the cable into two systems, the main cable which extends from the exchange to a cross connecting point called a pillar or a cabinet, and the distribution cable which continues from the pillar to a point outside the subscriber's premises. A lead-in cable or an insulated aerial wire completes the line to the subscriber's dwelling. Rearrangements of cable pairs can be effected at the pillar or cabinet by running jumper wires, thereby avoiding the opening of cable joints.

In country areas where the demand for services is low but is more stable, there is not the same requirement for flexibility in the distribution system. Here, small sized cables are laid for long distances, or if the demand is very low aerial construction consisting of several pairs of aerial wires is provided. Trunk circuits form an important link in the communication system and are constructed to give the desired standard of performance. They are designed to the appropriate transmission and noise standards and, in addition, will withstand the normal forces of nature, such as floods, storms and lightning. Originally the trunk circuits were provided entirely by open wire pole routes, but gradually cable and radio have been introduced, particularly on the more important routes. Coaxial cable systems, such as that linking Sydney with Melbourne, provide a large number of extremely reliable circuits.

Standards of Performance for External Plant

Since the external plant provides one of the links in the telephone system, its reliability should be equal to that of other components. In contrast to most exchange equipment faults, a failure can prevent a subscriber from contacting his local exchange or, if in the trunk network, can isolate a community: Since service is lost until the lines are restored, such faults should be prevented from happening if possible and should they occur, be restored with minimum delay. In addition, the paper insulation used in the cable plant rapidly deteriorates if water enters the sheath, making restoration a lengthy and costly process. For these reasons, external plant maintenance is aimed at the prevention of faults and the preservation of the plant.

Maintenance Methods Employed

The external plant in use at present throughout Australia has a book value of about $800 million. The maintenance system aims at keeping this plant in good working order and extending its economic life. Maintenance is made difficult by the dispersion of the plant over a very wide area, by the inaccessibility of the buried cables and by the exposure of the aerial wires to the elements. Under these conditions the initial standards of construction play an important part in the subsequent performance. In the event of trouble developing, its detection and localisation with the minimum of delay and expenditure are desirable.

The maintenance of this plant costs $26 million annually. As the network is doubling in size every eight years, construction and maintenance techniques must be improved if a similar increase in expenditure is to be avoided. Considerable reliance is placed on a system of fault reporting and analysis which brings to the attention of design engineers the weaknesses in the present materials and methods and to the field engineers particular areas of sub-standard construction. This system is supplemented by sampling studies of the performance of particular items of plant. These studies are conducted for a period and the results after analysis used for design purposes.

In addition, the condition of the cable plant is monitored by various means. Automatic routiners test the lines for insulation resistance and provide a print-out of any lines found to be below a set standard, while important cables are kept under gas pressure to give warning of any sheath breaks.

On aerial plant it is necessary to carry out routine inspections to locate and remove incipient causes of plant failure. Aspects inspected are the condition of the poles, the presence of trees and undergrowth near the lines, the condition of wires and crossarms and the clearance existing between power and telephone lines at crossings. The annual inspection of wooden poles and power line clearances are conducted for the protection of staff and the public and are closely supervised. The periodicity of the other inspections is based on the local requirements as indicated by the fault recording system and staff reports.

Cable Maintenance Techniques

The distribution of cable faults in a typical year is shown in Fig. 7, the fault patterns varying wih the different types of cable. As mentioned above, the lead-in cable connects the subscriber's premises to the street distribution cable which is designated minor cable as far as the pillar or cabinet. The major cable connects the pillar to the exchange. The figure clearly indicates the influence that constructional methods and environment have on the incidence, mechanical damage, corrosion and faulty joint seals being major causes of faults. A comparison of the fault incidence of metal-sheathed and plastic-sheathed minor cable shows that while corrosion faults have been eliminated, the sealing of cable joints still presents a considerable problem. This is due to the absence of materials that will satisfactorily form a bond with the polythene used in the cable sheath.

As a result of the rapid development of the road transport facilities in the post-war years, the Australian Post Office which has traditionally laid its plant in or near the road reserves, is facing a rapidly rising incidence of interference and damage to plant. The underground cable plant, because its presence is not always realised, suffers the most, the annual repair cost now amounting to $2 million.

This problem is being approached in a variety of ways. The Australian Post Office has a service advising the location of its cable plant on request. Publicity campaigns are undertaken to make the public more aware of the extensive system of underground cables that exist on both public and private property and the susceptibility of such plant to damage. The inconvenience suffered by the community in general as a result of the careless act of an individual is an important aspect of this trouble.

In past years, the corrosion of lead cable sheaths presented a considerable problem particularly in areas where stray traction current is present. Satisfactory methods have been developed for the drainage of the stray traction currents back to their source and also for the cathodic protection of plant where drainage is not possible. Now, plastic-jacketed lead-sheathed cable is available and is used in areas where corrosion is a hazard. The cathodic corrosion of lead cable in iron pipe is at present a major source of trouble in plant laid some 30 years ago. It is now possible to avoid this hazard by the use of

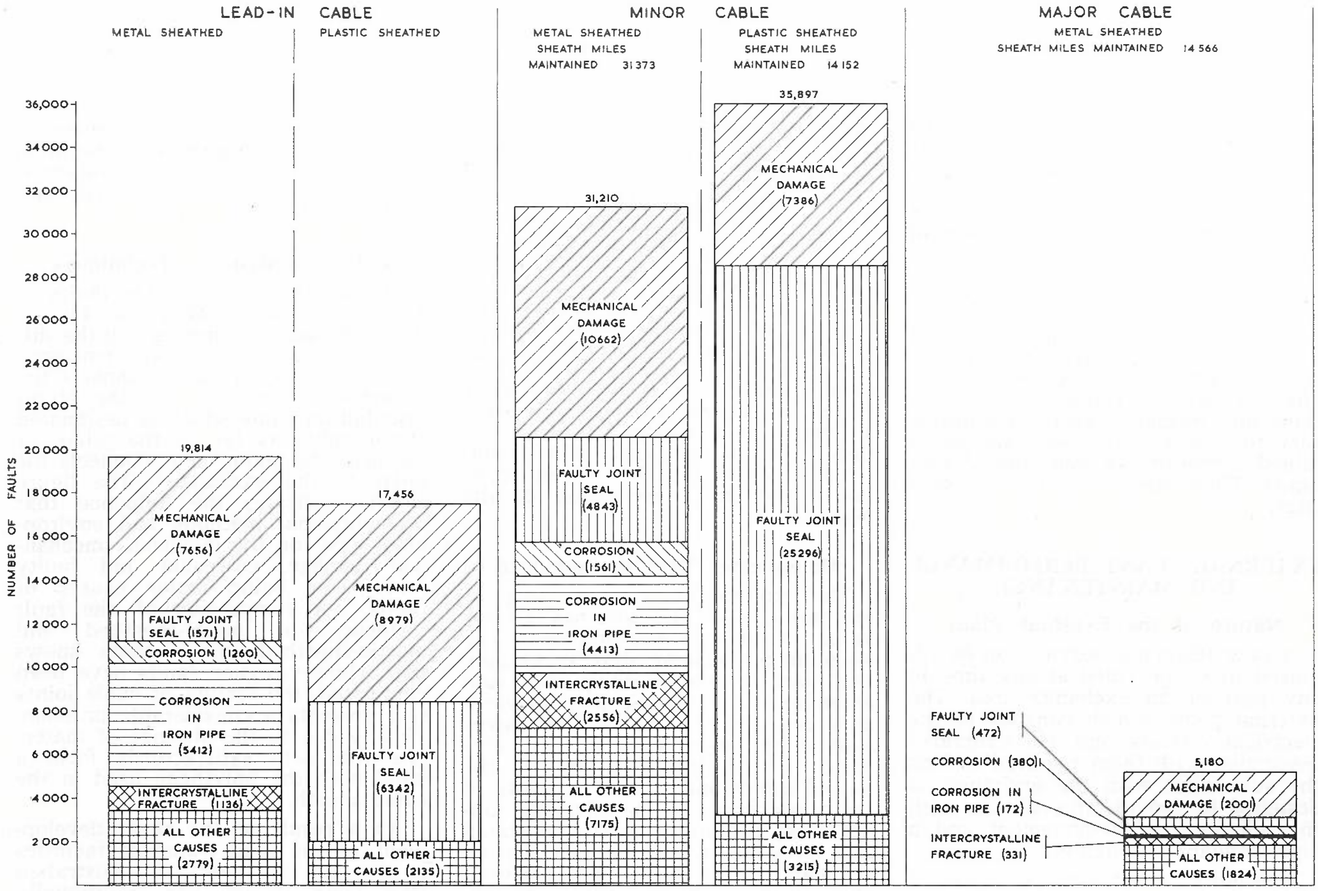


Fig. 7 — Sheath Faults, Commonwealth Exchange Cable, 1963/64 Financial Year.

plastic-sheathed cable laid in either iron or plastic pipes for protection.

The development of satisfactory jointing techniques in plastic cable has presented a number of problems due to the absence of materials that will bond on to the polythene cable sheathing. Advances are being made in epoxy resin casting techniques and while associated with some difficulties of future access to the joint, they offer means of excluding water from the joint. In cable systems it is possible to increase the reliability of the plant for a low expenditure on maintenance by placing the cable under gas pressure. In this system, the cables are filled with dry air at a pressure of 10 lb./sq. in., and damage to the sheath is revealed by the escape of air from the system. While there is a positive pressure of air in the cables it is not possible for water to enter and degrade the electrical performance of the system. Pressure recording devices are placed at intervals along the cables and these, in conjunction with flow-meters which record the amount of air entering the system, give an accurate indication of the condition of the sheath. When either the air flow is excessive or the cable pressure is falling below safe limits, the air leak is located. This can be achieved by indirect methods such as the plotting of the pressure gradient along the cable, or by direct methods such as sound detecting instruments, or by the injection of tracer gases into the system and finding the points at which they are escaping.

Both freon and radon gas are suitable for this work. At the present time, over 15,000 sheath miles of cables are under gas pressure.

As a result of this work the main lead-sheathed paper-insulated cables are protected from the effects of rain and continue to give normal service even under flood conditions. Maintenance costs are reduced as sheath faults can be located and repaired without interference with the cable conductors and at times suitable to the Post Office.

Aerial Maintenance Techniques

The performance of the aerial routes varies with their importance, typical performance figures are given below:

Trunk Carrier Routes	Voice Frequency Trunk Routes	Subscribers' Aerial Routes
3 faults/100 single wire miles/annum	8 faults/100 single wire miles/annum	30 faults/100 single wire miles/annum

The main factor affecting the performance is the gauge of line wire used and, in the case of subscriber's lines, whether the lines are connected to a central battery exchange or to a magneto exchange. In the first case, the potential constantly applied to the line will produce corrosion of the positive wire if leakage is present.

In recent years it has been possible to improve the performance of the plant and at the same time reduce the maintenance cost by the chemical control of undergrowth and the reduction of line wire fatigue by the use of vibration dampers and the closer control of wire tensions.

The use of preservatively treated wooden poles has produced substantial savings to date, with the prospect of further savings in the future. Since the sapwood is preserved in the treated pole, it has been possible by redesign to reduce the size specifications for poles. This has resulted in a light weight pole with consequent savings in handling costs and a saving of about $160,000 per annum in pole purchases. In addition, the maintenance inspection of standing pressure-treated poles and subsequent pole renewals can be reduced.

Damage to cable plant and equipment by lightning led at an early stage to the insertion of lightning protectors between the aerial lines and the connecting cable. While such protective apparatus reduced the incidence of cable and equipment damage, it was very fault-prone in itself and degraded the performance of the plant. At the present time, high-performance gas arresters are available and these, in conjunction with improved earthing systems, are capable of draining the lightning energy from the line without being damaged in the process. They have proved to be most beneficial in inaccessible locations where the restoration of service depends on the time taken by staff to travel to the affected point.

Analysis of Fault Data

As a result of improvements in both constructional and maintenance techniques, the performance of the external plant is steadily increasing without any rise in maintenance costs. In the past, the analysis of vast masses of fault data presented an impossible task, but with the development of automatic data analysis methods using electronic computers, such a proposition is feasible. In the external plant field, one million faults affecting the service occur every year. At present, one-fifth of these faults are being analysed by electronic automatic data techniques and this system will be extended throughout Australia by next year. The system gives both design engineers and field staff an appreciation of the performance of the various items that make up the external plant and opens the way to plant improvement either by changes in design or methods, or by improved maintenance in the field. It is used in general as an indication for the direction of design, construction and maintenance effort.

Fault Clearing Facilities

When a fault does occur in the plant, it is important to the subscriber that the affected service is restored with minimum delay. In metropolitan areas complaints are directed to centralised testing centres from which the line and terminating equipment can be tested. Depending on the results of the test, either a technician or a lines faultman is despatched to clear the fault. Where a major plant failure is revealed, lines staff with appropriate equipment undertake the restoration work.

Because of their importance as interstate and intrastate links, the coaxial cables are given special maintenance consideration. The possibility of mechanical damage is minimised by installing these cables at a depth of 4 ft., by the use of cable markers and by a regular system of patrolling. The cables are kept under gas pressure and should a fault affecting the tubes occur, special groups of workmen move in to restore the service in a minimum of time.

LONG LINE EQUIPMENT

Introduction

This section deals with the plant which is used in conjunction with the external plant described above, to provide facilities connecting the various exchanges.

Trunk circuits are provided by physical wires in cable or on poles, and on circuits of carrier systems; in some cases the physical wires are equipped with voice-frequency amplifiers. Carrier systems have been developed to the point where they are the normal method of provision of trunk circuits greater than about 20 miles in length. There are several types of carrier systems available for application under the various conditions applying, i.e., distance, number of circuits required, etc. These provide circuits to appropriate performance standards so that overall requirements are met most economically. The existing plant includes these modern systems and also equipment which has been installed for relatively long periods and must be retained, although not up to present standards in all respects. The present growth is being met by the broadband coaxial cable and microwave (line of sight) radio links on main backbone routes, with the longer established systems of 3- and 12-circuit capacity on other routes. In general, all these systems are engineered to international standards which provide circuits suitable for inclusion in intercontinental connections.

Smaller capacity radio systems are also provided as a means of communication where normal line provision is difficult, or as an alternative to lines which are subject to frequent interruption by flood, for example, in the Northern Rivers area of New South Wales. These systems normally provide circuits of standard performance but in some "outback" areas economic considerations limit the performance achieved.

There are routes in the undeveloped and sparsely populated areas where circuit requirements are low and the only facilities economically practicable are single-wire earth-return lines, generally of iron wire, which are unsuitable for the provision of normal type carrier systems. The service provided on these lines is sub-standard and communication is sometimes not possible into the normal network due to high losses and high noise levels. Transistorised two-band systems have been developed by the Australian Post Office Research Laboratories to improve the service in these areas. Two-band systems operate by using the voice-frequency path of the line for one direction of transmission with a low-frequency carrier channel for the opposite direction, thus providing an amplified 4-wire circuit, at the same time restricting the frequencies transmitted to line, to keep line losses to a minimum. High power levels are transmitted to improve noise conditions.

Reliability Considerations

Reliability is a basic consideration in the provision of long line plant. There are several aspects of reliability. Normal circuit provision for the public network must have a high probability that the required standard of service will be maintained but there is also a requirement to maintain virtually continuous service for essential communications, and to prevent isolation of communities. Economic factors enter into reliability considerations as the first cost of equipment and the amount of maintenance attention given obviously have great effects on the standard achieved.

Route Diversity: The first approach in ensuring reliability is to provide route diversity, preferably separated geographically to reduce the possibility of simultaneous interruptions. Where possible, this geographic dispersion should be supplemented by diversity of facility to reduce the effects of widespread disturbances such as floods and storms. Different facilities are vulnerable to different types of disturbance. Thus cables are vulnerable to earth-moving operations which do not upset radio systems. The ideal arrangement between major centres is for parallel coaxial cable and microwave radio broadband systems. Such an arrangement is, of course, very costly and cannot be justified for security provisions alone. However, normal growth tends to justify the building up of more than one system on main interstate routes. In addition to the division of normal facilities made possible, this arrangement permits transfer under emergency conditions of large groups of circuits to the spare frequency spectrum on the alternate route. Such an arrangement has applied for the past years on the route from Sydney to Canberra and has thus enabled the circuits normally carried on the coaxial cable to experience no interruption of greater than 14 minutes although damage to the cable has extended for several hours on occasions. Similar parallel facilities will be available from Melbourne to Sydney in 1968. Until this time a number of 12-channel open wire systems will be retained from Melbourne to Sydney and Canberra as a back-up to the cable system. This is the heaviest long-distance route in Australia, but this pattern will be followed with future expansion of other parts of the network.

Equipment Aspects: From an equipment aspect, optimum reliability is provided in a number of ways.

Components and construction methods are chosen for maximum reliability. Coupled with component reliability is the circuit design. Generally well tried and simple circuits should be used where these are adequate. Circuits are designed to be tolerant of changes in component characteristics; an important example of this is the application of negative feedback which was developed originally for long-distance telephone transmission purposes.

Facilities are built-in to equipment to monitor automatically the performance of certain vital items such as carrier supplies and broadband amplifiers and to provide alarms or automatic changeover to standby units. Equipment is also built to regulate the gains and line equalisation, carrier levels, etc., to maintain circuits within set margins.

During installation, equipment is "vibration" tested while carrying test signals to discover potential troubles which otherwise occur at random during the early years of system operation. After this test, a stability check is made on major systems by the continuous recording of a test signal transmitted by the equipment.

Principles of Maintenance

Many of the long line equipment developments in the past have been such as to reduce the need for routine maintenance by staff. This has been desirable from two separate considerations. The first is the cost. In the early stages of development the maintenance effort required to make frequent adjustment represented a relatively small proportion of the total annual charges of the plant, but such a maintenance requirement would be totally unacceptable now. It is also highly desirable to avoid, as much as possible, any interference with equipment to prevent accidental interruption or variation in equipment which is functioning satisfactorily.

With these factors in mind the general principles of maintenance are as follows:—

(a) Routine adjustment of systems should be made only when it is known with certainty that the need for such readjustments is inherent in the fundamental design of the systems. Such readjustments may be required to take care of seasonal variations in bearers of, for example, short balanced pair carrier cable systems, in which the rate of change of loss does not justify automatic regulation on all pairs.

(b) Routine checks (including observation and testing as appropriate) of equipment performance on a systematic sampling basis is necessary so that the behaviour of systems is known with reasonable certainty. These checks include utilisation of regulator settings and the continuous monitoring of appropriate signals by pen recorders, or part-time recording only when the need is indicated.

(c) Analysis of statistics of all faults is necessary to obtain information on design weaknesses and to indicate equipment which is giving undue trouble.

(d) Equipment overhaul by specialist staff is generally carried out only when shown to be necessary by an undue incidence of faults or by inadequate performance.

(e) Fault repair in central depots by specialist staff is used to the maximum extent practicable.

(f) Scrapping or rebuilding older equipment as indicated by performance and fault statistics. This is normally economic only to a limited extent.

Maintenance Methods

These principles indicate the suitability of a quality control approach to maintenance and the application of this is now in the process of introduction.

The term quality control is used here to cover the well-known method of using a control chart to maintain statistical control which is appropriate in some aspects, but also (and most importantly) the general principle that action is taken only when indicated by measurement of the end product. This is distinct from the routine adjustment of equipment irrespective of whether there has been any significant change in its operation. Routine maintenance was a natural requirement in the early applications of carrier (where the losses of open wire lines changed rapidly and frequent adjustments were necessary) but is now obsolete and uneconomic.

Detailed maintenance practices based on quality control principles have not yet been applied generally, although a number of approaches have been used in parts of the network.

One example of a limited application of quality control or qualitative maintenance has been operated for some years in New South Wales. This involves measuring certain essential parameters on all circuits periodically. On carrier circuits, measurements are made at intervals of 2 months. These measurements are the loss at line-up frequency of 800 c/s, frequency response by measurement at frequencies of 400 c/s, 1,600 c/s and 2,400 c/s, noise, and synchronism. Circuits found outside set limits, e.g., ± 3 db. for circuit loss, or with a synchronism error exceeding 5 c/s, are recorded as faulty. Approximately 3 to 4 per cent of circuits are found faulty and of those approximately 50 per cent involve adjustment of gain. Synchronism adjustment is required in about 0.2 per cent of faults. Faults involving replacement of valves approximate 5 per cent. Routine maintenance has been restricted, applications being limited to work such as seasonal adjustment of cable carrier gains, and periodic valve replacement in certain systems. This latter procedure is not generally favoured but is economic in a few special cases. This system was suitable for the conditions applying when a large proportion of circuits was provided on physical lines or the earlier types of carrier.

However, routine tests are not nearly so important on modern systems, e.g., on individual circuits of multi-circuit, and particularly broadband, systems which are now providing a large proportion of circuits between major centres. In these cases, a close check is kept by observation of pilot channels and by very frequent automatic measurement of circuits by equipment which checks that the circuits are within set limits of the nominal value. A sampling procedure for circuits in 12-channel groups is also used. It is necessary to measure noise and synchronism on only one suitable circuit per system. Similarly, faults in the frequency response of carrier circuits are relatively infrequent and need be measured only once per year.

Quality Control

With the system of quality control which is now being introduced into the network, a number of appropriate parameters are measured and the performance assessed in relation to objectives which are set. Corrective action is based on an analysis of these results. The two main parameters are circuit loss variation and circuit outage time.

Circuit Loss Variation: The objective is that the loss should equal the design value with a bias of not greater than ±0.25 db., and a standard deviation of the variation of 1.0 db. These values are achieved at present on only a few of the best routes where suitable terminal balance conditions are provided. It is generally not possible to line up to zero loss because of the low margin of stability which would exist. The methods of adjusting circuit loss used result in an average loss per circuit in a switched connection of approximately 2.0 db. The standard deviation of the variation of circuit loss from this mean, for the greater part of the network, averages approximately 1.7 db.

Circuit Outage Time: This is measured as the percentage of time the circuits are out of service during predetermined hours over the period.

The present objective for outage time is that it should not exceed 2 per cent of the normal business hours, i.e., excluding the time when traffic is light and circuits may be removed from service without disturbing traffic. The outage time exceeds the present objective for some of the longer trunk routes where these are on open wire systems.

In addition to the two main parameters, the following indicators are also of importance in ensuring that the trunk network is performing satisfactorily.

Duration and Frequency of Bearer Interruptions: The interruption rate and percentage outage time on carrier bearers is important in achieving satisfactory circuit performance. The performance in this regard is controlled by the number of interruptions and the time to clear faults. The interruption rate and bearer outage time on the Sydney-Melbourne broadband system are illustrated in Figs. 8 and 9. The outage times shown were achieved by alternative use of the alternative radio systems (Sydney-Canberra), and the use of spare coaxial tubes which are available in all sections. As would be expected under these conditions, this performance is better than that achieved on any other single system. Outage time on other broadband bearers (both coaxial cable and radio) has ranged from approximately 0.02 to 0.1 per cent per 100 miles of route. These results include some systems where standard "no-break" power was not provided or where interference was caused by installation work.

Circuit Noise: The objectives are weighted noise of -60 dbmo for circuits of 125 miles in length, with proportionately higher values of noise for longer distances. These values apply to the busy hour. Noise is measured monthly) on broadband systems on a sampling basis, and annually on other systems. Noise conditions on broadband systems are generally within these limits. In some cases, it is necessary for economic reasons to operate carrier systems on open wire pairs which are sub-standard as carrier bearers and on which normal noise standards are not met.

Variation of Circuit Loss with Frequency: This is measured annually at present. The nominal bandwidth of standard carrier circuits is from 300 c/s to 3,400 c/s. On modern 3-circuit systems in use in the A.P.O., the upper frequency limit is 3,000 c/s, and with older systems of this type the upper limit is 2,700 c/s.

Synchronism: The objective for synchronism is that the error in frequency should not exceed 2 c/s. This is achieved on broadband systems but tests have indicated that errors of up to 20 c/s occur for about one percent of connections made up of four carrier circuits in tandem.

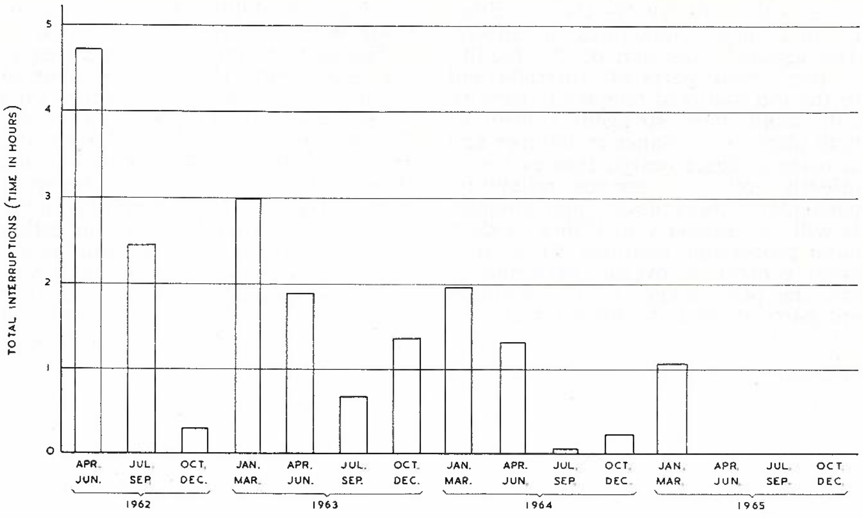
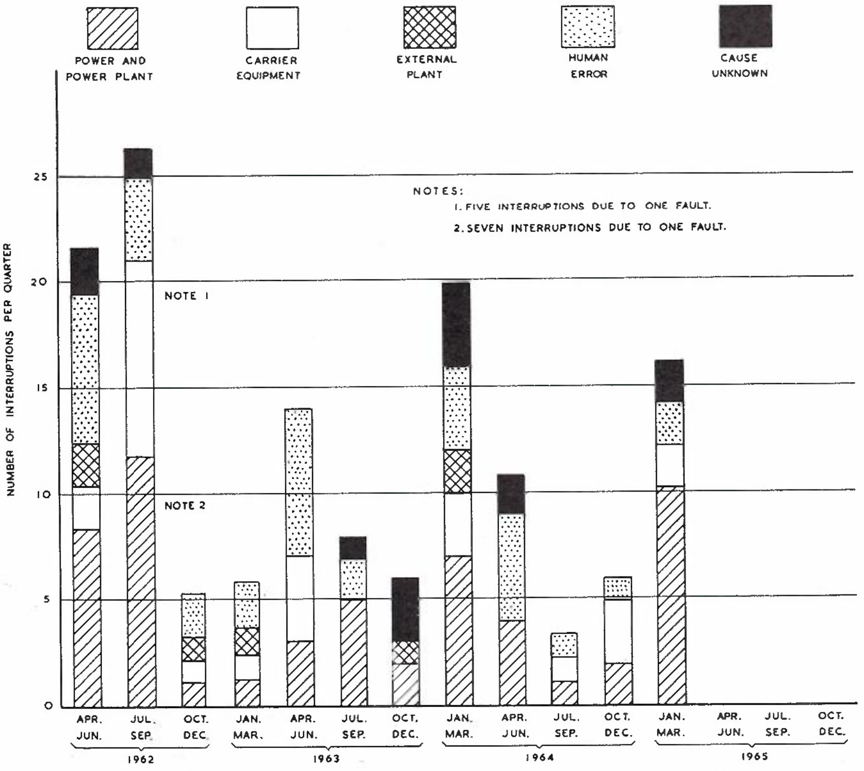


Fig. 9 — Sydney-Melbourne Coaxial Cable System Outages for Quarters Shown (Telephony Bearer).

Short Interruptions: The carrier systems used for the telephone circuits also provide circuits for voice-frequency telegraph and digital data. Short interruptions of less than 300 milliseconds in length are not serious for telephone operation, although longer interruptions can cause disconnection of established connections. However, even very short interruptions can cause errors in telegraph and data operation. These short interruptions have a number of causes including imperfect connections and contacts, power supply disturbances, accidental interruptions by installation or maintenance staff, and changeover of carrier supplies. It has been necessary to take measures to reduce short interruptions for data and telegraph transmission; these have had a beneficial effect on the performance in this regard and have also resulted in general improvements in respect to longer interruptions and the service in general.



NOTES:
1. FIVE INTERRUPTIONS DUE TO ONE FAULT.
2. SEVEN INTERRUPTIONS DUE TO ONE FAULT.

Fig. 8 — Sydney-Melbourne Coaxial Cable System Interruptions for Quarters Shown (Telephony Bearer).

CONCLUSION

It is evident from this paper that the maintenance of a satisfactory standard of service in a modern national telephone system is not simply a matter of fixing faults as they occur and slavishly following routine maintenance procedures. It requires in the first instance a critical appraisal and determination of the overall service objectives for the telephone system as a whole, followed by a determination of the service performance reliability which must be achieved in the various sections of plant, e.g., subscribers' equipment, underground cables, exchange switch plant, long line equipment, etc. The service performance targets for each type of plant must in turn be achieved by attention to basic reliability in the design stages, and the specification of an adequate system of plant maintenance, both corrective and preventive maintenance.

The current demand for new and more elaborate facilities from the telephone network (e.g., nationwide Subscriber Trunk Dialling and data transmission over telephone circuits) will call for a constant upgrading of performance standards and hence a continual review, and improvement where necessary, of basic maintenance procedures. Subscriber Trunk Dialling is only in its infancy and generally only one trunk line is involved on present S.T.D. calls. Ultimately

S.T.D. calls will involve the switching of up to nine trunk links in tandem. The general extension of the facility to the remote parts of Australia and to the international telephone network will entail more stringent control of both plant maintenance techniques and also those basic design factors which directly influence service reliability, particularly transmission performance. It will be necessary to utilise modern data processing facilities to keep a close control of overall performance and the performance of the component parts so that the need for corrective action can be quickly detected.

The telephone network in Australia presents a wide variety of engineering problems, much wider in fact than is encountered in many overseas telephone administrations, because we have both highly developed and densely populated areas and also sparsely settled areas, for which we must provide an efficient and reliable telecommunications system. As a result, the Post Office has always been obliged to appropriate considerable engineering effort to finding solutions to these problems.

DISCUSSION

Mr. R. T. O'Donnell:— The authors are to be congratulated on the presentation of a very thoughtful and informative paper on the problems met in establishing and maintaining service standards in a telephone network, with emphasis on the overall standards and on plant failure incidences. I would be interested to have their comments on some aspects of the overall problem, which could be covered in a way that brings into sharper focus the difference in call failures which are caused by fault conditions on one hand, and plant congestion on the other.

It is recognised that so far as the user is concerned, there is no difference, but from the supplier's viewpoint there is quite a distinct difference from the system and component design viewpoints.

It is invariably accepted that in designing networks the traffic handling capacity of the various links in the establishment of a call are based on the probability of the call being unsuccessful owing to all of the channels on one or more of the links being engaged at the time that the call is attempted. It is of interest only that congestion on one of the links is encountered because this is sufficient for the call attempt to be unsuccessful. Generally, an overall grade of service is designed for, and this grade of service is simply a measure of the probability of a call being unsuccessful. In the Australian network it is generally accepted as being between one call in fifty lost if the call traversed a trunk route or one call in eighty for an intra network call in the larger "7" digit step-by-step networks. The overall loss is a measure of the individual probabilities of loss on the various links traversed, and these individual probabilities are usually about 0.002 with certain other provisos.

The authors have mentioned that in the larger networks it is not unusual for 4 per cent of the attempted calls to be unsuccessful because fault conditions are encountered during the setting up of the call. It seems to me that the fault incidence loss, being of such a relatively high magnitude, must largely mask the effects of congestion due to shortage of plant, this shortage being a deliberately designed condition for economic reasons, whereas the fault conditions are designed against. It is accepted, of course, that congestion tends to cause some added measure of plant failure.

If, as has been suggested by various investigators in this field, the losses through congestion are about the level of loss which the users will accept without serious complaint, it seems difficult to reconcile this thought with the actual losses which are occurring as a result of plant failure and which appear to be accepted without widespread criticism. It has been further suggested that the amount of equipment which is provided to carry the traffic should be increased by say 5 per cent in order to compensate for the traffic channels which are out of service owing to fault conditions. These faulty channels are either self-busying or have been taken out of service by the technical staff. The other possibility is that a faulty channel may remain accessible to calls and cause the failure over a period of all calls that encounter that channel. If on one hand it is accepted that fault incidence cannot be reduced below the level of 4 per cent in large networks mentioned in the paper, the establishment of a percentage increase beyond the theoretical traffic-handling capacity of a traffic-carrying group may well be the correct thing to do, but it is not an encouraging prospect to have to increase the number of items of plant to cater for out-of-service components if in its turn this will further increase the total number of faults. It would also imply that on the average no component remains operative for more than 19 days in every 20 if the assumed 5 per cent is the correct percentage increase to handle fault incidence. It would seem to me that there is a wide and very fertile field of investigation available and it is very clear that even a small reduction in fault incidence must produce extremely good financial benefits in terms of the capital costs of the service. It would be, theoretically, at least a 5 per cent reduction in the amount of capital plant which is provided also and a consequent saving in the maintenance costs.

Perhaps the authors might care to comment on the foregoing with particular emphasis on any aspects of the setting of service standards which relate the traffic engineering elements of route congestion with the fault incidence which causes failure of an item of plant to carry the traffic offered. It would also be useful to me if some comment could be made on the role that traffic measurements play in the maintenance of service standards because there is little or no mention of this in the paper.

The Authors in Reply:

Mr. O'Donnell's comments and questions are appreciated because they touch on a matter that has received too little attention not only in this paper but by maintenance people generally. This is the question of the relationship between objectives for switching losses due to plant defects and plant congestion, and the costs incurred to meet these objectives. The following notes survey this question and include a brief outline of the present methods for keeping losses due to plant congestion within the desired limits.

In answering Mr. O'Donnell's questions some clarification of certain statements in the paper is required. The paper states that in very large networks, such as the Sydney network, 4 per cent of calls can be lost owing to fault conditions and plant congestion, not just fault conditions alone as implied by the question. The statistics quoted at the beginning of the section of the paper on Service Assessment of Line Traffic are an attempt to summarize the service performance of large telephone networks generally, particularly Subscriber Trunk Dialling networks.

Getting down to practical cases, all our capital city networks except Sydney have an average call-failure rate due to plant defects not exceeding 2 per cent; in some it is lower than 1 per cent. In the Sydney network the corresponding call-failure rate is approximately 4 per cent. The tremendous demand in Sydney for new services and facilities has overtaxed the Department's resources, and maintenance in some exchanges has fallen slightly in arrears. The Department does not regard this performance as satisfactory and efforts are being made to improve it. It should be appreciated that these call-failure rates are network averages, and calls on some individual traffic routes would encounter much lower failure rates than the average, whereas calls on other routes and calls from certain exchanges, would encounter higher failure rates.

In the case of S.T.D. traffic, some routes (e.g. a route between two cities) have call-failure rates due to plant defects of no more than 3 per cent and others have high failure rates, e.g. up to 8 per cent. Over the past twelve months the Department has placed in service a considerable quantity of new signalling and switching equipment to provide urgently needed S.T.D. facilities, and some of the high failure rates are due to "teething troubles" in this equipment; when these are removed better performance should be achieved.

The overall congestion loss in the telephone network is controlled by careful dimensioning of the quantity of equipment provided in each switching stage through which calls pass and the number of links (trunks or junctions) between exchanges. Each switching stage and link between exchanges is assigned a busy hour "design loss," and additional plant is provided when the in-service loss would otherwise approach a value of twice the design loss. Thus considering the local exchanges shown in Fig. 1 of the paper, sufficient selectors would be provided initially at each of the switching stages to ensure an average grade of service of .002 per stage during the busy hour period. This average applies to the design period and refers to the busy season busy hour, therefore the actual grade for most of the time would be better.

As junction and trunk circuits (connecting links between exchanges) generally cost more than switching equipment, there is an optimum distribution of losses between switching stages and connecting links. Thus in the case of junctions costing less than $800 per circuit, provided there is adequate supervision of congestion, sufficient links are provided to ensure that the probability of failure during the busy hour does not exceed .005. For junctions costing more than $800 the corresponding design loss is 0.01.

A switching stage must not be subject to serious traffic overload, and the design grade of service figure provides a safeguard against unforeseen traffic increases due to forecasting errors. A point can be reached under overload conditions where even a slight further increase in traffic offered can cause a very marked deterioration in the effective grade of service, because of the back feed resulting from repeated call attempts. In this connection, the common control crossbar system is more efficiently trunked than the step-by-step systems, and hence is more readily overloaded under peak traffic conditions. Under no circumstances should a switching stage be overloaded to the extent that one call in twenty is lost. To ensure this, no switching stage or route is dimensioned, even on a temporary basis, for a nominal grade of service poorer than one lost call in fifty. Traffic-measuring equipments are employed to measure the traffic flow and thus give an indication of "the probability of congestion" (see paragraphs below). Plant-provisioning policy is governed partly by the speed with which relief can be given when congestion does occur. If it is practicable to provide relief at relatively short notice then shorter design periods, each with smaller increments in plant, could be used.

In the case of metropolitan networks the design losses for the individual switching stages and the connecting links between exchanges are set on the basis that during the busy hour the average probability throughout the network of a call failing due to insufficient plant is about one in one hundred; the corresponding figure for S.T.D. traffic is one in fifty. It should be noted that these refer to the busy hour condition only, and that we would expect a lower failure rate from service observation measurements because they are taken in busy hour and in non-busy hour periods, provided that all the installed plant is actually available for service.

Because of the need to attend to faults, and in the case of step equipment to do certain preventive maintenance, not all the equipment is available during the busy hour to handle the traffic. This is of little or no consequence when the plant is well able to handle the busy hour load, but it can become a factor as the time for a relief project draws near. Mr. O'Donnell asks if we should revise our present provisioning policy and provide additional equipment specifically to meet this need. When traffic measurements are taken to ascertain the need for additional plant, it is usual practice to check the number of switches out of service for maintenance reasons and to regard these as available equipment i.e. no provision is made for equipments which may be faulty. In the case of junction routes and switching stages, the grade of service normally provided is such that additional plant is not justified to cover that plant which is out of service owing to faults. However, in the case of the more expensive trunk circuits for Subscriber Trunk Dialling the provisioning basis does not give so much latitude and there is a case for making an allowance for maintenance. Modern trunk circuit signalling equipment has facilities for automatically busying circuits from traffic under certain types of fault condition. Although a figure of 5 per cent as suggested by Mr. O'Donnell is sometimes quoted as the percentage of unavailable circuits, this has not been confirmed by any surveys known to the authors. Certainly such measures as,

(a) tighter supervision of maintenance work to ensure that faulty circuits are corrected and returned to traffic as quickly as possible and
(b) investigation of the reason for any unexplained intermittent blocking of circuits from traffic

should be taken before simply providing more circuits to cater for the faulty ones.

There is no simple answer to the question what maximum call failure rates due to plant defects and congestion would be tolerated by subscribers without complaint. The following factors are relevant:—

(a) The subscriber receives busy tone for both "wanted subscriber busy" and plant congestion conditions. As stated in the paper, we could expect 10 per cent of calls to encounter "wanted subscriber busy". In the case of some of the larger networks, this figure is as high as 13 per cent. It is not possible to distinguish these conditions in our new crossbar network at present, and although it is possible to make the distinction in the step network, many subscribers probably would not be aware of it. However, even in crossbar exchanges there is little doubt that medium and heavy calling rate subscribers become aware of say 5 per cent congestion on particular traffic routes they use frequently. It is proposed to introduce a new type of busy tone which will be only slightly different from the present busy tone, and which will be used by departmental personnel, including service observers, as a check of congestion in our networks.

(b) In some of our new types of equipment busy tone is returned in the event of some types of malfunction of faults.

(c) Mr. O'Donnell states that the user does not distinguish call failures due to plant faults from calls on which busy tone is recived due to congestion; this is very doubtful. Because of their inability generally to distinguish plant congestion from "wanted subscriber busy," subscribers would be much more critical of faults. I think most subscribers prefer a positive indication in the form of a busy tone (even if they know that it is not "wanted subscriber busy") than "no tone" or wrong number conditions, i.e. fault conditions. In fact there is a case for giving busy tone under fault conditions wherever this is practicable and this is done in modern equipments.

(d) The Administration's plant provisioning programme normally ensures that congestion generally throughout the network is kept within specified limits as described above, and it is only individual traffic routes which become severely congested if the provision of additional plant has been delayed. Thus subscribers connected to a certain exchange or exchanges will become conscious of abnormally high incidence of busy tone on certain calls, and this will give rise to complaints. Precisely what subscribers will tolerate without complaint is debatable, but in the authors' opinion, busy hour congestion of 6 or 7 per cent will almost certainly cause complaint and requests for assistance from medium and heavy calling rate subscribers. Infrequent telephone users would probably tolerate higher call-failure rates without complaint; what **does** produce subscriber reaction is a sudden deterioration in service performance.

(e) Service experience has shown that failures due to plant defects, i.e. actual misoperations of equipment, are not altogether independent of failures due to plant congestion. Certainly in the step-by-step switching equipment under heavy congestion conditions certain types of selectors and pre-selectors are subject to intermittent misoperation, which causes "no-progress' and misdirection calls under conditions of heavy traffic overload. This can add up to 5 per cent to the failure rate under conditions of severe congestion.

From the performance figures indicated in the paper, it evident that the total call-failure rate due to Departmental causes, i.e. failures due to faults and congestion, should not exceed 6 or 7 per cent at the most, otherwise it will become a major contributing factor to call failure and cause complaint. We have higher failure rates on some S.T.D. routes and from some individual exchanges in the Sydney network, and these do cause customer complaints and requests for assistance. In the Sydney network, the subscriber complaint rate is about 40 per cent higher than any other network, and this is attributed largely to the relatively poorer performance of this switching network.

Most telephone administrations have experienced at some stage the problems of high call-failure rates due to faults and/or plant congestion. This applies particularly to S.T.D. networks where the public demand for the service frequently outpaces the Administration's capacity to provide more plant. The recent adverse public criticism of the telephone service in the United Kingdom is an example of this problem. Some S.T.D. routes in the U.K. have call-failure rates of 20 per cent owing to faults and congestion.

Speaking of objectives it is the authors' opinion that for capital city networks, the call-failure rate due to faults and plant congestion, based on service observation results, should not exceed 3 per cent for the larger networks and 2 per cent for the smaller networks, with individual exchanges no worse than 4 per cent. If these targets are met, it should be possible to achieve an average S.T.D. call-failure rate (faults and congestion) of 4 per cent. Certainly we should not exceed 6 per cent on any individual S.T.D. route.

Mr. O'Donnell's question also poses the issue of the optimum balance between congestion loss and losses due to faults. Ideally we should operate at points where the same money invested in reducing faults and in reducing congestion would give the same service improvement, to the customer, or the same financial gain can be made by relaxing either the congestion standard or the fault standard without adverse customer reaction. To date no specific and detailed studies have been made of this question but it would be useful to do so. On the ground that the customer generally does not distinguish between plant congestion and "wanted subscriber busy" we probably could relax our congestion standards a little without risking severe customer reaction and make some saving in capital cost of plant. For example a network operated at 1 per cent. calls lost owing to faults and 1 per cent owing to plant congestion, could operate with 2 per cent congestion loss without undue customer complaint. On the other hand unless the plant in a network has deteriorated to a very poor state of service reliability (as may be the case for very old equipment for which spare parts are not obtainable) or it has serious design weaknesses which cause high maintenance, it is generally much cheaper to improve service performance by more maintenance than by reducing the loss due to plant congestion. It is not possible to generalize regarding the amount of service improvement which will result from a given maintenance effort, as much depends on the nature and distribution of the plant defects. A few early choice equipments in a selector grading can very seriously degrade service performance but they could be easily restored to good working order. On the other hand badly pitted contacts on every selector or relay set in a switching stage may also have a serious service effect and could be very expensive to rectify.

The main means of supervising plant congestion is to make regular checks, usually two-yearly, at the individual switching stages and links in the telephone networks. The ideal method for checking congestion would be to measure the ratio of calls offered to a stage or link to calls rejected because of congestion. Unfortunately it is not practicable to do this readily and the usual technique is to measure the traffic flowing during the busy hour period and, if this consistently exceeds the design load for that particular stage, action is initiated to provide more plant. A so-called resistor traffic recorder is commonly used for this type of measurement. It consists of a milliammeter which is connected to read the current flowing through a bank of parallel high resistors, one connected to each piece of equipment in the group being measured. Each circuit which is occupied on a call will cause a slight increment of current through the meter via the traffic recorder resistor. The meter is calibrated to read directly the number of circuits occupied at a given instant and is read every few minutes, calculations of average traffic being made from the tabulated results. The original resistor traffic recorder has been adapted for automatic operation to produce traffic data on punched paper tape suitable for processing on a computer.

Another recording device is the Erlang hour meter which is the equivalent of the watt hour meter used for measuring electrical energy in that it integrates the number of circuits occupied and the time for which they are occupied. The meter reads Erlangs of traffic directly, and the equipment is switched in circuit during busy hour periods. It is used for long term or continuous traffic observation and supervision. To assist in the determination of traffic dispersion and flow in our larger networks, more sophisticated traffic-dispersion measuring equipment is being developed which will record on paper tape suitable for data processing full details of call holding times and call destinations.

In addition to these regular annual readings of traffic, it is desirable that maintenance staff keep a watch on congestion conditions. A rough check can be made in step-by-step exchanges by means of so-called overflow meters, which give an indication of the incidence of calls which receive busy tone because of congestion out of a selector stage. Similarly, crossbar exchanges are provided with congestion meters which accurately record every call attempt which fails owing to lack of equipment. Congestion and overflow meters are read at regular intervals and, should the reading be excessive, a full check is made using the equipment mentioned above. Another check of congestion is the result of the test calls generated by means of the traffic route tester described in the paper.

RAPID TESTERS FOR STEP-BY-STEP EXCHANGE EQUIPMENT

L. J. BLOXOM and P. C. C. WAY, A.M.I.E. Aust.***

INTRODUCTION

The well known automatic routiners in 2,000 type exchanges were designed to check the condition of selectors by the automatic application of an extensive range of functional and marginal tests. (Ref. 1.) The severity of some marginal tests is such that selectors will fail under test, yet would operate satisfactorily in service. As a result, some doubts were cast upon the efficiency of this equipment as an aid to modern qualitative maintenance practice. (Ref. 2.)

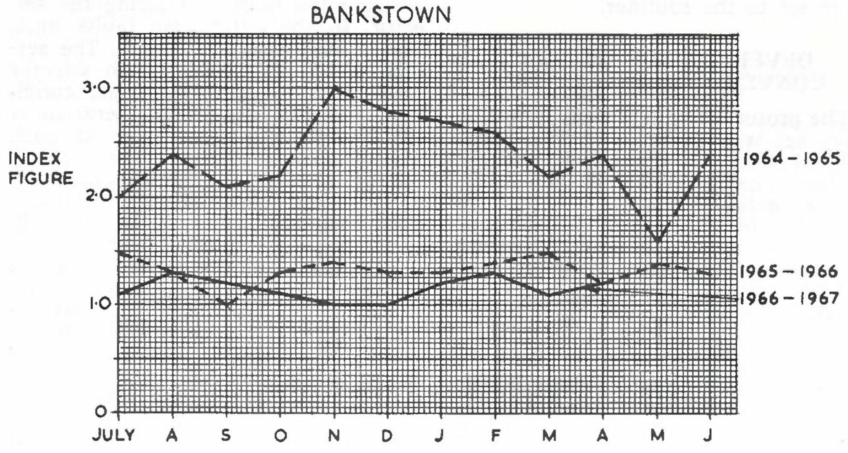
This article details work in the New South Wales Administration of the Australian Post Office leading to a very economical conversion of the routiner to provide rapid non-critical functional tests, including fully automatic starting of routiners and print-out of details of faults detected. (Another approach to the print-out of auto-routiner results is described in Ref. 3.) Mention is made also of the approach now current in the Sydney metropolitan network of completely automated testing of step exchange equipment and its role in qualitative maintenance. Extension of rapid automated testing to pre-2000 type equipment in the network, following beneficial experience in 2000 type exchanges is also described.

HISTORICAL

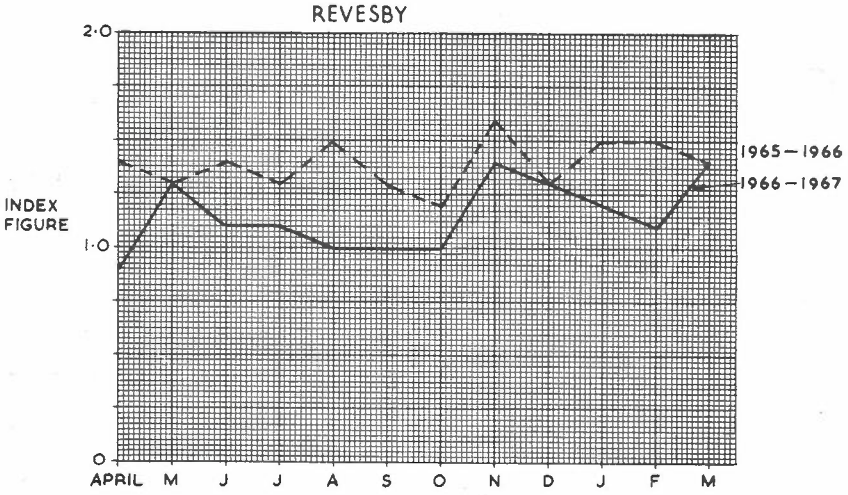
The prototype rapid testers used in the Sydney metropolitan network were developed by Mr. L. Bradley, Supervising Technician, Balgowlah Exchange in 1958. These comprised a group selector, final selector and discriminating selector repeater tester, and used subscriber registers to record the number of defective switches. In 1964, a B.P.O. printer (used with the Subscriber Call Record Print Equipment) was employed to give more detailed print-out information than that available with the registers.

Initially the testers had to be started manually during the day, but in 1959 an electric clock mechanism was attached which automatically started the testers after hours. By doing so, full advantage could be taken of low traffic density in the exchange and therefore maximum access of the testers to non-busy switches. The early a.m. hours were chosen as the testing period.

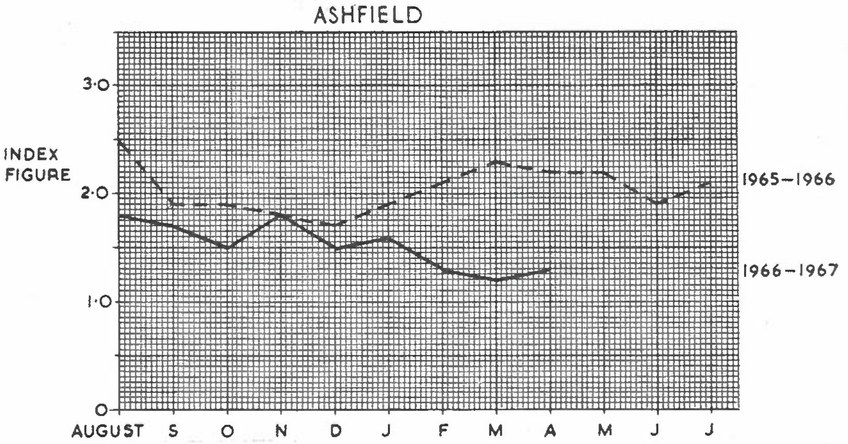
The A.P.O. Headquarters had been working along similar lines. In 1963 a modification to the standard Group Selector routiner was notified to the States. It was designed to convert them to functional rapid test operation with the added facilities of variable level testing. This modification was expensive in terms of labour, because it involved alteration to the hard wiring of the testers. Because of the many thousands of hours needed to complete the work throughout the Sydney network,



RAPID TESTERS INSTALLED JUNE 1965



RAPID TESTERS INSTALLED APRIL 1966



RAPID TESTERS COMPLETED IN AUGUST 1966 (MAJOR POSITION)

Fig. 1. — Graphs of Performance at Bankstown, Revesby and Ashfield Exchanges Showing Effect of Rapid Testers.

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* Mr. Bloxom is Senior Technical Officer, Metro Branch, N.S.W. See Vol. 15, No. 2, Page 160.

** Mr. Way is Engineer Class 4, Metro Branch, N.S.W.

the principle adopted by Mr. Bradley became a far more attractive proposition. In the latter case the new facilities are incorporated in a relay set which can be mass produced on a production line basis. Relatively few hours work are required to wire the relay set to the routiner.

DEVELOPMENT OF THE CONVERSION RELAY SET

The prototype of the production line relay set was made up during June-July of 1965 for the Bankstown exchange. The graphs of performance, Fig. 1, indicate how successful this proved to be. The prototype was produced in consultation with the Postal Workshops staff at Sydenham, and included minor improvement, to the Balgowlah exchange version and, the addition of a Sodeco printer. Two relay set bases were used.

For mass production, further refinement took place to compress the unit to a single base for both the group and final selector testers. These were produced for a cost of $130.00 and $140.00 each respectively. Approximately 40 manhours were required in the exchange for attachment of the relay set to the routiner.

It is of interest to note that designs to make use of teleprinters for print-out were examined by Mr. J. Harris, Engineer Class 2, Equipment Service N.S.W. and a workable solution was derived. However, in the interests of standardisation simplicity and costs, the Sodeco printer installation was finally adopted.

APPLICATION OF RAPID TESTERS

The rapid functional tester enables service personnel to apply qualitative or controlled maintenance in their exchanges with a much greater degree of confidence.

The testers will check every one of several thousand selectors in an exchange and record the details of faults detected. Having this information means that a dependable history of the plant performance for that particular exchange can be built-up. From such a history, the characteristic behaviour pattern of the equipment can be derived, which enables any departures from random fault incidence to be instantly recognised. Knowing this, the probability of failure for the equipment may be calculated.

The frequency of testing depends upon the plant performance objective and the probability of failure, which in effect relates directly to the reliability of the switching equipment. Projects to be undertaken to sustain or improve matters could well be initiated as a result of the evidence produced by the printers.

Experience to date with group selector testers is that with nightly test runs, a figure of 0.1% defectives (one selector failure per thousand switches) can be reached and sustained with plant in moderate condition. For very good equipment, a lower defective rate can be maintained with less frequent testing.

The maintenance objective is quite clear. Defective selectors are to be cleared from traffic immediately after each test and prior to the ensuing busy hour. This is done either by clearing the fault or busying the selector. In the latter case faults must be rectified within 24 hours. The service requirement is for each selector to be in a functionally sound condition so that a successful operation of the switch will take place at each first attempt by a subscriber.

The reliability of the equipment could be far from satisfactory and it may be impracticable to complete an effective rehabilitation project, quickly. In these circumstances, it is the contention that every opportunity should be seized to run the tests between each busy hour in an effort to reduce the in-service time of faulty or defective equipment. The rapid tester is fast enough to permit this to be done. In doing this the fault situation can be kept under control, but obviously the principles of qualitative maintenance would dictate that service action on an extensive scale should automatically follow until reliability in plant performance is once again restored to the equipment.

Summarising then, the rapid functional tester enables:

(a) All selectors in the exchange (amounting generally to thousands) to be quickly tested for functional operation at negligible cost.
(b) Defective selectors to be exposed and to be taken out of service — thus reducing the in-service time of faulty apparatus.
(c) Economical testing after hours or in unattended exchanges during the most suitable hours for testing.
(d) The characteristic performance of the equipment to be derived. Also the probability of failure to be deduced and consequently plant performance trends and project tasks to be more easily assessed.
(e) The quality of workmanship to be supervised. Positive recognition is given of any service activities leading to subsequent early failure or breakdown in reliability.
(f) More soundly based decisions to be reached on matters of service project work needed to maintain standards of performance.
(g) Service personnel to maintain control over their exchange with minimum staff, yet with increased confidence. (Experience would indicate that this situation is reached 2 or 3 months after the introduction of the rapid tester, and will happen only when defectives are being cleared in a thoroughly reliable manner).

PRINCIPLE OF OPERATION OF RAPID TESTERS

The conversion to rapid testing of 2000 and SE50 type exchanges by the modification of existing automatic routiners is a relatively simple operation. These routiners consist of 2 units:

(a) An access control unit, and
(b) A test unit

A routiner is converted by the addition of a standard relay set which provides for the quick functional tests. For this purpose it supplants the normal routiner test unit. (The full test cycle of the routiner test unit is still available at all times, by the simple restoration of the rapid test start keys). In addition to the standard relay set minor wiring additions and key provisions are required.

For automatic start and print-out the following equipment is additionally required per exchange:

240V a.c. time clock
5 Wheel "Sodeco" Printer (Type Tpb7)
Printer control relay set
5 Level control uniselector
8 Level scan uniselector (one for each working routiner)

The circuit arrangements shown in Fig. 2 apply to 2000 or SE50 type step-by-step equipment routiners and are designed to serve the group selector, final selector, D.S.R. or Auto-Auto repeaters.

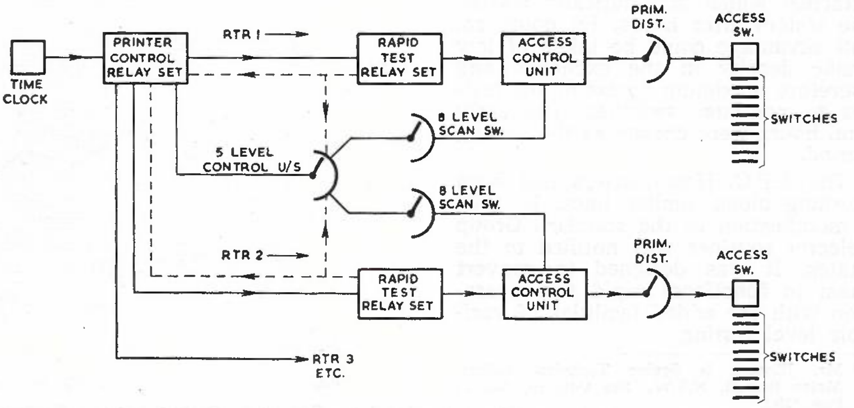


Fig. 2 — Block Schematic for Rapid Testing with Automatic Start and Print-Out for 2000 and SE50 Type Routiners.

Furthermore the arrangement is the same for pre-2000 type equipment of similar types except that the whole of the equipment in the schematic has to be manufactured and installed. There were no routiners or access wiring provided in the years when this equipment was being installed.

TYPES OF RAPID TEST UNIT

The following types are currently in use or being installed in the Sydney network.

(a) 2000/SE50 Group Selector (Dwg. ND. 34229)
(b) 2000/SE50 Final Selector (Dwg. ND. 33930)
(c) 2000/SE50 Auto/Auto Junction Tester (Dwg. ND. 34619)
(d) 2000/SE50 Discriminating Selector Repeater (Dwg. ND. 36025)
(e) Pre-2000 Group Selector (Dwg. ND. 35402)
(f) Pre-2000 Final Slector (Dwg. ND. 35403)
(g) Pre-2000 Auto/Auto Junction Tester (Dwg. ND. 34384)
(h) Pre-2000 Access Control (Dwg. ND. 34359)
(i) Printer Control R/S (Dwg. ND. 33928)

Types (a) to (d) inclusive use existing routiner access control equipment, whilst (e) to (g) are completely developed routiners provisioned with access switches and wiring to the equipment to be tested. Each rapid test unit has 'plug-in' type relay sets.

All or any of these types of testers can be connected to a single printer control relay set and printer, the limit in number being determined by the volume of print-out. In practice, about 8 testers per printer appears to be a desirable maximum. A reduction from this figure applies where switching plant in poor condition repeatedly gives a voluminous print-out.

All of the various type testers in (a) to (g) are in use nightly throughout the Sydney network. Because of existing routiner access equipment in the 2000/SE50 type exchanges, a maximum effort in the early period of the project was directed to providing rapid test and print-out to these types of exchange to enable a quick return in improved service performance to be obtained. The volume of work in building routiners and providing routiner access to pre-2000 type equipment has resulted in slower conversion of this type of equipment.

GENERAL DESCRIPTION OF AUTOMATIC START AND PRINT-OUT

At 1.00 a.m. daily in a typical exchange, a 240V time clock provides a start earth to a printer control relay set where a relay expands this earth to a multiple number of starts to various type routiners (rapid testers) in the exchange.

All routiners commence testing at once, starting with the first switch or equipment to which they have access. From this time the printer control relay set will accept calls from any of the rapid testers it is serving. Such calls will originate from either one of two causes:—

(a) On the rapid tester detecting a faulty selector
(b) On the rapid tester detecting a selector busy

When the printer control relay set is called by a tester, a 5 level control uniselector associated with it, searches for the calling tester. The control uniselector is a homing type and the rapid testers are arranged on consecutive contacts around the banks. The steps taken by the control uniselector are repeated in impulse form to wheel 1 of the Sodeco Printer; and are arrested when the uniselector stops on finding the calling tester. This printer wheel then has the testers identity. The printer control relay set then steps the 8 level scanning uniselector associated with the calling tester. The banks of this scan switch are wired to the routiners primary lamps, shelf-lamps and switch lamps and 3 fault categories. The scan switch is stepped at 10 pulses per second over these circuits and in-parallel pulses are sent to wheel 3 of the printer. Again the pulses to the wheel are arrested when the scan switch wipers momentarily rest on the primary lamp contact in use, giving the printer wheel the primary lamp identity, but the scan switch is stepped on. Printer control circuitry functions to print this information. Printer wheels are reset to zero and the paper moved forward in the printer for the 2nd line print-out. At this point the 8 level scan switch will have returned to normal. The scan switch is again stepped by the printer control relay set, its functions in this search are to determine (i) the fault code or category (ii) the shelf lamp and (iii) the selector in the shelf. This information is passed to wheels 1-3 and 5 respectively of the printer.

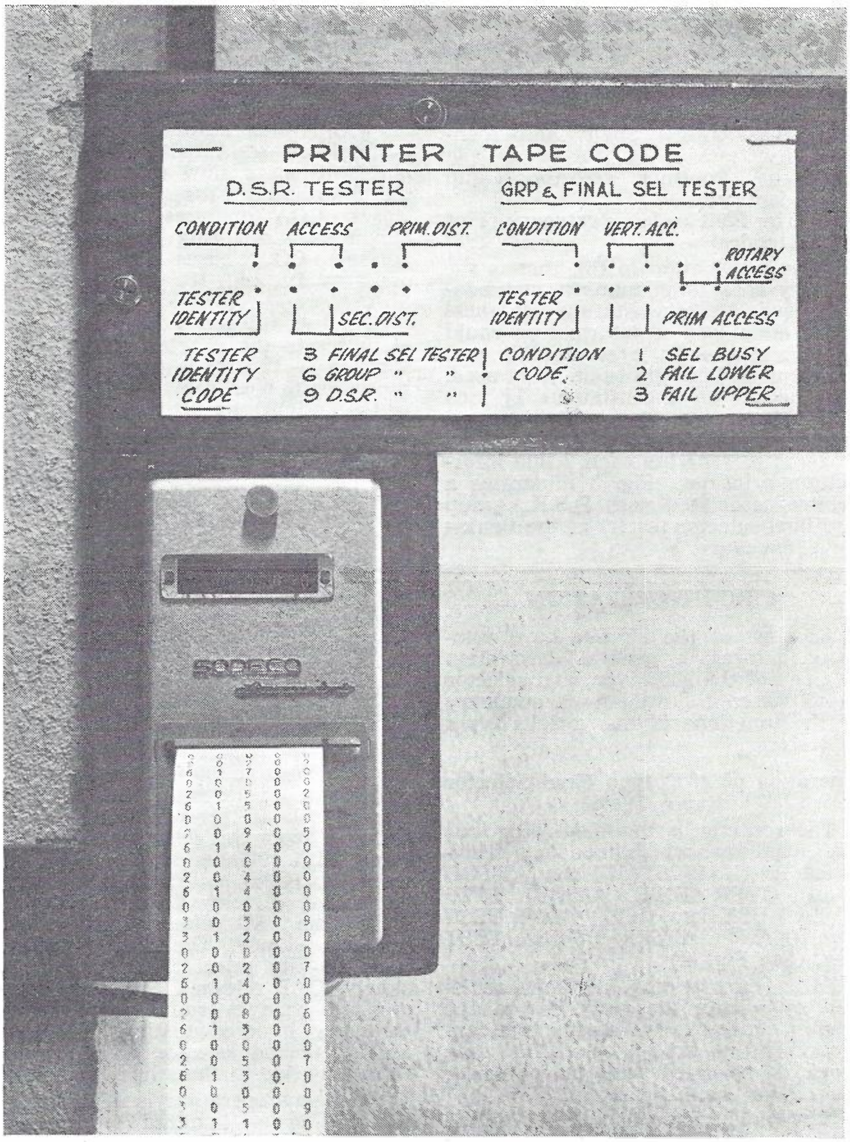


Fig. 3 — Sodeco Type Printer Common to Three Routiners.

Printer control relay set circuitry functions to print this information as a second line print-out, and then after resetting all printer wheels to zero, prints this zero reset as a separation between fault print-outs. The relay set resets the calling tester by application of earth to its 'test finish' lead, the tester is freed and steps automatically to the next selector to which it has access. The printer control relay set is freed and the control uniselector returns home. The printer control is ready to accept the next call. When simultaneous calls are made to the printer control relay set from 2 or more testers, the tester wired to the earliest bank contact of the control uniselector has first priority and other testers wait in this order, for the printer circuit to become free. After each fault print-out the printer control relay set circuit restores and the control uniselector homes to normal.

In summary the information passed from the printer control relay set to the printer comprises 5 bits.

(a) The Routiner (or Rapid Tester) Identity
(b) The Rountiner Primary Rack Lamp Identity
(c) The Routiner Shelf Lamp Identity
(d) The Routiner selector Lamp Identity
(e) The fault code or category (1 of 3 codes)

As the information in (b), that is the primary rack lamp number, commonly exceeds 10, necessitating a 2 wheel print, all 5 lots of information could not be printed in a single line and hence a 2 line print-out was used. This occurs on a continuous 1½ inch wide paper tape, the printer control relay set providing a distinctive row of zeros to separate each 2 line information print-out. Fig. 3 illustrates a printer associated with D.S.R., group and final selector testers at the Bankstown exchange.

CIRCUIT OPERATION

As most of the circuits have common features, a general description is given of the 2000 type final selector rapid tester, followed by a summary of the functions of the various types of testers.

Operation of 2000 type Final Selector Rapid Tester

The routiner is modified with four additional keys which have been designated as (KST) START key, (KSOI) STEP OVER IDLE, (KSOB) STEP OVER BUSY key, (KTT) TONE TEST key, (KAHT) AFTER HOURS TEST key. (See Fig. 4.)

After-hours testing has been achieved by wiring the relay set to the printer control relay set which is controlled by a time clock. This time clock is provided with an overrider switch for manual control.

The rapid tester is started by the operation of the KST key, KAHT key and the normal start key associated with the routiner. The rapid tester operates when the time clock starts the printer control or when the overrider switch is operated.

Positive on the "TS" lead, from the access control circuit, operates OAA relay, and SL relay slowly via a thermistor. SLA operates secondary to SL closing the circuit for OAB to operate. C relay is placed on a slow release of 8 seconds to time the complete test. IP operates. (It is presumed the final selector under test is free.) A loop is extended to the selector by SL operating. SLA transfers the private wire from the P relay to the PT relay which now monitors the private during the duration of the test. Any O/C private condition allows PT to operate and lock on its second winding, thus removing the positive from the successful test (SO relay) chain. IL operates slowly giving the A relay of the selector sufficient time to fully flux. IL operates the pulsing relay IG which commences to pulse at 10 pulses per second.

Pulsing of the CRA relay and the selector under test occur at the same time. When nine pulses have been sent, finger 9 of the CRA relay operates CO, which stops IG from pulsing and releases IL. CO, in operating, places IP on a slow release to time the interdigital pause. When IP releases, COA operates and CRA is blown out, restoring the fingers to normal. CO releases slowly and reoperates IP and IL. COA locks to SLA.

IG pulses and sends the second train of pulses to the A relay of the selector and to the CRA relay; when ten pulses have been sent, the 10th finger of CRA (COB), operates slowly giving time for an eleventh digit to be sent to the A relay. COB operates and locks to SLA, CO operates, and IL and IG release. The selector is then up 9 in 11 and the H relay of the selector operates to the dummy K placed on the lower hundred private by the SLA. K operates in series with the H relay.

Ringing conditions are extended from the selector, F in selector operates followed by the D relay via R11.

Reversal is given back to the A relay. REV relay in the test unit operates. CA checks for correct wiper polarity and operates if polarity is correct. Positive battery meter pulse on private operates M. SO operates causing SL to release. The loop is removed from the selector which restores. SLA releases slowly, OAA releases but OAB holds. C5 is re-charged to give C relay its next slow release time. SO releases slowly. SL operates slowly. The loop is re-applied to the selector. SLA operates slowly. OAB releases. SLT now operates and changes from lower hundred to upper hundred testing. The loop applied to the selector now changes from long line to short line conditions.

The relay operation is repeated as for the lower hundred testing but when SO operates, an earth extended on the test finish lead steps the access control equipment to the next selector.

Tone Test: With the Key TONE TEST (KTT) operated the rapid tester checks for ring tone while testing the lower hundred (after ring is applied to the line the trip circuit is O/C) and the routiner valve is connected across the loop circuit by the COA relay. When the valve circuit has detected ring tone AR operates followed by ARA slowly. SO operates, which causes the rapid tester to restore.

When the selector is pulsed to level 9 contact 11 for the upper hundred testing the absence of K relay battery on the private causes a busy line test, the valve input is again placed across the loop which is still in long line conditions due to KTT being operated. Busy tone being detected, causes AR to operate followed by ARA. SO operates and positive is placed on test finish lead, which steps the access equipment.

Testing of Large Group Finals: The testing of two digit large group selectors, has been achieved, by strapping the primary lamps that indicate the large group selectors, via diodes to relay LGX. The operation of this relay converts the rapid tester to step the selector to level 9, search for the first free outlet and check the functions as for the ordinary final selector. With relay LGX operated, the test is completed at this point, and the access control stepped to the next selector.

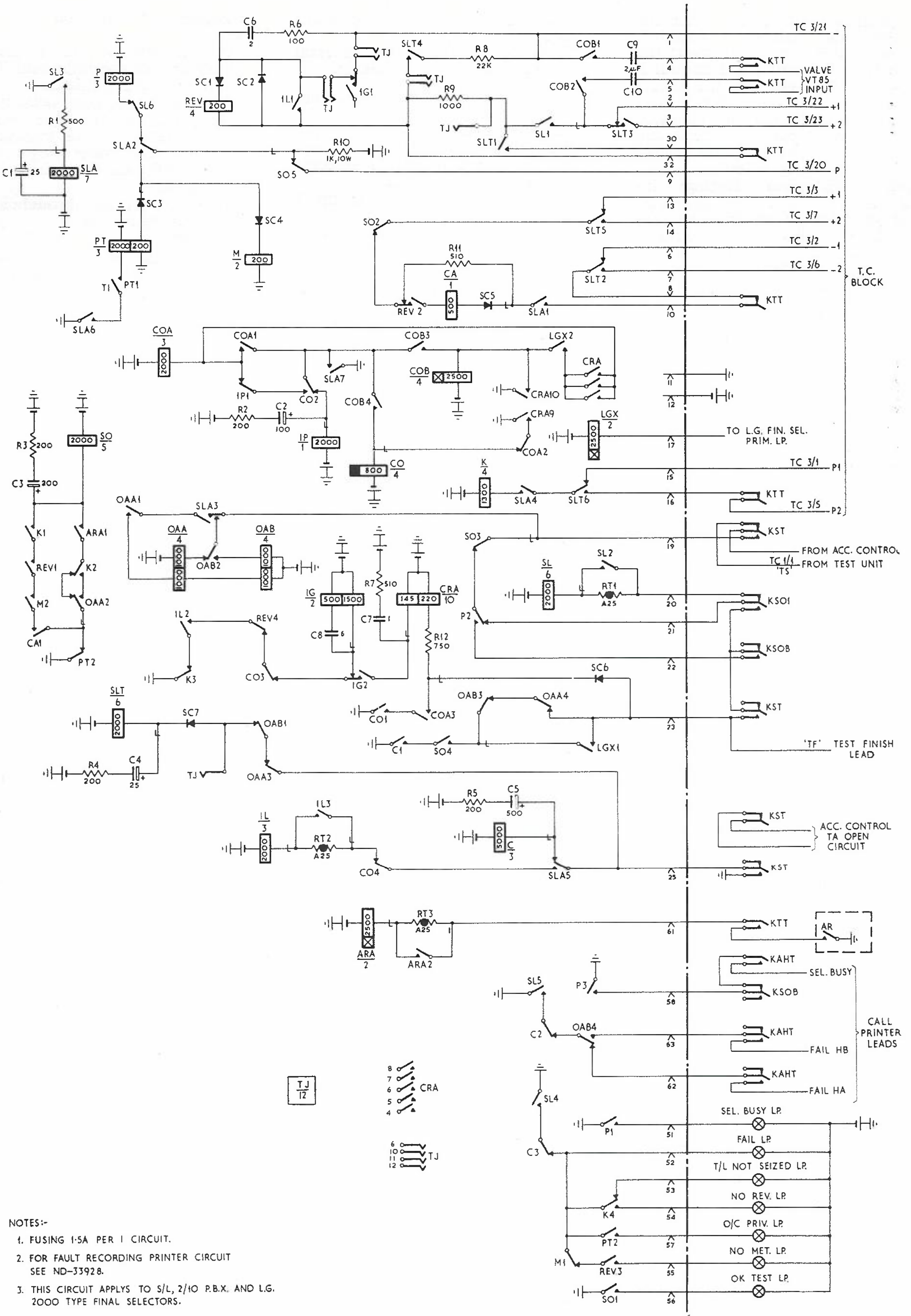
Modifications have recently been completed to allow the testing of one digit large group final selectors.

Faulty Final Selector: From the time SLA operated at the commencement of the test, C relay has an 8 second release time for timing either the lower hundred or upper hundred test. If the test cycle is not successfully completed during this time, C relay releases, closes the circuit for the display of lamps indicating the fault, and prevents positive from being sent on the test finish lead.

Where the tester is being used as an automatic routiner the Key KAHT (AFTER HOURS TEST) will be operated which extends a positive to the printer control circuit on one of two leads. This will cause the Sodeco printer to print out the necessary information indicating which selector has failed, followed by a positive on the test finish lead causing the access equipment to step to the next selector.

When busy selectors are to be recorded on the printer, relay P which operates if the selector under test has a positive on the private, will call in the printer and stop SL from operating.

Step Over Busy-Step Over Idle: Where a 'step over busy' feature is required, operation of the KSOB key places test start under control of the private testing relay P. If the final selector is busy, positive from TS lead is diverted to the TF lead by an operated P springest and the access control equipment steps on without a start



NOTES:-

1. FUSING 1·5A PER 1 CIRCUIT.
2. FOR FAULT RECORDING PRINTER CIRCUIT SEE ND-33928.
3. THIS CIRCUIT APPLIES TO S/L, 2/10 P.B.X. AND L.G. 2000 TYPE FINAL SELECTORS.

Fig. 4 — Rapid Test Relay Set Associated with 2000 Type Final Selector Routiner.

being given to rapid tester. When the 'step over idle' feature is required, operation of KSO1 key will divert the positive from TS lead via a normal P spring-set to TF lead and the access equipment will step on. When a busy selector is encountered the operated P spring-set will open this circuit and if key KAHT is operated the printer will record the busy selector.

Impulse Distortion Testing: Included in the circuit is provision for the insertion of an Impulse Distortion Unit. Links in test jacks 1 and 2, 3 and 4 are removed, and link in 7 and 8 is transferred to 8 and 9. The test plug from the distortion unit is plugged into TJ 1, 5. On lower hundred testing the output of the IG relay is returned to TJ 1 and 4 as a 20% make ratio. When the rapid tester changes to upper hundred testing, positive to TJ5 operates a relay in the distortion unit causing a change to a 60% make ratio; these distorted impulses are then delivered to the selector under test.

Functions of Other Types

The 2000 type/SE50 Type (Group Selector) Rapid Tester:

1. Tests the selector switching HA (long line).
2. Tests the selector switching HB (short line).
3. Monitors the private from loop to completion of all tests.
4. Checks the polarity of wiper cords.
5. Allows HA/HB testing on any levels from 1-0. This is done by means of the level selector switch.
6. On level 9, checks that the switch is driven to the correct level by seizure of the 19th and 20th trunk (HA and HB).
7. With the use of the impulse distortion set, allows the selector to be checked for performance with a 20% and 60% make pulse ratio (level 9).
8. Check of selectors "Off Normal" or looped be performed manually by operation of the "step over idle" key.
9. With "step over busy" key operated during busy traffic, a random outlet tests may be performed to prove bank wiring, etc.
10. On failing a test or detecting a busy switch, tester calls printer and after printing, resets for next test. The tester takes approximately 6 seconds for HA/HB switching functions.

Functions of the 2000 Type Auto-Auto Junction Tester:

(Functions of pre-2000 type Junction Tester similar.)

1. Checks the repeater for busy or idle condition.
2. Sends 1-2-3-4 or more digits, appropriate to the junctions particular reversal number.
3. Constantly monitors the private condition.
4. Checks for 3 Reversals from the distant Exchange answering relay base.
5. Provides 3 re-tests before printing.
6. Tests for a premature reversal before and between pulsing.

Functions of Pre-2000 Access Control:

1. On operation of the Start Key the primary distributor is stepped to the first access selector which is seized if free.
2. Steps the access selector up 1 and in 1 to connect the test commons to the selector under test.
3. Steps the access selector after each test.
4. Operates a lamp display to show the particular selector being tested.
5. Provides usual facilities such as, manual setup, continuous routine, step on, reset, step over busy, step over idle, un-equipped position, routine finish etc.

Functions of Pre-2000 G/S Test Unit:

1. Checks selector under test for busy or free condition and if free, applies loop conditions.
2. Checks for correct polarity and steps G/S to the level selected by the level selector switch.
3. Sends pulses under long or short line conditions, depending on key operation.
4. Monitors private throughout the test for open circuit or high resistance.
5. In the case of a Tone Test, receives a tone to ensure G/S has reached the correct level.
6. In the case of the switching test, checks that the G/S has stepped off normal and seized an outlet.
7. Checks polarity of wiper cords, and continuity of negative positive and private.

Fig. 5 — Pre-2000 Type Routiners — two per Rack.

8. Breaks the loop and tests for release guard ground as the G/S is releasing.
9. Sends pre-distorted impulses to the G/S when an impulse distorter is connected via the test jacks.
10. Detects fault conditions and calls in the printer.
11. Steps access equipment at the end of each test. The tester takes approximately 2½ seconds to test each selector.

Functions of Pre-2000 F/S Test Unit:

1. Checks F/S for busy or free condition and if free, applies loop conditions.
2. Checks for correct polarity and steps F/S to the test line (usually 99) under long or short line conditions, depending on key operation.
3. Monitors the private throughout the test for open circuit or high resistance.
4. Checks that selector seizes the test line and applies ring conditions.
5. Checks for presence of ring tone.
6. Trips the ring.
7. Detects a polarity reversal when the ring is tripped.
8. Checks polarity of wiper cords and continuity of negative positive and private.
9. Breaks loop and tests for release guard ground during release.
10. Sends pre-distorted pulses to selector when an pulse distorter is connected via the test jacks.
11. Detects fault conditions and calls the printer.
12. Steps access equipment at the end of each test.
13. With the Tone Test and Line keys operated, to test the selector for ring tone and busy tone.

Because in pre-2000 exchanges, the 99 test number is not always available, another relay set can be installed, which will change the number dialled by the test unit to correspond with the test number allocated to the particular F/S or group of F/S's being tested.

The tester takes approximately 6 seconds to test each selector.

Function of D.S.R. Test Unit:

1. Tests for busy selectors.
2. Tests for idle selectors.
3. Tests search and switching of junction-hunter transmission bridge etc.
4. Monitors private from time of seizure.
5. Pulses long or short line up 9 in 11 to prove vertical and rotary of selector.
6. Switches 9/11 to prove wiper continuity and polarity.
7. Checks repeating of A relay pulsing.
8. Provides facilities for connection of pulse distorter.
9. Provides normal "step over busy" or "step over idle" facilities.

INSTALLATION ASPECTS

All relay sets associated with rapid testing are of the 2000 plug in type relay set.

In 2000 or SE50 type exchanges, on existing routiners where space was available, a channel bar mounted and wired with a double row of 32 point U jacks, was used to accommodate a number of relay sets. Alternatively the relay sets were located remotely from the routiners on a MAR or similar rack. The control uniselector was mounted in a relay set and the 8 level scan uniselectors individual to each routiner or tester, were mounted on the routiner next to the primary distribution uniselector. A short form connected the scan switch to the primary, shelf and switch lamps.

In pre-2000 type exchanges, where there were no previous existing routiners or access wiring, a routiner patterned on the B.P.O. model was designed and after some development, it was possible to accommodate 2 separate routiners or rapid testers, on one 8 ft 6 in rack. (See Fig. 5.)

In all, the equipment mounted on the rack comprised a printer control relay set, alarm relay set, two test units, two access control units, two control panels of primary, shelf and switch lamps and associated control keys. Additionally two primary distribution uniselectors, two 8 level scan switches and one 5 level control uniselector.

The usage of this type of routiner fell into 2 categories:

(a) Pre-2000 type main exchanges where large numbers of selectors had to be tested.
(b) Pre-2000 type branch exchanges where usually smaller quantities group selectors were to be tested in addition to final selectors. A maximum of 3200 pre-2000 group selectors, was fixed as a practicable maximum for any one tester to handle, and because greater quantities were entailed in main exchanges, it was decided that the routiner rack cable forms be made and wired so that the rack would function as 2 group selector testers in a main, or as a single group and single final selector tester in branch exchanges. The selection of keys, U jacks etc. were nominated to perform the dual role.

By a simple change of plug in test unit, a pre-wired routiner rack may be converted from a two group to a group plus final selector tester. The supervisory lamps were signwritten according to the test unit types to be used.

A project team comprising 4 technician assistants together with a senior technician as supervisor completed a 2 in 1 routiner rack of this type every 2 weeks, at a labour cost of $800, plus material. (All plug-in type bases were manufactured by contractors to Post Office circuits and specifications).

PRE-2000 ROUTINER ACCESS

The provision of routiner access to pre-2000 group selector bays, was made in early installations by utilising two modified 200 bank 2000 type group selectors, mounted on each side of a double sided bay. Because of the acute shortage of these selectors, this arrangement was abandoned and 100 bank pre-2000 group; final and S.S.R. switches recovered from replaced pre-2000 exchanges, were modified and used in groups of 3,

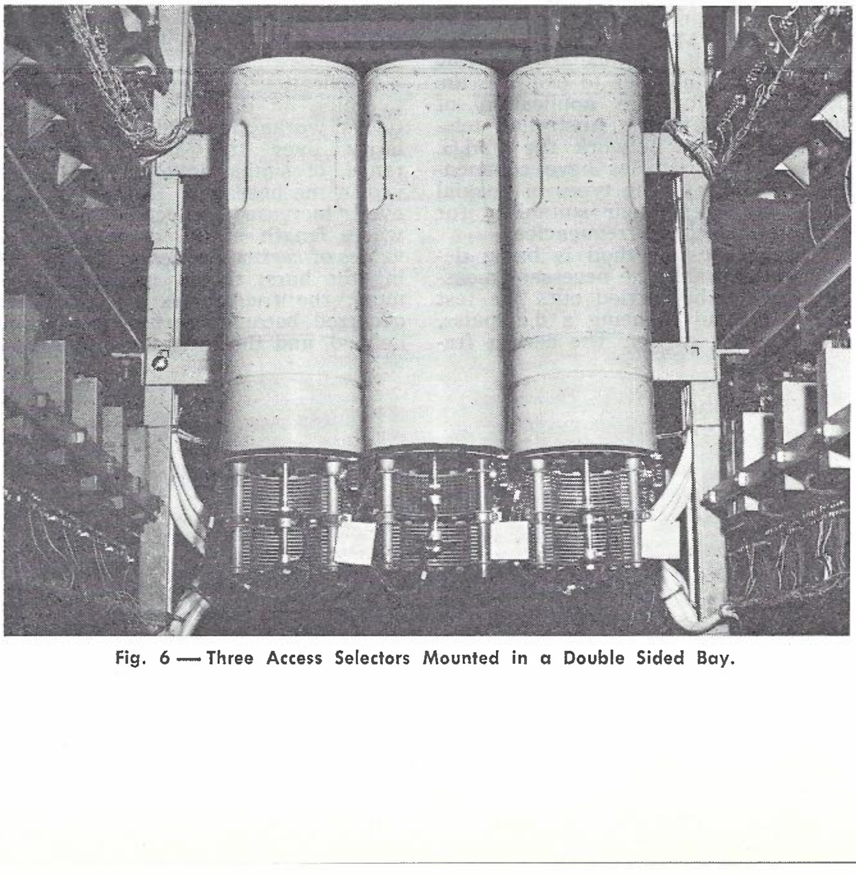


Fig. 6 — Three Access Selectors Mounted in a Double Sided Bay.

working levels 1-8, to provide access to the 240 selectors on a double sided bay, (see Fig. 6). Recovered banks were strapped and tailed with 63 wire cable cut to length, which was then secured and laced into the bays; the 20/3 wire circuits terminating on negative positive and private U jacks. Obsolete recovered D.S.R.'s have been used as access switches for the same purpose.

To reduce the time, cost and size of providing pre-2000 final selector routiner access, a different expedient was used. In a 6 digit numbered pre-2000 type exchange, a pre-2000 type late choice 4th selector was nominated in each 1000 group and modified by the addition of a relay to serve as an access selector for after hours or light traffic condition testing. The maximum number of final selectors in any 1000 group available for test by this means is a 100. Where the number of final selectors in a 1000 group exceeds this quantity, a tailed bank as described earlier was provided with 3 wire circuits to connect the balance of such finals.

CONCLUSION

In June, 1967 all testers for group selectors and final selectors 2000 type in the Sydney Metropolitan Network were converted to functional operation. At the same time, all pre-2000 type equipment to be retained over a number of years were wired for functional testing.

The experience to date has been such that a decided improvement in performance at each exchange has resulted from the introduction of the rapid functional tester. It is recognised that the frequency of testing will remain high in a number of cases until such time as increased operational reliability is achieved: either by more extensive service project work or by the replacement of vintage or poorly conditioned equipment.

ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to many colleagues, in particular Mr. L. Bradley, Balgowlah exchange, for help and co-operation with the circuit development of the various testers. The assistance of Mr. D. Pool, Divisional Engineer and staff of the Network Performance Division is also acknowledged.

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TECHNICAL NEWS ITEM

AN INTERESTING PHENOMENON OBSERVED AT 30-60 MHz ON STANDARD LONG DISTANCE COAXIAL CABLE TUBES.

Transmission equipment manufacturers in Japan and Germany are well advanced with the development of 40 and 60 MHz systems for application to standard 0.375 in coaxial cable with the purpose of providing capacity for some 10,000 voice-type circuits per pair of tubes. It is expected that systems of this type with repeaters approximately every one mile (for 60 MHz) or 1.5 miles (for 40 MHz) will be available in the early 1970's. In order to examine the possibilities for the application of such systems in the Australian telecommunications network the P.M.G. Research Laboratories have commenced tests on existing types of coaxial cables to assess their suitability for operation at these frequencies.

An echo test method is being developed to enable the necessary measurements to be carried out. The test signal, instead of being a d.c. pulse, is a burst of carrier. The carrier frequency may be varied over any desired range — for the present purpose, 10 to 60 MHz — while the burst length is adjustable from some 10-20 nanoseconds to several microseconds. It was originally conceived that a burst length of 100-200 nanoseconds, (corresponding to the length of 50-100 nanoseconds of the pulse called for by the present A.P.O. Specification 925 for cable to operate at up to 12 MHz), would allow such a band anywhere in the stated range to be examined as critically as was possible for the baseband with the standard pulse.

Application of the test as described to cable on drums at the manufacturers' works indicated general irregularity over the stated frequency range, of similar level to that observed in the baseband. There was, however, increased reflection from the whole length of the cable at a few values of carrier frequency. On increasing the burst to 500 nanoseconds or more, the frequencies at which this occurred became much more sharply defined, and the intensity of the echo became very much higher, 40 dB below the input signal, whereas the level of the general irregularity was some 60 dB down. On a length of coaxial tube on a factory drum ready for assembly into a cable, this effect was observed at four sharply defined frequencies in the range 40-60 MHz. It has since been observed in a laid cable. It can be explained in terms of an impedance or capacitance variation recurring periodically along the cable at intervals of the order of 8 to 12 feet; the magnitude of the variation may be small, of the order of one or two parts in ten thousand.

The significance of these effects in relation to transmission is at present under examination. They have an effect on both transmission loss and group delay. Although the effect over one repeater section would be small, the recurrence of the effect at the same frequency over several hundred repeater sections may become significant. This aspect is being examined analytically, while attention is also being given to possible relevant factors in the manufacturing process.

RELIABLE CONTACTS AND CONNECTIONS IN TELECOMMUNICATION PLANT

*G. FLATAU, F.R.M.I.T.**

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INTRODUCTION

Every item of telecommunication equipment contains a number of points where various components are interconnected, either permanently or in such a way as to provide alternative electrical paths. In the design of such circuitry, great care is taken in the choice of component parameters in order that the equipment will operate as intended. However, failures will occur often purely because some metallic contact point increases significantly in resistance or perhaps even goes open-circuit, or acts as a source of intolerable noise or microphony. The correct choice of the mode of interconnection and the materials to be used, or rejected, is therefore as vital as the choice of suitable insulating materials if equipment reliability is to be kept high. In this paper, the various factors which affect contact performance and reliability are discussed, and the reason for the choice of certain configurations and contact metals in some typical applications is described. The voltages and currents used in the equipment under discussion are seldom very high, and the very special problems encountered in the field of power engineering will not be mentioned.

Contacts can be broadly classified into three categories, each of which have their own special problems and solutions, viz:

(a) *Operating or switching contacts.* This type of contact provides facilities for opening and closing under controlled conditions. However, the number of operations can vary over many orders of magnitude during the contact life. Typical examples are relay contacts, keying contacts and other examples of the "make", "break" or "changeover" type. Also included are sliding contacts as employed in uniselectors, rotary switches, etc.

(b) *Semi-permanent contacts.* Such connections are not regularly operated, but must be capable of performing their function if and when desired, and without incurring a degradation in their performance during long periods of idleness. This group includes plugs and sockets, jacks, edge connectors, etc.

(c) *Permanent contacts.* This category is intended to remain connected for the whole working life of the equipment, and if it has to be opened for repair or maintenance purposes the connection will usually have to be replaced. Examples are soldered, welded or crimped connections, and also solderless wrapped connections.

The theoretical treatment in the main follows Holm (Ref. 1), but a number of other books on this subject have also been consulted (Refs. 2, 3 and 4).

THE CONSTRICTION RESISTANCE

If two perfectly clean metal surfaces are slowly brought together, they will first touch at one or more points only, as no surface, irrespective of how good the surface finish, is ever perfectly smooth. Hence, first contact is made via the "high spots" of the surfaces, and if current is impressed across the contact pair, this current will flow from one contact to the other only via these microscopic asperities usually referred to as a-spots. The resistance encountered by the current flow is thus not due to the whole contact area, but only due to the very small cross-sectional area of true metallic contact, explaining why the contact resistance even with perfectly clean metallic surfaces is not zero, but has a finite value. This resistance, called the constriction resistance, can be calculated simply if one assumes that the contact spot is circular:

$$R_c = \frac{\rho_1+\rho_2}{4a}$$

R_c = constriction resistance of one a-spot.
a = radius of a-spot.
ρ_1, ρ_2 = electrical resistivity of the metals of the two contact members.

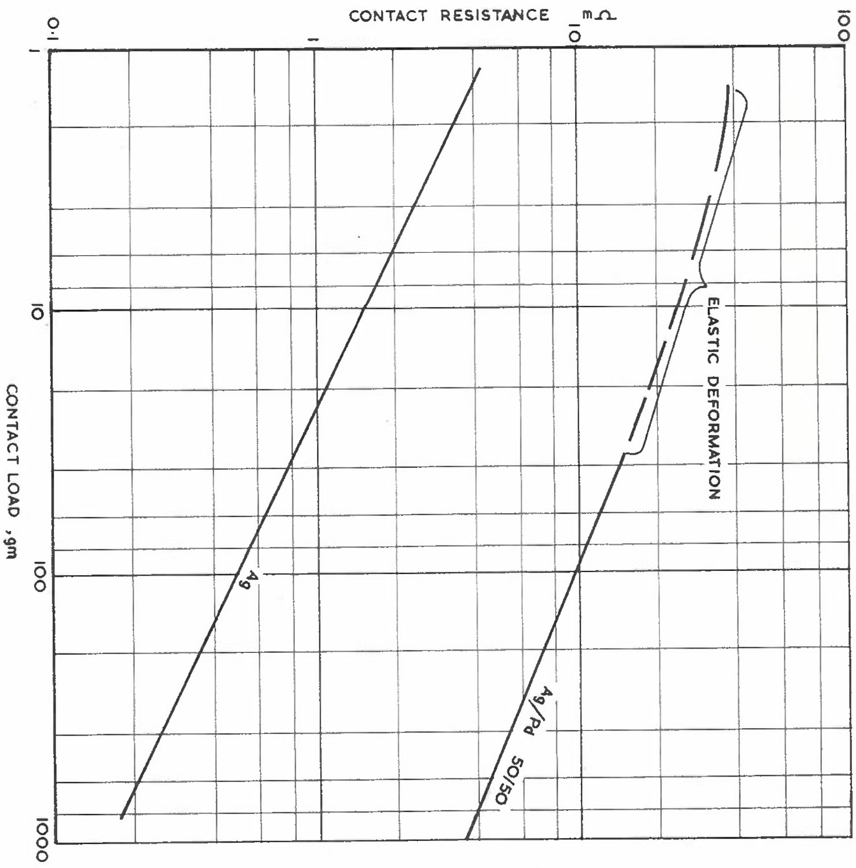

Fig. 1.—Resistance-Load Characteristic.

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[*] Mr. Flatau is Principal Officer, Physics and Polymer Sub-section, P.M.G. Research Laboratories, Melbourne.

Of course, in practice the a-spots are rarely circular, but conversion formulae are available. Also, in an actual contact pair, there would be generally more than one a-spot, hence the constriction resistances must be summed.

It is evident that with all current conduction taking place via a small number of these a-spots only, high current densities will exist at the true contacting surfaces, even when the current magnitude in the associated circuit is comparatively small. This must result in ohmic heating of the contacting surface and hence a temperature gradient will exist on both sides of the contact point, and the resistivity of the asperities will be higher at the tip than the base. Formulae to calculate the resultant resistance increase are given in Ref. 1.

THE CONTACT LOAD

When two contact surfaces are forced together under the action of an external load, the load bearing area will be the sum of all the contact, areas, or a-spots. As the external load is increased, the contact asperities will first deform elastically, and with higher loading permanent (plastic) deformation will occur. The change in contact area, and hence in resistance, is difficult to calculate for most common contact shapes, but the following formulae are applicable for contact between crossed cylinders of equal diameter, undergoing elastic deformation.—

$$a = k\sqrt[3]{\frac{Pr}{E}}$$

where a is the radius of the contact surface.

k is a constant

$= 0.86$ for Au, Ag, Pd.

$= 1.11$ for Cu, Ni.

r is the radius of the rod.

P is the load.

E is the Young's modulus of the rod metal.

$$R = 0.58\rho\sqrt[3]{\frac{E}{Pr}}$$

R is the contact resistance.

ρ is the resistivity of the metal.

In the practical case of flat contacts with some unevenness, the load bearing area A can be calculated, if one assumes that the asperities deform plastically whilst the underlying metal itself is deformed elastically. The asperities carry the entire load P, and deform until the average pressure P on them approaches or equals the contact hardness H. We then have:

$$A = \pi a^2 = \frac{P}{cH}$$

where c is a correction factor which depends on the surface finish and the mode of deformation, and can have values in the range 0.3-1.0. Under purely plastic deformation conditions the contact resistance is inversely proportional to the square root of the pressure (see Fig. 1).

THE MELTING VOLTAGE

As has been explained, two metal surfaces in contact really touch only at a number of a-spots, and the voltage drop at the contact is determined by the current and the constriction resistance. Any increase in current at a given load must result in an increase of the asperities temperature, because of ohmic heating, and, of course, the contact voltage drop also increases. (This is shown in Fig. 2, Region AB.) Because of the very high current densities involved, even at modest total currents, the stage is soon reached where the temperature causes softening of the metal in the asperities (BC), and eventually melting will take place (DE). The melting temperature is the highest temperature attainable in a solid contact, and thus every attempt to increase the contact voltage beyond the melting voltage, corresponding to this melting temperature, must result in the contact asperities collapsing and hence an increased contact area results. This larger contact area can carry the current without melting, and thus the voltage will drop below the melting voltage (EF). The only way the melting temperature could be exceeded would be by mechanically constraining the two contact surfaces from being able to approach each other when the asperities begin to collapse. (This is shown as dotted in Fig. 2.) In this manner, the boiling point of the metal can be reached, a phenomenon which, as will be described later, does happen in switching contact on opening. The softening, melting and boiling voltages of some

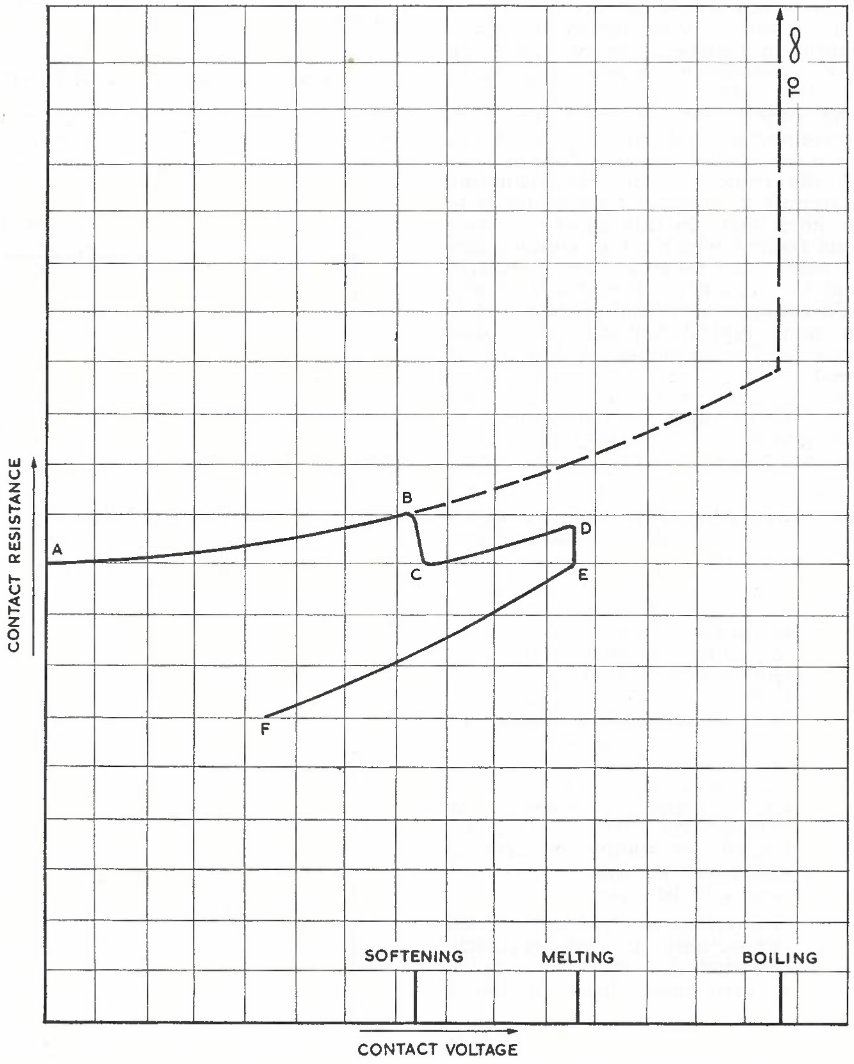

Fig. 2.—Resistance-Voltage Curve for Clean Symmetrical Metal Contacts.

typical contact metals are listed in Table I.

TABLE I

Metal	Softening Voltage	Melting Voltage	Boiling Voltage
Al	0.1	0.3	
Cu	0.12	0.43	0.79
Ag	0.09	0.37	0.67
Au	0.08	0.43	0.90
Pd		0.57	1.30
Pt	0.25	0.65	1.50
W	0.40	1.10	2.10

FRITTING

The contact surfaces considered up to this stage have been assumed to be perfectly clean. In practice, this ideal is unfortunately not always met, and the presence of surface films can profoundly affect contact performance and life. Surface films will be discussed in greater detail in a later section, and it will suffice to merely mention them here, and state their general properties. Tarnish films are met on most base metals and some noble metals, and are most commonly oxides or sulphides. Tarnish films consist of metal atoms or ions of the solid metal grouped in a lattice with oxygen, sulphur, etc. (e.g., Cu_2O, Ag_2S). Most tarnish films form, under favourable conditions, in a few seconds at room temperature, and even faster at elevated temperatures, and soon reach a thickness of 5-20 A° (1 A° = 1 Angstrom = $1/10^8$ cm). Subsequent growth is slower but can proceed at times to thicknesses of several hundred Angstroms. Most tarnish films have high resistivities, normally in the range 10^4 to 10^8 ohm-cm. Adhesion films, commonly oxides, are bound to the surface by van der Waal forces, or are chemisorbed, i.e. bound by covalent forces to the metal atoms. These films are generally extremely thin, and whilst of high resistivity, can usually be broken down by the tunnel effect. Passivating films are always thin, 10-15 A°, and penetrable by tunnelling electrons. Their mode of growth is still not clearly understood.

The various surface films would be an even greater problem in contact operation, if it were not for a phenomena commonly called "fritting". When a voltage is applied to a pair of contacts, insulated by a surface film, the electrical breakdown of the film is termed fritting. The process destroys the coherence of the dielectric film, either by electrically puncturing it, or by causing the film to recede around an existing a-spot, enabling metallic contact to be re-established. Holm (Ref. 1) distinguishes between two types of fritting. A-fritting implies that the breakdown leads to such a voltage as to just produce melting in at least one contact member. The ultimate result of A-fritting is a metallic micro-bridge through the insulating film. The bridge is easily destroyed by vibrations, and is also likely to be ruptured with time due to atom migration from the bridge to the parent contact. A-fritting makes itself evident in a sudden reduction of contact resistance, as the voltage across the contacts is increased from a low voltage to the "frit voltage". For Cu_2O, frit voltages range from 0.2 volt for a 60-A° thick film to 4 volts for a 1500-A° film.

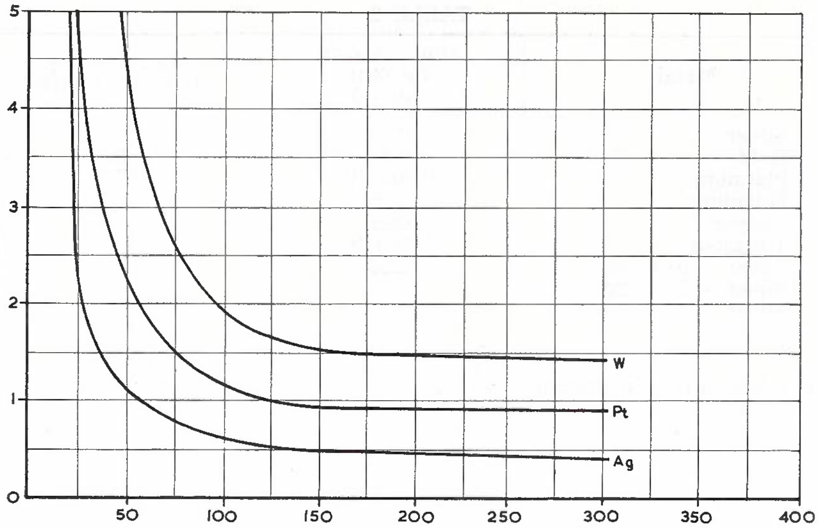

Fig. 3.—Limiting Arcing Current-Voltage Curves. (After Hunt, Ref. 4).

If the voltage at breakdown is too low to produce melting, one speaks of B-fritting. The usual effect is to produce an increase in the existing contact area by causing the film surrounding the a-spot to recede. B-fritting is confined to films thinner than 50 A°.

Fritting always requires electrical field strengths of the order 10^6–10^7 volts/cm.

ELECTRICAL PHENOMENA IN SWITCHING CONTACTS

When a pair of energized contacts are operated, an electrical discharge will occur under certain circumstances, either on opening or closing. As a consequence, the contact surfaces can become roughened, contact material can be lost, or transferred from one contact surface to the other, thus creating pips and craters. Electrical discharges and the resultant erosion of the contacts, often to the point of destruction, is the single most common cause of switching contact failure. A pair of contacts when closed will exhibit a resistance which is the sum of the constriction resistance and the resistance due to any surface films. As the contacts open, the load on the contacts decreases, and consequently the current carrying area is reduced, leading to an increase in resistance. As the current remains unchanged, the current density in the remaining contact area is greatly increased, and this will result in softening and then melting of the contact asperities. The molten metal forms a bridge between the two separating contacts, and if the rate of separation is slow enough such that it does not produce mechanical rupture of the bridge, the latter will heat to the boiling point and explode. As the hottest part of the bridge will be near the anode, material will be lost at the anode and built upon the cathode. Some contact materials exhibit a bridge diameter which is greater at the anode than at the cathode (e.g. gold, silver), whilst other metals have equal diameters at both electrodes (e.g. palladium, platinum). The former group usually produces greater amounts of material transfer. Erosion due to bridge transfer depends on the current magnitude, the current density as a function of time, the electrical and thermal conductivity of the contact metal, and the speed of opening.

Once the bridge on an opening contact pair has been ruptured, the resistance in the developing contact gap will be high, the voltage between the contacts will suddenly increase, and an electrical discharge can occur. One way in which such a discharge can occur is by the breakdown of the insulating medium separating the contact. The voltage required is a function of the contact gap and speed of separation, and in air has a lower limit of 300 volts (approx.) for zero gap width. With the lower magnitude voltages usually met in telecommunication circuits, it is, however, a different mode of discharge initiation which is of major importance. It can be shown that for any metal there is a minimum current and a minimum voltage below which arcing will not occur when contacts of this metal are opened. Table 2 shows values for some typical contact metals. These values are based on experimental results (e.g., Fig. 3) and are dependent on the cleanliness of the surfaces, relative humidity, and furthermore can at times be safely exceeded providing only one of the parameters is above the limiting value, whilst the other is kept well below it.

TABLE 2

Metal	Min. Arcing Current (amp.)	Min. Arcing Voltage (volts)
Silver	0.40	12
Gold	0.38	15
Platinum	0.70-1.10	17.5
Palladium	0.60	15
Copper	0.43	13
Tungsten	1.00-1.40	16-17
Silver +10% Pd	0.35	11
Silver +50% Pd	0.60	12
Silver +10% Au	0.25	11
Carbon	0.10-0.30	15-22

Providing either the minimum arcing voltage or current is exceeded, or a breakdown of the insulating medium takes place, the arc that occurs can take two distinct forms, the distinguishing factor being the direction of the material transfer. If arcing occurs at a time when the contact separation is still so small that the anode is within the influence of the positive space charge surrounding the cathode, one speaks of a "short arc", and material transfer is from anode to cathode. When the distance between the contacts is great enough that the anode is outside the cathode space charge, a "plasma arc" is produced with material transfer from cathode to anode. Fig. 4 shows the material transfer in a 6-volt, 5-amp. arc as a function of the inductive load on opening.

As the inductance increases, so does the duration during which the arc is maintained. It can be seen that beyond about 5 μH, the curves for gold and platinum tend to turn over, i.e., the arc changes from the "short" to the "plasma" form. This results in material transfer back from cathode to anode, which eventually reaches the stage where the cathode shows a net loss. Arc discharges are maintained at voltages from 10 to 20 volts. Another type of discharge, which can however occur only at voltages exceeding about 300 volts is the "glow discharge". Glow discharge material transfer is from cathode to anode, but generally presents few problems in the type of circuits under consideration, due to the high voltage requirements and the slowness of the process.

When a pair of contacts close, arcing or glow discharges can again take place, if voltage and/or current conditions are favourable. There is no bridge transfer, but instead welding of the contact surfaces can take place, if these surfaces on closure have "hot spots" in the molten condition. Contact welding can be particularly troublesome in contacts required to operate under small forces, which on opening might not be sufficient to fracture the welded areas.

Under certain circumstances of contamination, arcing can occur under electrical conditions which the theories quoted above designate as safe. The cause of this is the presence of carbon, usually as a consequence of certain organic vapours being present in the atmosphere, on the contact surface. The arc is then initiated between carbon, rather than metal surfaces, and as can be seen from Table 2 the minimum arcing current is much reduced. Because the arc will burn the carbon away at the point of strike, and new carbon compounds are continuously formed by the decomposition of the organic vapour, at other points of the surface, the arc tends to wander and restrike at different spots, with the result that the whole contact surface is being eroded. Contacts contaminated by carbon compounds in this manner are said to be "activated". Many substances have been proved to cause activation (Ref. 8), including kerosene, turpentine, benzene, styrene as well as many cleaning, waxing and polishing compounds which might otherwise be used in a building containing operating contacts. It is essential that any proprietary compound to be used for such purposes be tested for activation tendencies, before approvel for its use is given.

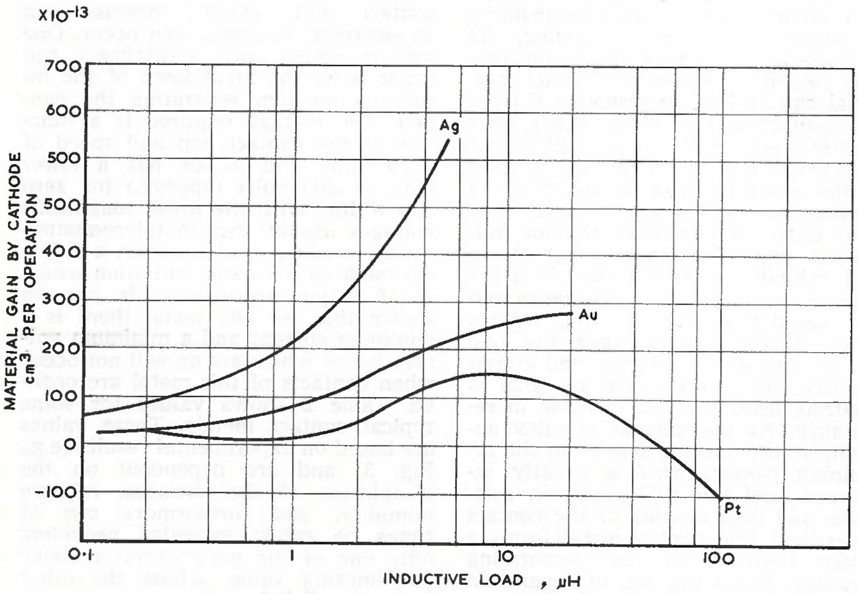

Fig. 4.—Material Transfer of Various Metals as a Function of Inductance. (After Keil, Ref. 2).

In the design of operating contacts and their associated circuitry, it is essential to consider the best means to prevent or at least reduce contact damage due to bridge transfer or arc erosion. If the contacts make and break no current, or only a very small current, there is no problem. However, if the current to be interrupted enters the range of tens of milliamperes or larger, or if transients due to reactive loads are encountered, steps have to be taken both in the selection of contact material and shape, as well as in the control of the electrical circuit parameters. Ideally, to prevent pips and craters of appreciable magnitude caused by bridge transfer, one would have to make the point of contact frequently change its position on the surface. This could be achieved by a rotating cathode, which is clearly an impractical solution. Another method is to use a metal or alloy which oxidizes in the hot stump of the ruptured bridge, and on cooling becomes relatively non-conductive, thus causing the contact area to be transferred on the next operation to another point on the surface. Instead of pips, there is now a tendency to form broad, low domes which will not seriously affect operation, although contact resistances of such metal pairs might be somewhat high. Other solutions which at times meet with success are the use of base metals plated with noble metals, or making one contact of noble metal and the other of base metal.

To prevent arcing, the contacts should operate as fast as possible. The minimum arcing current and voltage should, if possible, not be exceeded. In reactive circuits, where there is a likelihood of the breakdown of the insulating medium (usually air), a suitable suppression circuit (spark quench) will have to be incorporated. When the circuitry is such that the critical arcing voltages or currents are likely to be exceeded, the contact material chosen should tend to oxidize and hence force the arcing point to move to different locations. However, as it would be obviously undesirable to create conditions where the whole surface becomes oxidized and non-conducting, the properties of the oxide to be formed must be clearly understood. For comparatively moderate voltages, the oxide must be capable of being broken down by fritting. For higher voltages, the oxide should have a disassociation temperature lower than the arc temperature, so that the arc in effect can clean some of the oxidized surface surrounding the arcing point, and hence some clean metal is always present.

CAUSES OF HIGH CONTACT RESISTANCE AND FAILURE

Tarnish and Corrosion

In some of the previous discussion, it has been assumed that contact metal surfaces are perfectly clean, and that the total contact resistance is defined by the constriction resistance. In practice, this ideal state is never achievable, and surface films of metallic oxides, sulphides, chlorides, etc. are always present. On base metals, surface films will form or re-form after even the most thorough chemical cleaning, in a matter of seconds and rapidly grow to a thickness of tens of Angstroms; and at a slower rate they will often achieve thicknesses of the order of hundreds of Angstroms. Film growth rates are usually accelerated at elevated temperatures (particularly in the case of oxides) and hence heating of contacts in the presence of arcing will result in enhanced oxidation. However, the even higher temperatures in the arcing path can result in the decomposition of the oxides and thus ensure re-establishment of metallic contact. Certain surface films are self-passivating and will not grow beyond 10-20 A°. This type of film will be partially conducting due to the tunnel effect, whereas the thicker films mentioned previously have good insulating properties, with resistivities of the order of 10^3 to 10^8 ohm-cm.

The noble metals are much less subject to tarnish films, although an extremely thin oxide layer is usually present which, however, is easily penetrable by the tunnel effect. Silver will oxidize at ambient temperatures only in the presence of ozone, and gold, platinum and palladium will not oxidize in air. The most important tarnishing phenomenon affecting the noble metal family is the sulphide tarnishing of silver. The sulphide film grows slowly, changing in colour from gold to brown and eventually black as the thickness increases. The resistivity of silver sulphide lies in the range 10^4 to 10^8 ohm-cm. depending on how the structure is formed. The film growth is dependent on the availability of free sulphur atoms, and in clean, non-industrial atmospheres the tarnish thickness increases slowly. As the hydrogen sulphide and sulphur dioxide content of the air increases above a few part in a thousand million of air, the reaction rate is accelerated, and in certain locations, such as near steel mills or geothermal springs where concentrations might be greater by a factor of 100, tarnishing proceeds at a fantastic rate. However, in most instances it is not the sulphur compounds in the air which cause troubles, but rather sulphur containing materials associated with the equipment, such as rubber or ebonite, which are in close proximity to the contacts, often under a cover which restricts ventilation. Resistances up to 50 ohms are often encountered in telephone relay contacts in a matter of weeks, if the contacts are operated "dry". The silver sulphide tarnish film is extremely tenacious, and only mechanical means will clean the contact. Regrowth seems to be more rapid if the contact profile is pitted or scarred, no doubt because the tarnish cannot be cleaned out of these cavities, permitting the tarnish to creep out and over the cleaned surface. High humidities will assist film formation. Arcing will destroy the tarnish film at the contact points and high resistance problems are seldom encountered on contacts which "break" with a few volts applied. To protect silver contacts from sulphide tarnishing, plating with a thin gold or rhodium films is sometimes resorted to, but unless this protective film is non-porous, sulphide films will form at the pore sites (Ref. 7).

Polymer Deposits

Members of the platinum family of metals (in particular palladium) are likely to exhibit extremely high contact resistance when operated in the presence of certain organic materials (Refs. 5, 6, 14 and 16). The disturbance is due to a polymer type of film, often called "brown powder", which is formed by purely mechanical means, even on unenergized contacts. The film is formed by the frictional effect of the sliding action of the contacts acting on chemi-sorbed organic vapours on the metal surface, resulting in polymerization. Many aliphatic and aromatic compounds, in parts per million concentrations, have been shown to produce this effect, and many organic materials commonly used in telecommunication equipment are hazardous for the same reason. These materials include cellulose acetate, phenolics, acrylics, PVC, mylar, polystyrene and oleo-resin enamel. In some instances it has been shown that the plasticisers used are the chief source of organic vapour. Apart from palladium and platinum, polymer deposits are formed also on rhodium, tantalum, ruthenium, chromium, etc., and to a smaller degree even on gold. Silver is entirely immune from this phenomena, as are copper, nickel and tungsten, Alloys between susceptible and immune metals behave in an intermediate fashion, the polymer formation decreasing with reduced concentration of the catalytic metal. If contacts carrying polymer deposits are made to open or close under arcing conditions, the contact erosion will be very much more severe, because of activation, than what would be expected from a consideration of contact metal and circuit conditions only. No positive means to prevent polyermization has yet been discovered although some chemical inhibitors show promise (Ref. 9). The use of a gold alloy overlay has been partially successful (Ref. 7).

Silicone Films

The silicone materials are used extensively as lubricants, high-temperature insulants, sealing compounds and mould release agents. There is thus a strong possibility that contacts in telecommunication equipment will find themselves in close proximity to these materials or their vapours (Ref. 10). Evidence has accumulated over the past few years that many high resistance contact problems are directly attributable to the presence of silicone on the contacts, either due to deposition as a vapour or due to the creeping of silicone fluid from an adjoining structural part. The silicons are of course excellent insulators, and because of their extremely low surface tension will soon cover the entire contact surface with a continuous high-resistance film. If the contact pair is unenergized at make, the silicone film is almost impossible to displace even at the highest contact pressure, and a near open-circuit will result, as any subsequent applied voltage is rarely of sufficient magnitude to cause breakdown. However, if the contacts make or break with applied voltage of sufficient magnitude to create arcing conditions, the silicone will be decomposed to silica, a hard glassy material which adheres tenaciously to the underlying metal and cannot normally be removed without destroying the contact. Fluid silicone can be dissolved by some organic chemical, but unless the last vestige of silicone is removed not only from the contact but also from the source of contamination the film will re-establish itself rapidly. The hazards from silicone contaminations are regarded so seriously that in at least one telephone administration even the cosmetics used by operators in the manufacturing plant must be free of this material.

Dust

The presence of dust can be detrimental to contacts in two ways. In the case of operating contacts, dust particles lodged between contact surfaces can prevent complete closure, and as many types of dust are too hard to collapse under prevailing contact forces, metallic contact is prevented (Refs. 17 and 18). Under arcing conditions, pollutants of an organic or carbonaceous nature tend to enhance erosion due to activation of the metal surface. With sliding or rotating contacts, the main danger comes from hard, abrasive dust particles which will tend to score or abrade the contact surfaces and accelerate the normal wear phenomena. As a result of the severe abrasion, metal dust is often picked up by the moving contact and deposited on insulating parts, resulting in the bridging of the latter by metal dust, leading to arcing or tracking, and breakdown of the insulant.

Ageing and Relaxation

Contacts whose closure depends on the maintenance of applied mechanical forces, such as spring tensions, hoop, torsional or compressive stresses, sometimes are found to go high-resistance or even open-circuit with time. Whilst this is not a true contact phenomena (the associated structural support members being responsible), the problem is real and requires careful evaluation in design. Relaxation is a function of both time and temperature, and is furthermore dependent on the geometry of the contact configuration. As stress relief due to relaxation normally proceeds fairly slowly, malfunctioning of contacts is usually detected by increased microphony or noise, long before the contact resistance assumes a major magnitude.

Vibration

Many types of contacts are closed by fairly low applied forces, and in such cases vibrations transmitted from associated equipment can cause the contact pair to reopen at a frequency determined by the stiffness of their structural support members. Apart from the circuit interruptions, which might be tolerated by many types of equipment, there is the danger of greatly accelerated contact erosion, as a tiny arc will be struck each time the contacts open.

THE CHOICE OF CONTACT MATERIAL

The various factors which can affect contact performance having been discussed, Table 3 briefly summarizes the advantages and shortcomings of some of the more popular contact metals (Refs. 12 and 15).

RELIABILITY AND THE DESIGN OF CONTACTS

It is obvious that no general rules for contact design or expected reliability can be made, as the type of application, the operating environment as well as economic factors can differ over wide limits. In many instances, the associated equipment can tolerate reasonably large fluctuations in resistance (of the order of tens of ohms) and appreciable contact noise, whereas in other cases these factors must be kept several orders of magnitude smaller to prevent severe malfunctioning. At times contacting surfaces are completely inaccessible, whilst in other cases preventative or qualitative maintenance is feasible and can result in significant extensions of life expectancy. Naturally, the life expectancy of a contact must be related to that of the associated equipment, and such factors as the ease and economics of having to change a contact will also have to be considered. Such circumstances dictate that whilst an underground cable joint should have a life of from 20 to 40 years, some telephone switching contacts need last only from 5 to 10 years, even though the life expectancy of the rest of the equipment is much higher.

Hence a choice of contact material, geometry and mode of mounting will depend on many factors. Those which would, for instance, be considered for a relay contact are listed in Table 4.

Not all these factors are likely to be of equal importance, and obviously compromises would have to be made not only for economic reasons, but also because of the manufacturer of the telephone equipment might not be geared to make radical changes in contact materials or geometry.

In the next section, some typical contact applications are discussed, and the reasons for particular choices are shown. It will be seen that whilst various alternatives are available, their applications are only slowly becoming established. This is no doubt due to the reluctance of almost all telecommunication authorities to make changes in contact materials and practices, unless a definite need due to exces-

TABLE 3

Contact Material	Silver	Palladium	Platinum	Gold	Copper	Rhodium	Silver-Copper (72-98%)	Silver-Palladium (20-50%)	Tungsten	Rhenium	Silver-Nickel (5-20%)	Silver-Cadmium Oxide (5-15%)	Gold Alloys	Platinum-Gold-Silver (6-69-25%)
Contact Resistance	Low	Low	Low	Very Low	Mod.	Very Low	Moderate	Low	High	Moderate	Moderate	Moderate	Low	Low
Tendency To:														
Oxidise	Nil	Nil Below 400°C	Nil	Nil	High	Nil	Moderate	Nil	High	High	High	Nil	Low	Nil
Sulphide Tarnish	High	Nil	Nil	Nil	High	Nil	High	Low	Nil	Nil	High	High	Nil	Nil
Form Polymer Deposit	Nil	High	Moderate	Low	Nil	Low	Nil	Some	Nil	Nil	Nil	Nil	Nil	Moderate
Weld on Closure	Moderate	Low	Nil	High	High	Nil	Low	Low	Nil	Nil	Low	Nil	Low	Low
Resistance To:														
Arc Erosion	Moderate	Moderate	Good	Poor	Poor	Poor	Good	Good to Moderate	High	High	Good	Good	Moderate	Moderate
Abrasion	Poor	Moderate	High	Poor	Poor	High	High	Good	High	High	High	Moderate	High	High
Material Transfer	Some	Some	Low	Some	High	Some	Some	Some	Nil	Nil	Low	Low	Low	Low
Available in all Shapes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes
Cost	Low	Low	Very High	High	Very Low	Very High	Low	Low	Moderate	Very High	Moderate	Moderate	High	High
Remarks	Associated insulants must be chosen with care to guard against Silver Migration (Ref. 19)			Usually used as coating or overlay		Used as coating only			Corrodes in the presence of some organic materials	Oxides are unstable and low resistance			Alloying elements Pt, Ni, Si Co or Ag.	

TABLE 4

Parameter	Consideration
Current, voltage	A.C., D.C., peak value.
Frequency	A.C., D.C. pulsing.
Electrical load.	Resistive, inductive, capacitive.
Contact protection.	Is spark quenching necessary?
Contact loading.	Spring pressure.
Method of operation.	Make and break, wiping action.
Frequency of operation.	Pulsed, intermittent.
Speed of contact, closure and opening.	
Contact redundancy.	Single or twin.
Operating Environment	Temperature, humidity, salt air, dust, vibration, contamination by adjacent materials of construction.
Permissible resistance and noise fluctuations.	Long term and short term.
Expected life of associated equipment, cost and ease of replacement.	
Is optimum contact material available in desired form?	Strip, rivet, wire, plating, inlay.

sive faults can be shown. As many types of contact faults are only transitory, they often do not show up in fault statistics, and it is only the advent of new switching systems and methods or cable types which force a re-appraisal of contact performance.

CONTACTS IN TELECOMMUNICATION EQUIPMENT

Telephone Relay Contacts

Telephone switching apparatus is expected to have a life of up to 40 years and during such a time the contacts in relays may be required to operate tens or even hundreds or million times before being replaced. However, in the same apparatus there will be found other relay contacts which might not be called upon to operate more than ten thousand times. Some of the contacts merely prepare circuits, and never open or close with voltage applied, whilst others are subjected to considerable arcing during operation, often inadequately protected by spark quenches. Telephone switching apparatus, whilst normally in an enclosed space, is still subject to an enormous of climatic conditions, in terms of temperature, humidity, industrial pollution and contamination (Ref. 13). Whilst operating voltages are usually low and D.C., high inductive transients are common as are pulsing speeds up to 20 impulses per second. Due to the large number of relays involved, it would be clearly impractical to tailor each contact to its own special set of circumstances, especially when it is remembered that adjoining contacts in the same spring-set often work under radically different circuitry conditions. Hence it is usual to use only one or two different contact materials in a given system, the differentiation being based largely on the magnitude of the voltage and current to be switched. On impulsing relays (which must break an appreciable current) a common choice is platinum. For higher electrical loads, tungsten contacts are sometimes used; however, this metal produces high contact resistances and its tendency to oxidize and the difficulty of attaching it to supports are disadvantages. The great bulk of telephone relay contacts are either silver or palladium, sometimes alloyed with other metals or each other. If it were not for silver's readiness to sulphide tarnish, this metal would be full satisfactory for most relay contact applications in telephone switching. Suitable choice of insulants, anti-vibration mountings, grommets, etc., associated with the contacts can often reduce sulphide tarnishing problems to minor proportions. Silver-cadmium, silver-cadmium oxide and silver-nickel sintered alloys are more sulphide resistant, but have higher resistivities. Gold plating of silver produces a tarnish resistant contact, but the gold overlay must be non-porous and of adequate thickness. Under arcing conditions the gold film is likely to be destroyed. Palladium contacts were considered fully satisfactory until the polymer deposition phenomena was recognized. By careful selection of all organic materials in the equipment, "brown powder" formation can probably be kept down to tolerable levels. However, a more reliable contact can be obtained by either a gold overlay, or by employing a palladium-silver alloy (40/60 or 50/50) or a silver-platinum-gold alloy.

Telephone relay contacts should be mounted in the vertical plane, so that dust particles have difficulty in settling on the contact surface. Protection from dust by covers as well as good house-keeping practices in the equipment room are essential. It is normal practice to have twin contacts on each spring. Whilst this practice obviously raises costs, there is clear evidence of increased reliability, well beyond what would be expected from simple probability theory. Reductions in the failure rate by factors ranging from 25 to 100 over that observed for single contacts are quoted in the literature. For highest reliability the contacts should be hermetically enclosed, but under these conditions it becomes even more essential to ensure that no tarnish or corrosion producing materials are inside the enclosure. A telephone relay contact pair will normally have a contact resistance below 1 milliohm, and unless subject to surface film contamination of major magnitude, should not increase in contact resistance by more than a few milliohms during its life. When the contact resistance does increase appreciably, and no apparent surface films are present, usually the cause can be traced to relaxation in the support springs. Telephone relay contacts are often exposed to vibrations, particularly when associated with step-by-step switching equipment, and heavier springs will partially alleviate the problem. The demands made on telephone relay contacts can be expected to become more stringent in the future, as data transmission and similar services will require ever lower resistance fluctuation and noise conditions. Providing the electrical conditions are not too severe, such cases can be met best by the use of hard gold alloys and/or hermetic sealing.

It is difficult to quote firm figures for contact reliabilities, as these values vary widely with both electrical load and environmental conditions. A further difficulty is that the failure criteria, in terms of maximum allowable contact resistance, can vary over several orders of magnitude, depending on the circuit application. Generally, precious metal relay contacts would be expected to exhibit no fault over the broad range 10^6 to 10^9 operations, the higher figure being representative of zero electrical load and/or hermetic sealing. However, the first fault, be it high resistance or open circuit, need not necessarily persist for more than one or two operations of the relay, and it is quite common to find that persistent faults of the same type do not recur until another order of magnitude of operations have been accumulated.

Conductor Jointing

Telecommunciation cables and wires must be jointed, often under difficult outdoor conditions, in a manner requiring the minimum of specialized tools, with as little dependance on variation in operator skill as possible, and with a life expectancy at least as good as that of the cable or wire containing the joint. Whilst joints in underground cables are normally fairly well protected from environmental influences, joints in open wire lines are exposed to most of the atmospheric characteristics of a particular site, such as high or low temperatures, humidity and rain, salt air or dust. In both cases the aim is to produce a joint with extremely low lifetime resistance variation, and one which will not inject noise into the circuit of which it forms part. There is little doubt that a well-soldered joint provides the optimum solution to the requirements, but unfortunately soldering is not easily or readily performed under field conditions. The provision of a portable power source (as mains power is usually not available) for a soldering iron, or otherwise some other source of heat for a solder-bath requires a vehicle and ready access to the point at which jointing is to be carried out, which is not always the case. On overhead construction, the problems are magnified by the lack of protection from winds and the difficulty of manipulation. The result is that most telecommunication authorities are still investigating alternative means of jointing conductors and wires. Most of these methods rely on mechanical means of holding the two conductors or wires together. In the case of plastic insulated conductors, it is desirable that removal or penetration of the insulation form part of the operation. In lead-sheathed telephone cable, with paper-insulated copper conductors, simple twisting of the conductors has given satisfactory results for years, but with the advent of very much smaller wire sizes, where the conductors tend to fatigue when being twisted, even here new jointing methods are required. One approach to this problem, which has proved most useful also in other applications, is resistance welding or arc welding. The method still requires a power source (usually an accumulator) but is otherwise simple, and with well-trained staff gives excellent results. Various types of splicing guns, which strip the insulation, twist the wires and tip weld in one operation, have been developed and are undergoing trials in various parts of the world. The Australian Post Office is investigating tip welding of aluminium conductors, and results to date have been promising. In the field of plastic-insulated conductors, a number of mechanical connectors have been developed, of which the "B-wire connector" developed by the Bell System is probably the best known (Ref. 20). This connector consists of a thin, springy, metallic inner shell having sharp tangs on the inner surface, and a plastic-encased outer brass shell. When the connector, with the insulated wires inserted, is pressed with a pneumatic, hand-operated tool, the tangs penetrate the wire insulation and establish contact with the conductors. The resultant joint is claimed to be equivalent to a soldered joint, with a probability of less than 0.01 per cent of increasing in resistance by 2 milliohms in 40 years.

Another method used extensively in open-wire line jointing (although application to the smaller cable conductors is also under investigation), are press type sleeves. Here the wires are inserted into a thin-walled metal cylinder (Cu, Ni, etc.) and the latter is compressed radially by a special tool at several points along its length. Providing the inside diameter and radial thickness are chosen correctly with regard to the wire sizes to be jointed, the intense deformation will create good and permanent contact between wire and sleeve, the mechanical strength of the joint being equivalent to that of the wire. However, the joint as such is not insulated and hence under outdoor exposure conditions, great care has to be taken to ensure that no corrosion can occur at the wire-sleeve interface.

Plug-Ins

The ever increasing demand for miniaturization and module construction in many fields of telecommunication equipment has resulted in the common use of printed wiring and printed circuit boards. Such boards must be capable of being plugged-into a chassis in such a way that the connection achieved is of the highest reliability, particularly as the circuitry is based on solid-state devices and the voltages available are usually very low. As a rule, the number of insertions and withdrawals to which the board is subjected will be small, and generally the environmental conditions in which such equipment is placed are not particularly severe. Plugs and edge connections on printed boards should be gold-plated, or even better, use should be made of electro-deposited gold alloys. Pure gold is soft, and troubles due to cracking, flaking or pores are often encountered. The use of gold alloys, for example Au-Co-Ni or Au-Si, leads to increased hardness and abrasion resistance, provided the electro-deposit it kept thin enough to prevent cracking, as the materials are not very ductile. Some use of palladium plating has been made, but the danger of polymer deposition films is great. For this reason, chrome electro-deposits over palladium appear to be more promising.

In applications where socket contact forces are great enough to compensate for changes in the plug geometry due to abrasion, and films are destroyed on insertion, base metals are usually adequate. For more critical applications, gold plating with or without rhodium flash are used successfully. Silver or palladium plating is subject to the usual problems of these metals, as already discussed.

Terminals

Terminals generally can be regarded as semi-permanent contacts, disconnection being infrequent and, in many cases, occurring only during repair or maintenance. In fact, many terminal connections can be classed as permanent contacts, as the wire leading to the terminal is not re-used if the connection has to be opened, but is shortened or replaced entirely. Probably the most reliable terminal connection is soldering providing it is done properly. However, in situations where enormous numbers of such connections must be made, and furthermore space is at a premium, soldering can be difficult, expensive and (particularly in the proximity of the now widely-used thermoplastic insulants) most damaging.

As in conductor jointing, the aim is therefore to produce a connection by purely mechanical forces, but with the advantage that the equipment is usually adequately protected from the environment, and furthermore that most frequently the operation can be performed inside a building with access to power and specialized tools, if required. A simple terminal construction, which used to be popular when space considerations were no object, was the screw-down or spring-loaded pillar type. The wire was held purely by mechanical forces, which often were not sufficiently high to prevent movement under vibration or even an accidental knock, or on the other hand the terminal could be screwed down so hard as to fracture the wire. Today the trend is to either plug-in types of terminals or to solderless wrapped connections. The plug-ins have already been discussed above. A solderless wrapped connection is made by wrapping a copper wire for several turns tightly around a terminal, with a power or hand tool. The connection is held together permanently by the elastic stresses in the two members and, if properly designed, relaxation over a life time of more than 40 years will be so small as to make the connection mechanically and electrically equivalent to a soldered joint. The wire size, the terminal size and shape (normally rectangular), the number of turns and the applied hoop stress must be considered in the design. This type of connection is extensively used in the Bell System, where it is specified that not more than one connection in 10,000 should exhibit a resistance fluctuation greater than 0.1 ohm during service life, and that the electrical noise produced by resistance fluctuations must be below the threshold of transmission impairment in the most critical circuits in service (Ref. 11). The major draw-back in the use of solderless wraps is the cost of the power-operated wrapping tool, and the need for careful and continuous maintenance of this tool. Hand-operated tools are cheaper, but probably far less reliable. The other objection to this type of connection is that once the wrap has to be opened for some reason, the unwrapped end of wire cannot be re-used, and hence either an extra length of wire has to be provided as a reserve, or the circuit has to be re-wired. To overcome this problem, a method has been developed in England in which wire and terminal are held side by side, and are wrapped by an auxiliary wire, which when the connection must be opened, is the only part to be discarded. The double-wrapped connection has not been extensively investigated and some doubt exists if this method is truly equivalent in performance to the single wrap. Whichever method is used, the terminals must be designed specially, and this prevents the adoption of solderless wraps in many situations where existing terminals are unsuitable, and replacement is economically unjustifiable.

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DEATH OF SIR HARRY BROWN

The first Director-General of the Postmaster-General's Department, Sir Harry Brown, K.B., C.M.G., M.B.E., M.I.E.E., died in Sydney on 6th June, 1967, at the age of 88. In January, 1923, Sir Harry was invited by the Commonwealth Government to come to Australia as technical adviser to the Australian Post Office. At that time he had a distinguished record of service with the Engineer-in-Chief's staff of the British Post Office, especially during the First World War. Shortly after arriving in Australia he was appointed Director-General and he remained in this position until 1939.

Sir Harry displayed great managerial skill in controlling the affairs of the department in the difficult financial times of the depression period. A study of his writings reveals an active appreciation of the problems of the Department's postal, telegraph, telephone and broadcasting activities, and a pride in the use of the latest technological developments such as carrier systems.

He was deeply conscious of the importance of organisation, competency in administration, and staff morale. He instituted many managerial and administrative techniques such as the serial and itemising of the commonly used engineering material. However, his greatest achievement was the splendid spirit of co-operation which he fostered throughout the service.

Even in this day of television relays by satellite his words still ring true, as illustrated by the conclusion of an address he gave to the Victorian Postal Institute on 25th August, 1927: "There is not one soul in this great Department who need feel that he or she is denied the opportunity of labouring in the best cause which is known to humanity, namely, service to our fellow creatures. The Post Office is a great civilizing agency, its contribution to the sum total of human happiness, prosperity, and advancement is real and extensive; and in its efforts every member of the staff has a share. We need only to realize what our service means in the life of the nation, and the rest will follow, because there does not exist an Australian who does not pride himself or herself on the nation's achievements, not least of which will be the extent and quality of the service rendered by its greatest national undertaking".

BUSH FIRE DISASTER — SOUTHERN TASMANIA

*R. S. COLQUHOUN, A.M.I.E. Aust.**

INTRODUCTION

The disastrous fires which swept through 1,000 square miles of Southern Tasmania on Tuesday, 7th February, caused the deaths of 62 people, burned out nearly 1,500 homes and major buildings, destroyed two important industries and numerous smaller plants, brought huge losses of crops and stock in rural districts and caused wide-spread damage and interruption to communication and electricity services.

After good rains in spring and early summer, the countryside was carrying prolific growth which had become tinder dry after a prolonged period without rain. Rising temperatures culminated in above century heat on February 7th, a day on which violent northerly winds reached more than 70 m.p.h.

Many fires broke out over a wide area. From the thickly wooded slopes of Mt. Wellington, fire swept down towards the city and into suburbs as far as Glenorchy, Rosetta, Lenah Valley, Dynnyrne, Fern Tree, Cascades, South Hobart, West Hobart, Mt. Stuart, Mt. Nelson and Taroona. At Cascades, a well known brewery and a cordial factory were destroyed, together with numerous houses. Farther south in the Channel district, the fires cut a path of destruction through Kingston, Electrona, Margate, Snug, Woodbridge and Middleton. At Electrona, Australia's only Carbide factory was destroyed. Snug, a town largely built of weather-board houses was practically razed to the ground and many residents had to flee to the nearby beaches to save their lives. North of Hobart the fires swept into the towns of New Norfolk and Bridgewater and east of the Derwent River the rural towns of Colebrook, Campania, Richmond, Sorell and Rokeby were seriously affected. The major suburbs of Lindisfarne, Warrane, Bellerive and Howrah were threatened but providentially escaped significant damage.

In all the affected areas there was severe wide-spread devastation. Over 1,100 families lost their homes and all their possessions and many more suffered serious losses. The total value of damage to domestic, industrial and commercial buildings in Southern Tasmania has been assessed at nearly $7,000,000. Damage caused to industrial plant, personal property and public utility facilities greatly exceeded this figure. The cost of repairing or replacing Post Office communications plant was more than $800,000. This article describes the extent and nature of the damage caused to communication facilities and the measures taken to effect their restoration as quickly as possible.

DAMAGE TO COMMUNICATION PLANT AND FACILITIES

No specific warnings of fire danger were received by this Department from external sources in the period immediately preceding 7th February, 1967. Some informal advices were exchanged between staff members at various levels of responsibility as to the general situation during the morning of 7.2.67 but it was not until 11.15 a.m. on that day that the first definite report was received at Headquarters from a field officer that actual fire damage to telephone plant was occurring. This initial report referred to the main pole and wire trunk route between Hobart and Launceston which was severely damaged near Bridgewater causing all trunk line services over this route to fail by 12 noon. This report was followed by many others through the day and night of 7th February, 1967, and related to plant destruction and service failures in most centres in Southern Tasmania including a number of Hobart suburbs. Because of the extensive geographic area traversed by the fires very substantial damage was caused to Departmental plant and property in a large number of districts and that sustained by overhead line plant was particularly wide-spread. At the height of the disaster, virtually all trunk routes from Hobart to other parts of the State and interstate were interrupted but fortunately the route to Northern Tasmania via the West Coast remained operative. Of particular importance was the very serious restriction placed on trunk calls to other States and to Northern Tasmania by the failure of the main Hobart-Launceston trunk route. The loss of these channels made more difficult the efforts of the Post Office, as well as other authorities, to secure outside aid.

Plant damage included the complete destruction of a 200 line automatic C.A.X. exchange and building at Kettering and a 100 line manual exchange installed at the non-official Post Office building at Colebrook. Eleven other non-official Post Offices containing minor telephone plant were also lost. Aerial line plant consisting of over 1,400 poles traversing some 150 miles of pole route together with associated wires, cables, cable boxes and other miscellaneous line plant was destroyed. Generally, underground line plant was little affected although a few instances of heat damage to underground cables occurred due to smouldering tree roots, burned out supporting wooden bridges and similar causes.

Telephone instruments in burned out premises numbering almost 450 installations were destroyed and, at the worst period, approximately 3,500 subscribers were deprived of service: about 1,200 in metropolitan and 2,300 in country districts. Nearly 470 trunk channels were interrupted and this included all main route channels from Hobart excepting those to the West Coast. A large proportion of the subscriber services which failed were not directly affected by fire but interruption to service was due to the failure of commercial power supplies and, in many cases, before alternative power arrangements could be improvised, the exchange batteries became exhausted. This difficulty threatened even the Central Exchange in Hobart itself but fortunately power was restored while reserve battery capacity remained despite exceptional demands amounting to 480 amperes compared to a normal busy hour load of about 350 amperes. (The standby emergency power plant at this exchange has a maximum capacity of 240 amperes).

Almost all commercial power reticulation in Tasmania is by overhead open wire construction and the Hydro-Electric Commission suffered very severe damage to its line plant including many pole mounted transformers and switch gear installations.

Many sections of the Southern Tasmanian community were isolated from each other and from the rest of the State communication network for varying periods of time. Fifty-eight exchanges suffered complete isolation for significant periods.

The Auto Telex Exchange, Hobart, was also isolated for a period of some hours. Some 40,000 telegraph messages were handled at the Hobart Chief Telegraph Office in the week of the fire as compared to a normal weekly average of about 10,000. In fact, over 10,000 messages were handled each day, 8th-10th February, resulting in considerable congestion. To clear this exceptional traffic it was necessary to air-lift some 2,000 messages from Melbourne to Hobart and 1,500 from Hobart to the Mainland during these three days. On 9.2.67, two additional simplex 'Tress' telegraph circuits to the Melbourne office were provided to assist in meeting this high demand. Considerably augmented telegram delivery arrangements were also required at Hobart and other centres involving the hire of taxis and the assistance of members of a Boy Scout organisation. Difficulty was frequently encountered in effecting delivery of individual telegrams because of the displacement of the addressees.

National broadcasting and television services were interrupted when commercial power supply failed but actual transmitter 'off-air' time was of short duration only while standby plant was brought into operation. At the Ralphs Bay broadcast transmitter station (7ZL and 7ZR) local staff members were obliged to make strenuous efforts to

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* Mr. Colquhoun is Engineer Class 4, Tasmania.

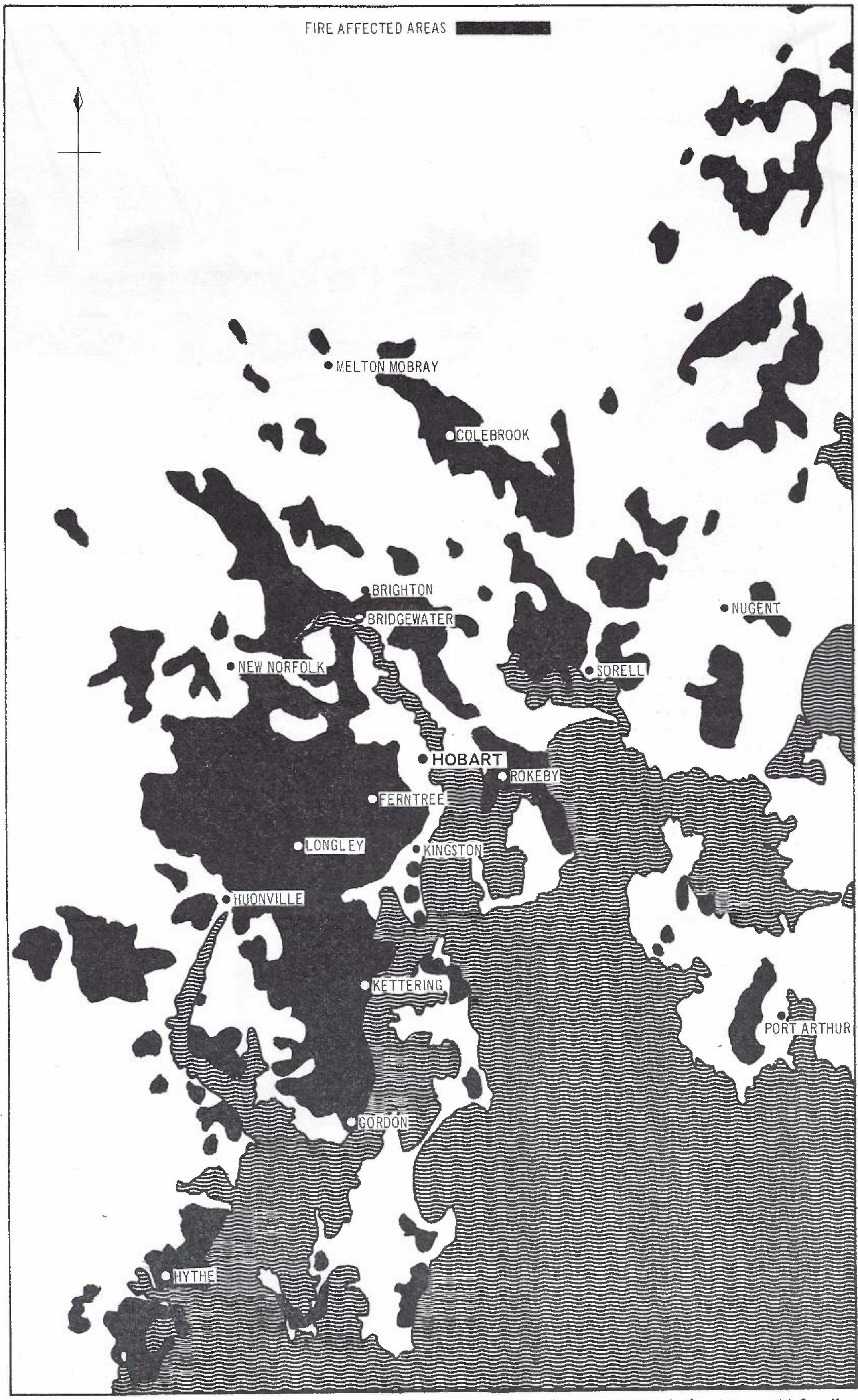

Fig. 1 — Southern Tasmania — Extent of Fire Spread, Tuesday, 7th February, 1967. Scale: 1 in = 11.3 miles.

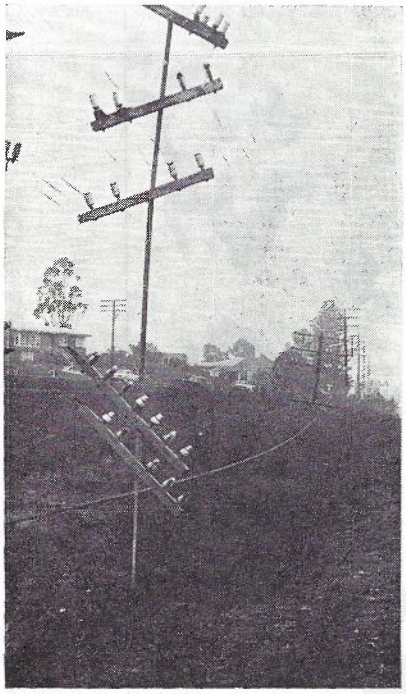

Fig. 2 — Hobart - Launceston Trunk Route.

Fig. 3 — Township of Snug after Fire.

control the grass fire which swept over the station grounds. At the Mt. Wellington TV Station, 4120 feet above sea level the shade temperature reached 83 degrees, a most unusual level. At about 3.00 p.m. a wide front fire crossed this mountain from the south and this passed the TV station to the west but was halted some distance from the transmitter building at a cleared area. A later fire approached from the north-west but this too was stopped but not before it had destroyed the co-axial cable linking the adjacent commercial channel station to the Departmental installation.

The frequency measuring and radio emission monitoring station at Radio Hill, South Hobart, including the station building, masts and associated aerial systems, and all installed equipment and facilities was totally destroyed. The equipment loss included receivers, frequency measuring equipment and ancillary plant valued at more than $40,000.

On the day of the fire a work party was engaged in the installation of a 12 tube co-axial cable between the Hobart trunk centre and the southern terminal of the Hobart-Launceston radio broadband route at Chimney Pot Hill. The cable route at the Chimney Pot Hill end traverses heavily timbered country and the whole of the area quickly became a raging inferno. Very providential escapes were enjoyed by members of the work party but several items of mechanical plant, a number of motor vehicles and a quantity of tools currently in use sustained minor to severe damage.

RESTORATION

The work of re-construction and re-establishment of communication facilities began at once and initially consisted of reconaissance and assessment of the extent and nature of the damage. This essential activity continued well into the late hours of the 7th February and began again early on the 8th. It was not until the latter day was well advanced that a reasonably full account of the diversity and magnitude of the damage was known. Early efforts were particularly directed to the restoration of trunk links with emphasis on the main Hobart-Launceston open wire trunk route which had been severely damaged near Bridgewater. By the evening of the 8th, following the installation of lengths of interruption cable and the clearing of partially destroyed poles and wires, six 12 channel systems were operating on this route. Because of the disaster, the trunk traffic demand between Tasmania and the mainland was extraordinarily heavy and at one period was believed to be in delay by over a day in the Melbourne-Tasmania direction. Despite the limitation of

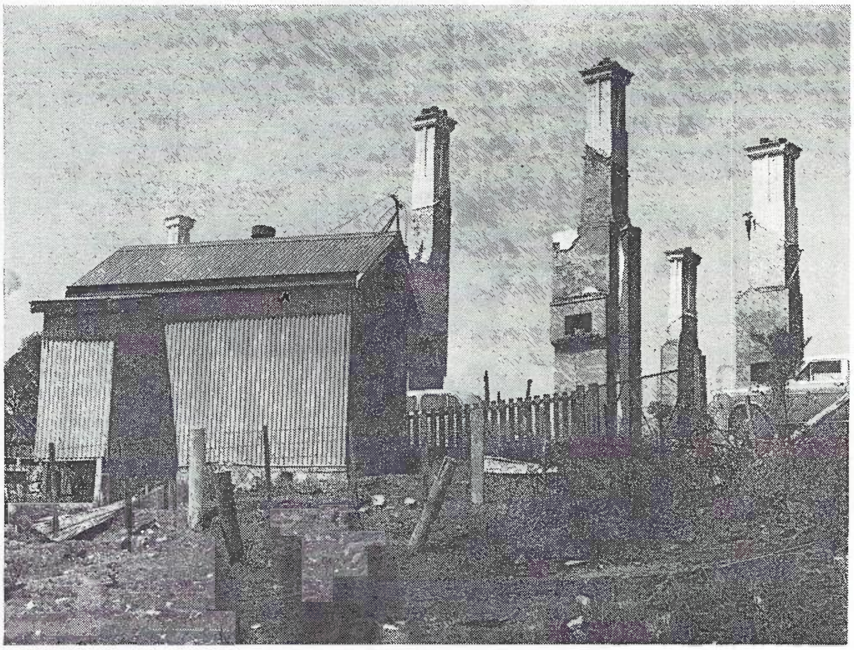

Fig. 4 — A Lucky Escape — Fern Tree C.A.X. Adjacent to a Destroyed Hotel.

acceptance to urgent or priority calls, over 30,000 trunk calls were booked at the Hobart Trunk Exchange during the week of the fire. With the restoration of all channels on the Hobart-Launceston main route, the provision of an additional 12 channel system on 10 February, 1967, over wires owned by the Tasmanian Government Railways, and the re-arrangement and diversion of some existing Northern Tasmanian channels relief was provided to meet this demand. Normal interstate traffic levels and delays were resumed on 15 February, 1967.

All of the plant damaged in the fire was in areas contained in the geographic territories controlled by the Hobart Metro Lines and the Southern Country Divisions and by the end of Wednesday 8th an appropriate emergency organisation had been set up in these Divisions. Similar or complementary measures were also taken in the Trunk Service and Telegraphs Radiocommunications and Broadcasting, Long Line and Country Installation, Metro Equipment Installation and Service, and Services No. 1 and No. 2 Divisions.

Wide-spread diversions of staff engaged on normal works were arranged and, in addition, substantial assistance in staff plant and materials was obtained from Northern Tasmania and Victoria.

In addition to some 400 field staff members normally attached to the operative Divisions involved, 33 men were transferred from Victoria, 50 jointly from the Burnie and Launceston Divisions, and 37 Instructors and Trainees from the Hobart Lines Training School. The assignment of this staff together with the securing of accommodation etc., represented in itself a substantial problem bearing in mind the high demand for temporary accommodation in respect of the large number of homeless families who required immediate re-housing, and the currency of the normal Tasmanian tourist season. The staffing organisations set up were supported by the procurement and allocation of additional mechanical plant units including one complete mole plough team and two pole erection teams made available by Victoria as well as similar plant immediately transferred from other Tasmanian Divisions. Mobile workshops to service the mechanical aids were also established.

Throughout the restoration work, beginning with the initial field survey of damage, the existing mobile radio telephone networks operated in the Southern Country and Metropolitan Lines Divisions, offered invaluable assistance. From the time of initial awareness of the disaster during the afternoon and evening of the 7th February and throughout the following restoration period, these networks were used for the transmission of damage reports, co-ordination of staff assignment and material supply, works planning and control, movement of emergency power supplies and mechanical aids, repair progress reports and many other purposes.

Concurrently with the setting up of the fire restoration organisation, urgent arrangements were made for the assessment of material needs and by Wednesday, 8th February, the initial order for cable supplies and other materials had been passed to Victoria. Subsequent orders were placed later and initial deliveries had commenced to Tasmania via the Bass Strait ferries on 10th February. Altogether some 204 sheath miles of cable containing 8,348 kilo pair yards of wire were obtained from Victoria and other material to a value of $141,726 was also obtained from this source. The unfailing co-operation given and the efficient and expeditious action taken by Supply Branch and Engineering Division personnel in both States and at the Central Administration, achieved excellent results in provisioning the disaster areas.

The organisation set up to cope with the disaster covered the following prime functions:—

(a) Assessment of damage;
(b) Planning of restoration work;
(c) Procurement and delivery of material to the work site;
(d) Allocation of staff, mechanical plant and motor transport;
(e) Work execution;
(f) Recovery of damaged material of scrap value;
(g) Assessment of costs;
(h) Amendment of records and plans.

In addition to these main functions a number of important complementary activities were initiated at the earliest stage and these included:—

(a) Restoration of exchange power supplies by provision of portable generators or replacement re-charged exchange batteries;
(b) Provision of interim trunk channels by improvised radio bearers;
(c) Collection of statistical information in relation to permanently damaged subscribers' premises, and where possible their immediate and future requirements.

In determining and designing the methods to be adopted in restoring both trunk and subscriber services, careful regard was paid to the need to effect the earliest possible restoration with maximum economy, not only in the short term but with direct reference to long term planned developmental requirements. In general, the policy of replacing destroyed open wire plant with underground plant was adopted so as to secure the usual economic advantages in relation to the cost ratio of the maintenance of open wire plant versus that of underground, and to minimise the possibility of future fire damage. On important trunk and junction routes, the actual basis of restoration was in accordance with the approved co-ordinated Engineering State Plan and a number of trunk and subscriber proposals planned for future years were advanced accordingly. In respect of subscribers' routes for which no developmental proposal had already been designed, the following general, but not inflexible policy was adopted in determining the basis of replacing aerial plant by underground cable:—

(a) Routes having more than 20% of poles destroyed;
(b) Routes having more than 50% of wire requiring replacement;
(c) Spur routes associated with main routes being cabled;
(d) Provision of cable entries to rural subscribers' premises where the public road route was being cabled and where wiring costs on private property would, in any case, be a Departmental charge;
(e) In the absence of a recent subscriber development survey in respect of some areas, the size of rural cables was assessed on the basis of two pairs for each existing subscriber;
(f) In all areas it was assumed that all subscribers whose premises were destroyed would ultimately rebuild and require reconnection at the same or near adjacent site.
(g) Where aerial routes were restored as such, these generally have been re-erected wherever possible with double length spans.

In restoring damaged aerial trunk facilities consideration was given, not only to the extent of physical destruction and hence the effort required to re-construct in situ, but to the planned development on each route. The Hobart-Launceston route, for example, was programmed to be replaced by a radio broadband system in 1966/67. Unfortunately although terminal and repeater buildings and towers were available neither radio bearer or channelling equipment had been delivered and it was, therefore, necessary to re-construct the substantial section of the pole route destroyed at Bridgewater. The Hobart (Sorell) to Tasman Peninsula aerial trunk route was also extensively damaged but as radio bearer equipment previously planned for installation in 1967/68 was in store and the required channelling equipment was immediately available by transfer from Victoria, a decision was taken to install the proposed system rather than to rebuild the open wire route beyond the immediate interim restoration of priority physical bearers with interruption cable. The radio bearer for this system was established on 18th February, 1967, the route being from Hobart Trunk Centre to a repeater installed at Chimney Pot Hill and thence to the previously selected communications site at Koonya (Tasman Peninsula). This involved the transportation and erection of a portable building at Koonya, the provision of emergency power at both Koonya and Chimney Pot Hill, and the connection of the radio borne channels to existing plant beyond the damaged areas. Elsewhere, particularly in the Sorell-Campania, and the Snug-Kettering-Woodbridge-Middleton districts, the destroyed aerial trunk routes were

Fig. 5 — Emergency 200 Line Transportable Exchange in Position Adjacent to Completely Destroyed Automatic Exchange at Kettering.

replaced by U.G. cable, the mole ploughing technique being adopted to achieve maximum expedition in execution.

Due to the almost completely rainless summer which preceded the fires and to the effect of the fire heat, the dry ground conditions were extremely adverse to mole ploughing progress. Nevertheless good results were achieved and by the end of the restoration period some 200 sheath miles of cable had been installed by this method.

Early restoration efforts were aimed first at the elimination of exchange isolations and at the provision of maximum channelling facilities on important trunk routes. To some extent the restoration of subscribers' services was, as a consequence at least in the early stages, given secondary consideration but the prompt connection of improvised or regular power supplies to a number of exchanges had the immediate effect of restoring quite large numbers of individual services to working order. Many varied methods were adopted in arranging emergency power supplies. These ranged from the use of borrowed 250 volt 500 ampere-hour battery sets, weighing 5 tons, to modified portable arc welding generators. At the worst period power was supplied by either regular standby generators or improvised emergency sources at a total of 33 exchanges and 5 other communications installations.

Early attention too, was given to the replacement of the two exchanges destroyed at Kettering and at Colebrook. At Colebrook the existing manual exchange was replaced with a temporary 200 line magneto switchboard installed in a mobile work hut and placed adjacent to the burnt out Post Office premises on the day following the fire. The exchange was in operation the next day with trunk access to Sorell provided by means of two modified mobile radio transceivers. The Colebrook end 'radio-terminal' was, of necessity, located on a hill some half mile away to meet radio propagation needs and was connected by cable to the exchange. When alternative trunk facilities became available by other means on 14th February, 1967, the modified transceivers were re-used to provide a trunk channel between Sorell and Nugent.

The 200 line automatic step exchange which was destroyed at Kettering was temporarily replaced with a transportable exchange fortunately available as a recovered unit following the installation of an ARK exchange at Somerset some 250 miles away. Installation began on Saturday, 11th March, 1967 and some subscribers' services were in operation shortly after. Unfortunately many of the subscribers at Colebrook and Kettering no longer had premises to which service could be restored. Permanent exchange replacements were subsequently made at both those centres with new ARK units very helpfully made available by the Victorian Administration.

Good progress was made with all works and by 17th February, ten days after the fire, all exchange isolations had been lifted and the total number of subscribers without service had been reduced from 3,500 to 531; not including 506 services permanently installed at premises which had been completely destroyed. At the end of 5 weeks all subscribers with premises available and requiring service had been re-connected except for a small number in remote rural localities. The last of the latter was restored on 23rd March.

The re-establishment of the Frequency Measuring and Radio Monitoring Centre on a permanent basis will be delayed for some time pending the acquisition of a new site and the erection of an appropriate new building. In the meantime, basic technical facilities and services have been established in temporary accommodation. A number of non-official Post Offices, also, will of necessity operate at temporary locations until the owners have re-built or other alternative arrangements have been made. Six

Fig. 6 — Colebrook Post Office and Exchange after Fire.

of the twelve offices destroyed were progressively re-opened by 1.3.67. The office at Wattle Grove will not be re-established.

TECHNICAL ASPECTS

It is difficult to draw meaningful conclusions in relation to the vulnerability of external plant to fire damage because of the wide variation in the intensity of the fire and associated temperatures from place to place. It is evident from an inspection of the surrounding country-side and the remaining vegetation and the physical condition of the damaged plant, that the temperatures reached during the fire covered a very wide range. As indicated previously, two exchanges were lost when in each case the accommodating building was destroyed. A number of other rural C.A.X. exchanges, completely surrounded by fire enjoyed remarkable escapes. This is attributed to good house keeping and to some extent to the standard galvanised iron clad buildings. The grass surrounds of these buildings are kept regularly mown or chemically controlled and it is thought also that the corrugated galvanised iron external walls may have, to some considerable degree, reflected away infra-red radiation.

In regard to external line plant generally it seems evident that the standard wooden pole used in Tasmania which is treated with a water borne salt type preservative is fairly susceptible to total destruction by fire. While the good condition of the outer surface due to the preservative did result in greater fire resistance than an untreated pole, at least to initial ignition, the presence of large longitudinal cracks and checks characteristic of this type of preservative treatment no doubt facilitated the entry of the burning embers etc. A very large proportion of damaged poles of the treated type were totally consumed. Crossarm destruction appeared to depend upon the severity of the associated pole fire and on the closeness and magnitude of the adjacent scrub fire. Many were totally destroyed but quite a proportion burned through at the pole bolt hole and after falling from the pole, became extinguished. From a small sample, it is thought that creosote impregnated arms resisted initial ignition better than untreated arms but once burning there appeared to be little difference in the two types.

Although all damaged aerial cables both of the wire spun and integral bearer types required full replacement a few cases were experienced of where the outer polythene sheathing was damaged but the aluminium foil screen protected the plastic insulated conductors inside permitting delayed renewal. Porcelain insulators were unaffected but glass types deformed or cracked readily. There appeared to be little difference in the reliability of aluminium pole fittings as compared to steel but in any case the consideration is academic because with the destruction of a substantial number of consecutive poles the nature of the fitting had no bearing on the survival of the service. A large number of pole mounted cable boxes were destroyed and both the plastic cover and the plastic cable tail were completely reduced to ashes. Aluminium sheathed public telephone cabinets, on a very limited sample, appear to have a higher survival probability than earlier painted wooden types although examples of the latter were found in an extremely charred condition with broken window panes, but otherwise serviceable. As very little underground plant was effected by the fire no significant experience was obtained of the effect of high temperatures on this class of plant.

FUTURE OUTLOOK

So far as the future practice is concerned, the conclusion has been drawn that because of the nature of the terrain and vegetation common in Tasmania, aerial plant cannot be adequately protected from wide front fires except by very extensive route clearing practices of a magnitude such as to be patently uneconomic. It is believed that the continuation of existing developmental policies in this State aimed at reducing the statistical level of aerial plant by its replacement with underground cable in case of subscribers' services and by either cable or radio facilities in respect of trunk services will, in the course of time, very largely eliminate serious future fire hazards, at least of the magnitude recently experienced. An example of this is, of course, the replacement of the Hobart-Launceston open wire trunk route by broadband radio facilities programmed for the current financial year. In addition, the minor trunk cable programme in all regions of the State is well advanced and by the end of this decade few significant trunk routes in open wire construction will remain.

STAFF APPRECIATION

Special mention is made of the magnificent efforts of all the staff concerned in the restoration work. This includes the normal staff of the several Engineering Divisions directly concerned and also the staff from other Tasmanian Divisions and those freely made available by the Victorian Administration. Long hours were worked by these staff members under extremely uncomfortable and adverse conditions. Morale remained at a high level and there is no doubt that the speed with which services were restored was fundamentally due to the vigour and concerned interest of each individual member of the staff. These splendid efforts attracted very gratifying public comments and have been the subject of letters of commendation received from the Hon. Alan S. Hulme, Postmaster-General, and from His Excellency, Lieutenant-General Sir Charles Gairdner, K.C.M.G., K.C.V.O., K.B.E., C.B., the Governor of Tasmania.

CHANGES IN BOARD OF EDITORS

The Telecommunication Society has approved changes in the Board of Editors of the *Journal*. Mr. H. S. Wragge has resigned to become Editor-in-Chief of the Society's new journal, Australian Telecommunication Research, and Mr. E. J. Wilkinson and Mr. D. A. Gray have been appointed as Editors of the *Journal*.

Mr. Wragge has been an Editor of the *Journal* since October, 1964. His energetic approach to his editorial responsibilities has enabled him to make a substantial contribution during this period. The Board of Editors expresses its appreciation for his efforts and wishes him every success in his new editorial post.

In recognition of the increasing need for more specialized attention to the various branches of telecommunications, the Society has appointed Mr. Wilkinson to represent the Radio and Transmission fields and Mr. Gray to represent Research. Mr. Wilkinson has been associated with the *Journal* in the past as a Sub-editor and the Board is pleased to welcome him back in his new role. He is currently Engineer Class 5, Radio Section at Headquarters.

Mr. Gray is Engineer Class 4, Principles, in the Systems Section, Research Branch. His appointment as Editor to represent Research activities underlines the continued emphasis which will be placed on these activities in future issues of the *Journal*.

STANDARD BUILDINGS FOR AUTOMATIC EXCHANGE EQUIPMENT

E. A. GEORGE, A.M.I.E. Aust. and P. H. SPAFFORD***

INTRODUCTION

The authority for design, documentation and construction of buildings for the Australian Post Office (A.P.O.) is vested with the Commonwealth Department of Works. The planning and specification of functional requirements for each building is prepared by the A.P.O. and this forms the basis on which the building design is developed within the Department of Works. Cost savings are therefore available to both departments if building design can be standardised as far as possible. For the Department of Works there are economies in the preparation of documentation (sketch plans and working drawings, specifications, etc.), and for the A.P.O. standard buildings should cost less and reduce considerably the time required for planning and the preparation of briefing information in the Department of Works.

For buildings concerned with telecommunication engineering facilities there is an important additional advantage for the A.P.O. A program of standard buildings should be capable of being more closely scheduled with the associated engineering works programme than is possible under a procedure of individual design for each building. The closer scheduling of the two programmes has major cost advantages for the A.P.O. in meeting, more economically, the demand for new telecommunication services.

This article describes the development of plans for standard automatic telephone exchange buildings and is based upon an investigation carried out by the Department of Works and the Engineering Division of the A.P.O. It discusses, from a telecommunication engineering viewpoint, the considerations which led to the planning and specifying of functional requirements for standard plans. From these, officers responsible for the architectural, structural, mechanical and electrical design work in the Department of Works produced final plans to the mutual satisfaction of both departments.

Briefly, the investigation resulted in the development of plans for a standard building to accommodate exchange equipment with a nominal capacity of 2000-10000 lines. The plans are capable of 'mirror image' treatment thus giving four (4) standard designs. The first plan, known as Type 1 is smaller and has a lower capacity for providing telephone services than the second plan (Type 2). A feature of the Type 1 plan is its capability of simple development to a Type 2. Both plans have fixed ancillary areas, and are capable of extension using a modular building principle. In addition, "inherent" flexibility will permit other applications of both buildings in the telecommunication field.

REASONS FOR THE INVESTIGATION

The basic reason for a study of this nature is the desire to improve productivity in both departments by conserving the financial and professional manpower resources normally utilised in the planning and development of building plans for terminal telephone exchanges. Some of the more important resources which will be influenced by the study within the Department of Works are:

(a) Administrative costs — the A.P.O. is debited with a flat 6% on all expenditure associated with the Postal Buildings Vote — which embraces all telecommunication building projects.
(b) The most efficient use of professional skills — any system of documentation which will streamline procedures and reduce building planning time will greatly assist production.
(c) The most appropriate architectural treatment and use of materials.

The specific reasons for the investigation, from the Post Office viewpoint, are to conserve effort involved in specifying requirements and to obtain better results from improved building programming. The following advantages should result from the study:—

(a) A reduction in the professional engineering effort involved in developing A.P.O. functional requirements for telecommunication buildings.
(b) Less administrative costs in the scheduling of buildings in accordance with the co-ordinated programme of developmental works.
(c) The best timing of provision of building accommodation — the focal point for consideration being the interim or final occupation of the building for installation of equipment which must be arranged in association with other plant and facilities in order to provide telecommunication services in the area concerned.
(d) A closer liaison should be possible in the forward ordering of new equipment and the need to avoid unnecessary storage before installation in accordance with (c).
(e) A reduction in uneconomical alternatives when building provision is delayed.

So far we have considered the late provision or non provision of telecommunication building accommodation. The provision of a building completed ahead of schedule, and by this is meant, ahead of complementary lines plant and subscribers equipment (or other facilities) can also be an embarrassment. An idle asset of this nature not only invites public criticism but represents a non-profit-earning capital investment with recurring interest payments. Within a limited budget such premature expenditure could prejudice another situation awaiting building provision.

Therefore it appeared desirable to embark upon a joint departmental investigation into means by which the economic and time factors in the provision of telephone equipment accommodation could be improved to the mutual benefit of both departments. The terminal telephone exchange building was the area considered the most profitable at this stage following an analysis of previous building programmes and the fact that this type of exchange is the most prevalent in automatic switching plans for Australia (Ref. 1). Investigations into the practicability of standardisation of other types of telecommunication buildings will follow in the future with priority decided by the available savings in resources for both departments.

OUTLINE OF INVESTIGATION

The authority for the investigation was given by the Directors-General of both departments. A joint steering committee of interested headquarters' personnel was formed comprising representatives in the architectural, building and telecommunication engineering fields. A working party was selected from members of the steering group with power to co-opt specialist professional staff on an ad hoc basis. The working party, of which the authors of this article were members, carried out the detailed investigation and periodically reported to the steering group on progress. Because the working party were also members of the steering group, communication at all times was facilitated with policy quickly disseminated to all concerned thus reducing considerably the time taken for the investigation. The investigation proceeded on the following general lines:

(a) The A.P.O. as the client would specify the functional requirements for terminal telephone exchanges and advise other general requirements such as site usage and orientation.
(b) From this information, the Department of Works would produce standard building documentation.

From the telecommunication engineering viewpoint the specification of functional requirements was subdivided into the following phases:—

Phase 1: Study of the engineering planning requirements for a standard building.
Phase 2: Specification of equipment and ancillary area requirements, the desired orientation of functional areas: and the optimum size of building extensions.

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* Mr. George is Engineer Class 3, Exchange Equipment, Headquarters.
** Mr. Spafford is Principal Buildings Officer, Headquarters.

Phase 3: Specification of building services to meet phase 2 requirements.

When the investigation had reached the stage of preliminary sketch plans, representatives from the engineering groups of A.P.O. State Administrations were briefed on the proposed measures and many suggestions arising from these discussions influenced the final form of the sketch plans. However, when setting standards to embrace the many and varied requirements of departments as large as the Department of Works and the A.P.O., it necessarily follows that to incorporate all ideas which may arise from such representative discussions is virtually impossible. The final sketch plans were prepared by a Headquarters group in the Department of Works and represented the basic plans. From these, the State branches of the Department of Works developed standard sets of working drawings and specifications to comply with local building and statutory authority ordinances.

BUILDING PROVISION POLICY

General

The investigation was conducted in accordance with policy based upon an A.P.O. study in 1962 into the economic principles for application in Telecommunication Building Provision (Ref. 2). This report laid down a solid foundation, based upon extensive economic studies of the practices which should be followed in specifying planning and initial provisioning criteria for telecommunications buildings in Australia. The principles used in planning the provisioning of standard buildings were:

(a) A planning period of 20 years to formulate accommodation requirements.

(b) An initial telecommunication building provision to cover development for a period of 10 years from the estimated date by which the building is available for equipment installation.

(c) Extension of a building should be in stages to bridge the gap between the initial 10 year period and the 20 year date.

(d) Cases for a longer initial period than 10 years to be justified on economic, practical grounds, or both.

(e) Sites, to be capable of supporting at least double the 20-year planning requirement for the building.

The planning period for telecommunications buildings is defined as that period for which the building is planned, but not necessarily constructed initially. A planning period of 20 years represents the basis on which a building layout plan is formulated and layout plans should show a means whereby the building structure can be developed, in stages, to meet the 20 year requirement as a logical extension of the initial building construction. The period of 10 years, on which is based the initial provisioning of space, represents a nominal figure. In practice, particular growth rates, economic factors and the like, may shorten or lengthen the nominal period of 10 years. Under some circumstances, proposals for 15 year requirements are considered in accordance with policy. However, the 10 year development point represents an economic optimum period compatible with A.P.O. financial policy and practical considerations in the Australian building industry.

The provision of any building in stages has a number of 'penalty' costs which vary in degree according to the number of stages. The following are the major penalty costs incurred as the result of adopting a staging programme for telecommunication building provision:—

(a) High contractural costs because each stage represents a smaller separate project with consequential additional alteration work to the existing building, e.g., removal of temporary walls, restoration of plaster, repainting, etc.

(b) Additional costs in protecting equipment from the effects of construction work, e.g., mechanical vibration and dust. The ingress of dust into equipment can result in a legacy of poor equipment performance and higher incidence of faults for a considerable period of time after the building extension is completed.

(c) Additional costs associated with planning and documentation of building extensions for both the Department of Works and the A.P.O.

The following measures were adopted during the investigation and aimed directly at preventing these penalty costs from adversely influencing total or overall economics in the design of standard buildings:

(a) The equipment area should be extended on a building modular system. This type of building structure (in either single or multiple modules) represents the most economical form of extension thereby reducing the penalty costs for smaller separate projects and minimising alteration work.

(b) To reduce costs in protecting equipment from construction work a temporary end wall to the equipment room was specified to be constructed in such a manner as to permit the demolition of the outer skin and retaining the inner section as a dust shield until the completion of building operations.

Cases will always arise which justify a departure from current policy. The extent of building provision that can be deferred is a function of the rate of growth of the area to be served. Therefore in some slow-growing exchange areas it is economically advantageous to provide, initially, for a longer period. This consideration influenced the standard building design in that there is an optimum size of building below which it is uneconomic to build. The equipment area requirement can be so small that the costs of the ancillary and amenity areas in a standard building completely dominate building costs resulting in an uneconomic proposal. Based upon current building costs and equipment space requirements, it was found that a standard building was uneconomic unless the initial period supported a demand for at least 2,000 lines.

Planning and Design Criteria

To implement A.P.O. policy in specifying requirements for a standard building, some variation to the normal procedure was required using survey figures for a particular exchange area. Survey figures are the result of systematic periodical studies into anticipated subscriber development for defined geographical areas. This information, amongst other things, is used to develop planning requirements for buildings and has reasonable accuracy in the time period of eight to 10 years ahead. Beyond this the figures become increasingly speculative until, at the 20 year date, they are considered indicative only of the size and building capacity likely to be required. In the case of standard buildings, survey information obtainable from State Administrations was studied to define patterns of growth rate and the frequency of occurrence of the different values of proposed telephone exchanges in the eight to 10 year period and also at the 20 year date. Although two basic sets of growth rates and figures resulted from this review, it was necessary to permit some degree of overlapping between the two in order to meet the majority of exchange requirements predicted for the future in which the application of a standard exchange building appeared a possibility. The basic planning data thus determined was:

(a) A growth rate resulting in a demand for approximately 5000 lines in the 10 to 15 year period.

(b) A growth rate in excess of (a) but resulting in less than 10,000 lines at the 20 year period.

Fig. 1 illustrates the above basic development information and shows graphically how a range of growth rates can be met, together with the necessary overlapping of some areas, to meet all likely conditions within the stated boundaries. Area A growth can be catered for, most economically by the use of telephone equipment installed in transportable buildings. Transportable buildings are used before the erection of a permanent building and where survey figures do not exceed 1,000 lines at the 5 year period. Under exceptional circumstances two transportable buildings with a maximum total capacity of 2,000 lines are tolerated before the erection of a permanent building. (Excessive use of transportable buildings is not an alternative to adequate planning.) Therefore Area B represents an overlapping region where growth can be met either by two transportable buildings or preferably by a permanent building.

Areas A to E represent the commonly occurring situations where, al-

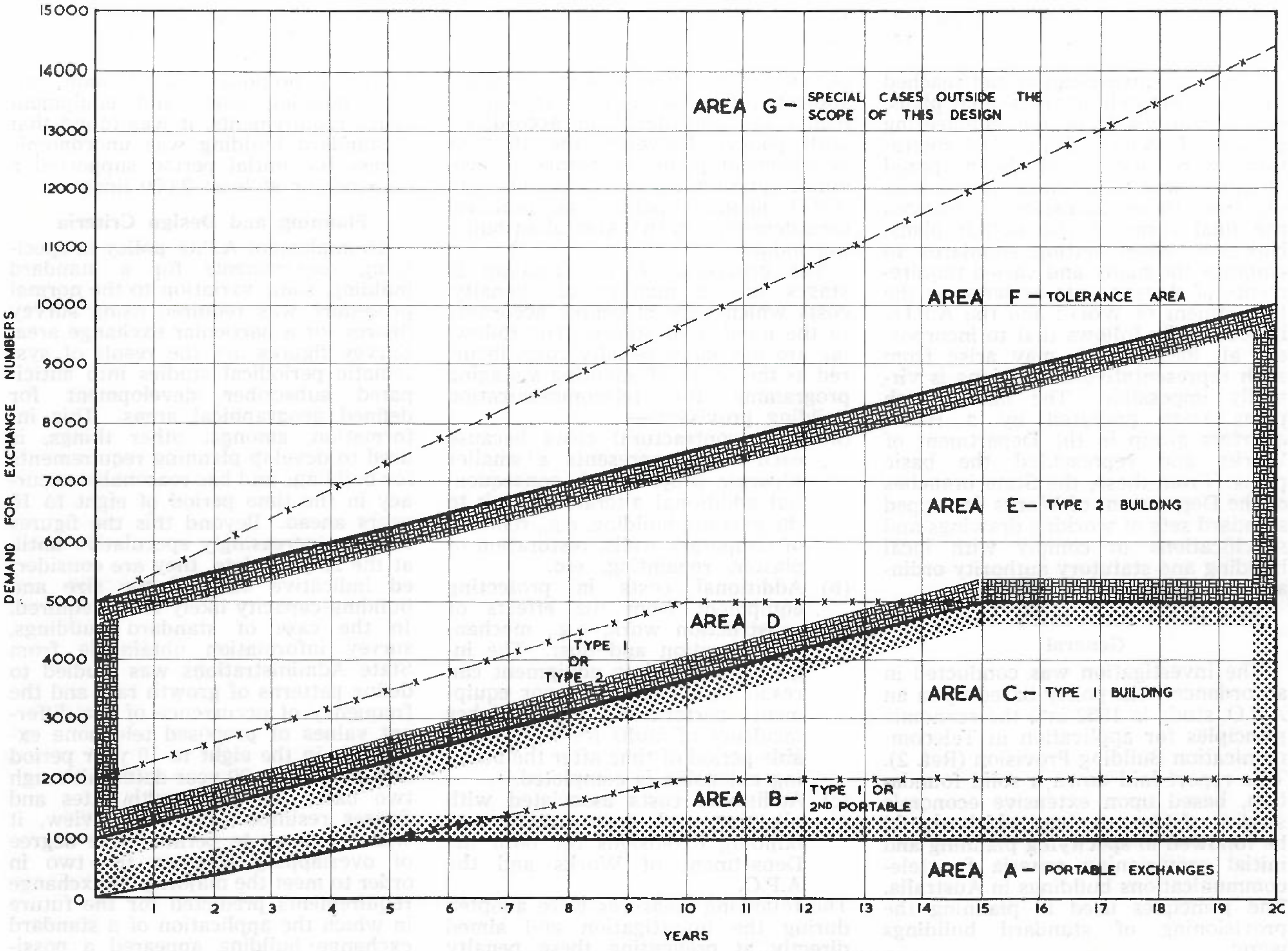


Fig. 1 — Subscriber Growth Rates Used in Standard Building Design.

though growth rates can vary within these regions at any point of time (particularly in the 5 to 10 year period), they generally conform to the 15 to 20 year figure. Area F represents the tolerance area for Area E where growth rates can accelerate the demand for service into this area but only under unusual conditions.

Area G represents situations which demand over 10,000 lines at the 10 year date and therefore are outside the capacity of the standard building design. Such special cases are met in the larger cities and provincial centres where either the growth rate is excessive or the exchange area to be served will require a total volume of services well in excess of the more common requirement of less than 10,000 lines.

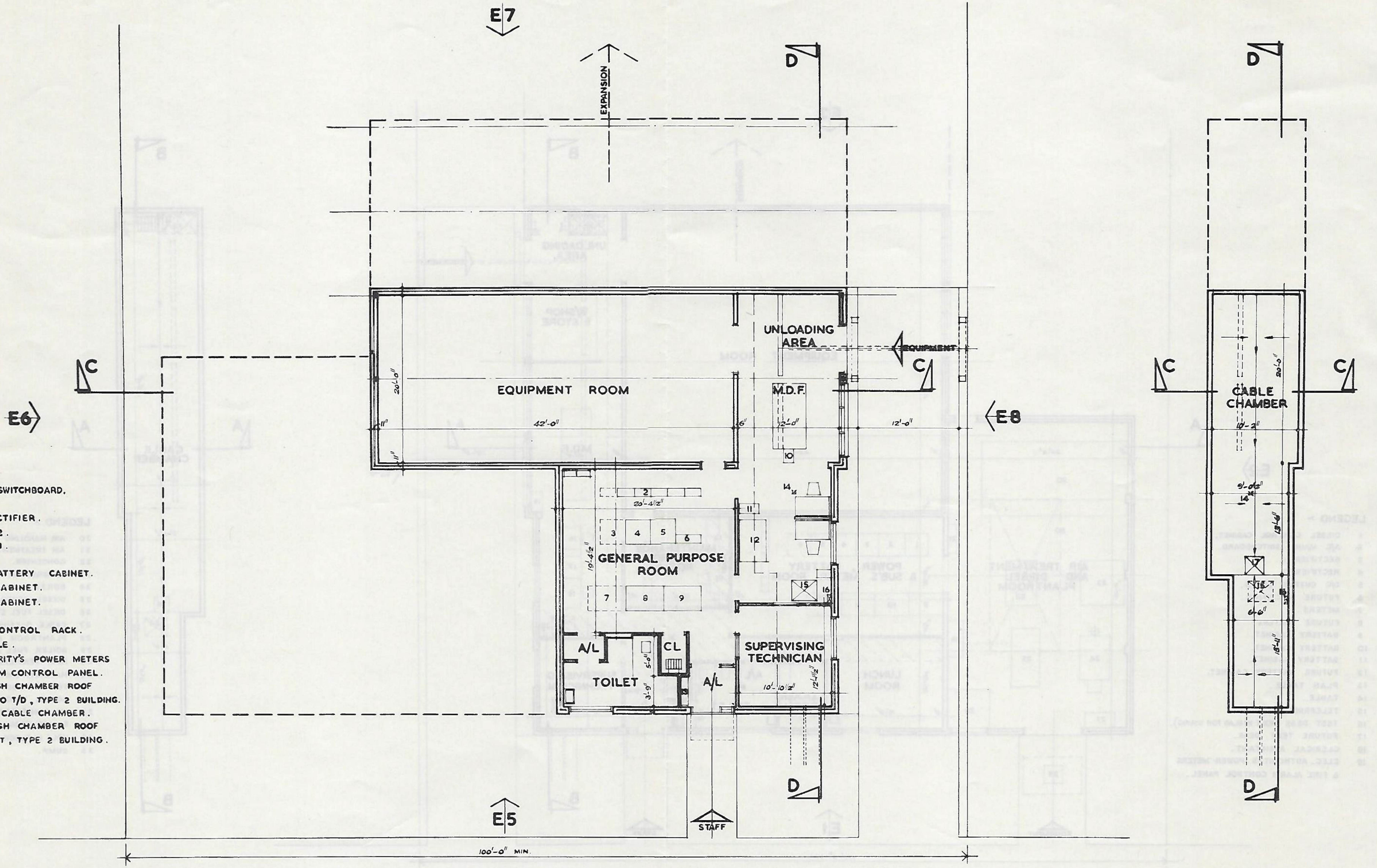
Using the above growth rate information the following planning criteria were developed as the basis on which the design phase could proceed:—

(a) One building (Type 1) which could accommodate 5,000 lines for the 10 to 15 year period.
(b) A second building (Type 2) to cater for a demand exceeding the Type 1 building at the 10 year period but less than 10,000 lines at the 20 year period.
(c) Because of the fluctuating character of growth rates which can occur in practice a requirement for the Type 1 design would be the ability to develop into a Type 2 building if dictated by future demand at any time in the planning period.
(d) A known demand in excess of 10,000 lines at the 10 year date would not be catered for in the design.
(e) Site utilisation would be in accordance with A.P.O. policy, i.e. it must be possible to extend the building to cater for a capacity of at least double the 20 year requirement.

The following parameters were used as guides during the design development stage to meet the planning criteria:—

(a) To achieve the maximum benefit from standardisation it was considered mandatory that the number and type of standard plans should be kept to a minimum.
(b) Plans and the appropriate documentation should apply to the building above floor level with the foundations being the only section requiring supplementary documentation for each project.
(c) It was decided that the standard plans once prepared would not be reviewed for at least 5 years. Unforeseen anomalies which might arise would be corrected in local documentation.
(d) Plans must be based only upon standard equipment and current practices and not on proposed equipment and unproven techniques either proposed or under development.
(e) Plans should cover a comparatively wide range of application and be capable of adaption to other uses through the medium of flexibility in design.
(f) Modular extension of the Equipment and M.D.F. rooms would be a fundamental requirement.
(g) Single storey construction would be preferred to multifloor designs.

The above planning and design parameters represent the broad view on which an investigation of this nature must commence. In short, it defined the performance criteria to be met by a standard plan design. The next phase in the investigation was the determination of final design arrangements to meet the specified performance criteria. This stage represented the sorting and searching



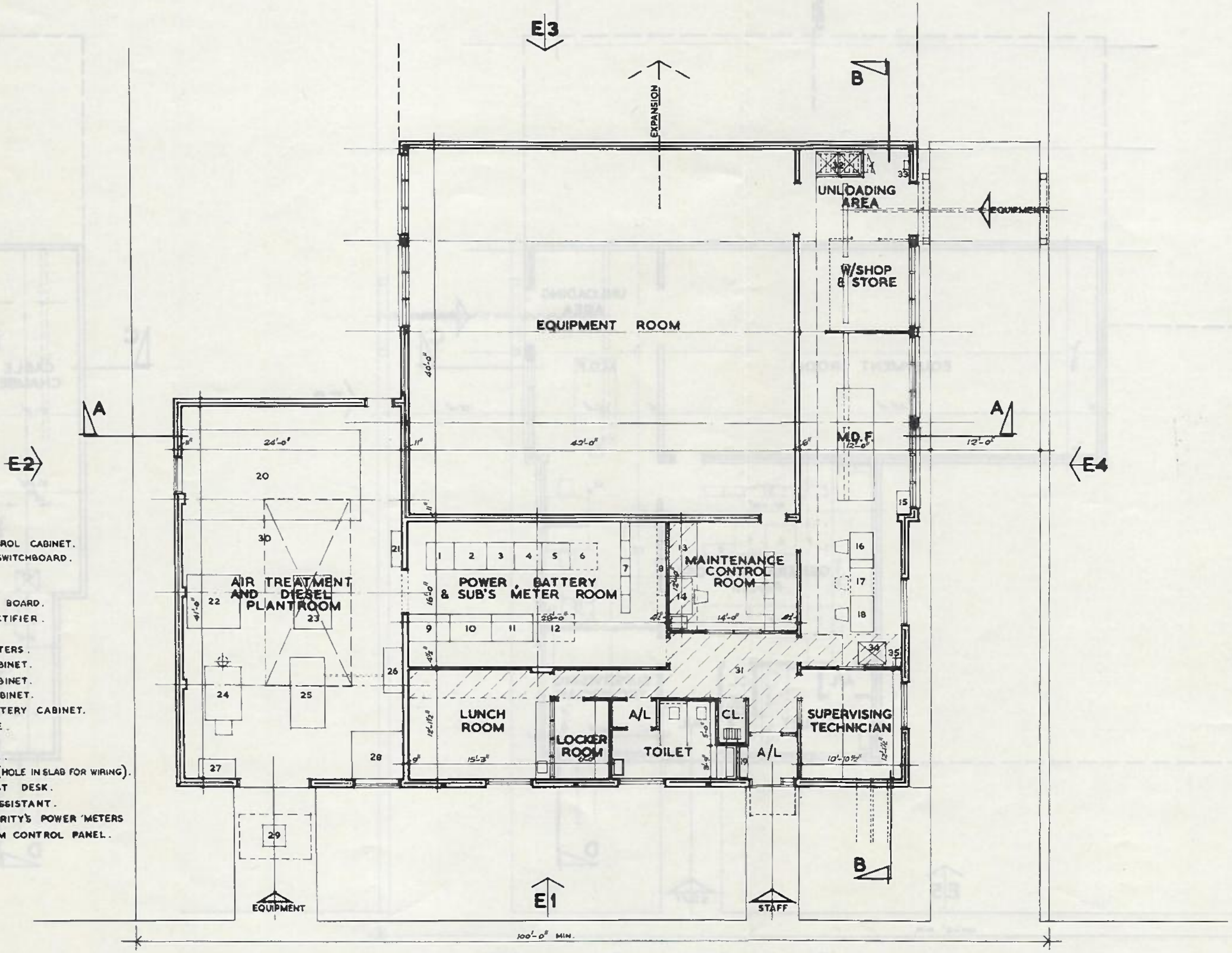
LEGEND :-

1 A/C MAIN SWITCHBOARD.
2 METERS.
3 FUTURE RECTIFIER.
4 RECTIFIER 2.
5 RECTIFIER
6 DISCHARGE
7 FUTURE BATTERY CABINET.
8 BATTERY CABINET.
9 BATTERY CABINET.
10 TEST RACK.
11 SERVICE CONTROL RACK.
12 PLAN TABLE.
13 ELEC. AUTHORITY'S POWER METERS & FIRE ALARM CONTROL PANEL.
14 HOLE THROUGH CHAMBER ROOF FOR WIRING TO T/D, TYPE 2 BUILDING.
15 ACCESS TO CABLE CHAMBER.
16 HOLE THROUGH CHAMBER ROOF FOR AIR DUCT, TYPE 2 BUILDING.
17 SUMP.

PLAN

PLAN OF CHAMBER

Fig. 2 — Standard Telephone Exchange Type 1 Building.

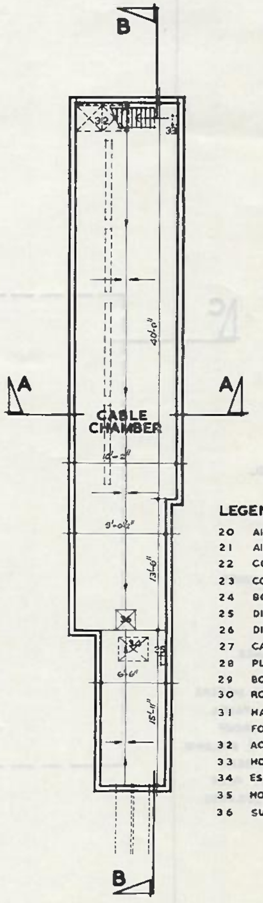


PLAN

LEGEND :-

1 DIESEL CONTROL CABINET.
2 A/C MAIN SWITCHBOARD.
3 RECTIFIER 1.
4 RECTIFIER 2.
5 D/C OUTPUT BOARD.
6 FUTURE RECTIFIER.
7 METERS.
8 FUTURE METERS.
9 BATTERY CABINET.
10 BATTERY CABINET.
11 BATTERY CABINET.
12 FUTURE BATTERY CABINET.
13 PLAN TABLE.
14 TABLE.
15 TELEPRINTER.
16 TEST DESK (HOLE IN SLAB FOR WIRING).
17 FUTURE TEST DESK.
18 CLERICAL ASSISTANT.
19 ELEC. AUTHORITY'S POWER METERS & FIRE ALARM CONTROL PANEL.

Fig. 3 — Standard Telephone Exchange Type 2 Building.



PLAN OF CHAMBER

LEGEND :-

20 AIR HANDLING PLANT.
21 AIR TREATMENT PLANT SUB-BOARD.
22 CONDENSER.
23 COMPRESSOR.
24 BOILER.
25 DIESEL GENERATING SET.
26 DIESEL FUEL STORAGE TANK.
27 CABLE GASSING PLANT.
28 PLANTROOM AIR SUPPLY.
29 BOILER FUEL STORAGE TANK.
30 ROOF VENTILATOR ABOVE (DOTTED).
31 HATCHING SHOWS FALSE CEILINGS FOR AIR DUCTS.
32 ACCESS TO CABLE CHAMBER.
33 HOLE IN FLOOR SLAB FOR AIR DUCT.
34 ESCAPE FROM CABLE CHAMBER.
35 HOLE IN FLOOR SLAB FOR AIR DUCT.
36 SUMP.

processes to find the best dimensional configurations in which experience, and even intuition, had as much a part to play as the more conventional forms of optimisation techniques employed to achieve an economical yet functional design.

THE RESULTANT DESIGN

General

Appendix 1 details part of the briefing information (Ref. 3) prepared by the A.P.O. to specify final requirements for the Type 2 building design. The Type 1 building was specified along similar lines. Fig. 2 and Fig. 3 show the plans which were finally developed. Fig. 4 is an artist's impression of the completed building and indicates clearly the integration of Type 1 and Type 2. The orientation of areas and other particular design features were based upon:—

(a) qualitative maintenance operational requirements employed in the A.P.O.,
(b) the requirements of standard switching equipment and other standard apparatus, and
(c) the need to ensure all areas are compatible (or capable of extension in a logical manner) to support increased capacity following extension of the building on a modular system.

Qualitative maintenance (Ref. 4) governs the maintenance operations of telecommunications plant in the A.P.O. It demands, from a building design viewpoint, an emphasis upon the elimination, as far as practicable, of dust particles into the equipment room. The main design measures to minimise dust were:—

(a) Areas were oriented to avoid unnecessary staff movement through the equipment room.
(b) Certain building materials were selected because of their maintenance-free properties as a means of reducing disturbance to equipment in later years through building maintenance activities.
(c) A stringent specification for air-treatment in the equipment room.
(d) Separate areas segregated from the equipment room, for staff activities not directly concerned with switching maintenance, such as power and meter room, uncrating and workshop areas.

Crossbar exchange apparatus is the standard switching equipment at present in use within the A.P.O. and of course influenced considerably design arrangements and requirements. A particular example of this is the specifying of a maintenance control room. This room accommodates automatic surveillance equipment and other apparatus which permit, as much as possible, service supervision and performance of the exchange plant to be observed outside the switchroom. It will be seen from the plans (Figs. 2 and 3) that this room was strategically placed for such purposes and also as a means of control over unauthorised staff entry into the equipment room. A further example of the influence of crossbar equipment is the elimination of a storeroom. Essential stores for crossbar plant are confined to a number of critical relay sets installed and working in parallel with similar equipment and ready for use at any time. Other spare parts are small in size and can be accommodated in cupboards. Any demand for a temporary storage area can be met in the workshop, and uncrating area situated at the end of the M.D.F. room.

In specifying area requirements and the layout of functional areas so that the ultimate capacity of the building plan is achieved, considerable detail is involved in manipulating critical dimensions. Particular attention is recommended to the work of dimensional configurations in a study of this nature, because of the bonuses in flexibility which can sometimes occur when a design deviates slightly from precise needs. The power conversion plant room was a particular example of this when it was observed that by redimensioning the planned area to give a small increase in area, it was possible to increase the capacity to an ultimate figure capable of meeting the power needs of about 15,000 automatic lines of equipment. Other minor advantages were gained in different sections of the plan which resulted in the gaining of 'room to move' without any unwarranted space wastage. This increase in flexibility is in addition to the engineered flexibility introduced into different sections and which is described later in the article. The design of the three (3) key areas of Cable Chamber, Main Distributing Frame (M.D.F.) and Equipment Room are discussed below together with features of the ancillary and amenity areas.

Cable Chamber Specification

The most fundamental of design criteria is the specification governing the number of external line plant cables to serve the telephone facilities planned within a telecommunication building. The number of line plant cable pairs is always greater than the number of telephone lines in the telephone exchange building. Basic data for the design of the cable entry section of the cable chamber was obtained from a study of:—

(a) The cable occupancy of subscriber lines in existing terminal exchanges.
(b) Typical junction patterns of development within local switching networks.
(c) The miscellaneous usage of cable plant with respect to other subscriber facilities such as fire alarms, data transmission, etc.

Analyses of these factors resulted in the practical design specification for:—

(a) external plant cable pairs per telephone exchange equipment number, and
(b) number of cables required at the 8 and 20 year dates with an indication of ultimate numbers based upon double the 20 year figure.

The ratio of line cable pairs to each telephone equipment number is a major design parameter for the M.D.F. and the actual figure used in the investigation was 2.5 cable pairs per telephone number. The calculated number of cables provided the duct sizes and number required into the building at the different stages of its development. The average size cable used in these calculations, and based

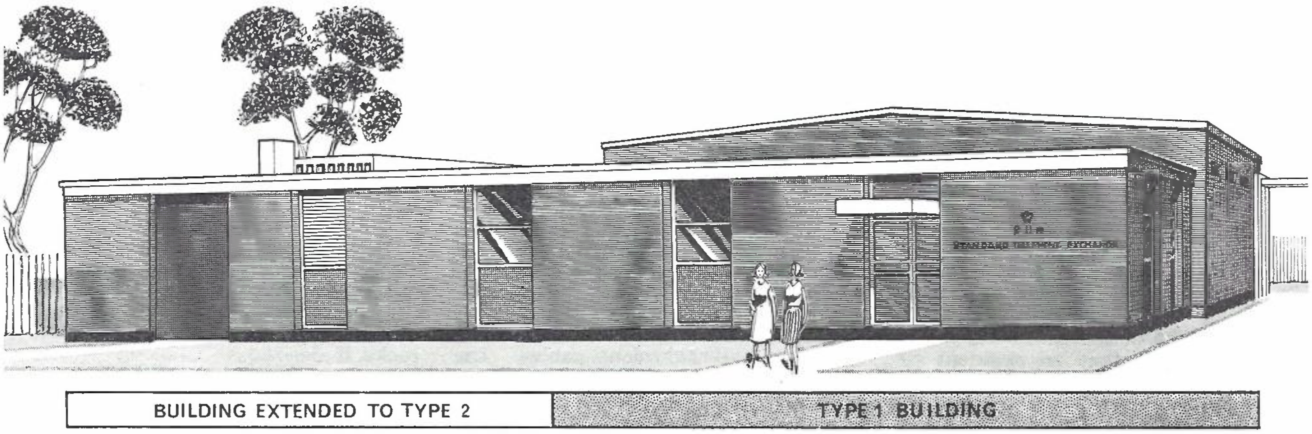


Fig. 4 — Artist's Impression of a Standard Telephone Exchange Building Showing Type 1 and Type 2 Extension.

upon present standards for line plant was 1,200 pairs which included, and made allowance for, junction cables. The growth rates used in Fig. 1 for the 8 and 20 year periods determined the ratio of cable pairs to equipment lines and hence the number of cables for both sizes of the standard buildings. In accordance with normal A.P.O. practice, cables will be provided on the 8 year requirements whilst ducts are provided on a 20 year basis.

With respect to cable chamber design there existed, at the time of the investigation, what could be called two standards. Because the cable chamber would be part of the particular design for each application of the standard building alternative cable chamber dimensions were allowed, the choice of which would be a function of each State Administration preference. By the time the next review of standard plans is made, a common set of design dimensions should be available. For cable access between the cable chamber and the M.D.F. a slot 6 in wide was specified which is considered a more flexible design than the previous A.P.O. standard of a series of 4 in square holes at 6¼ in centres.

Appendix 1 gives the detailed design data used to specify cable chamber requirements. A cable chamber below ground level was specified for both buildings. The economies of this requirement were closely examined because of the known difficulties and high cost experienced in the past at some sites. Cable chambers below floor level can be costly because of the presence of water tables close to the surface under particular sites throughout the Commonwealth, and rocky sites can raise chamber construction costs by 30%. Cost studies revealed marginal conditions for typical site situations known at the time for Type 2 building. For a Type 1 building the short term economics favoured a slotted type entry rather than the cable chamber and in a few instances, State Administrations may prefer the slot. However, the A.P.O. has had experience of the difficulties and high costs in the past where the cable entry has proved inadequate and extension measures become necessary. The problem of maintaining continuity of service during extension work demands a complex building operation based on a comprehensive plan calling for the utmost care in the rearrangement (and sometimes replacement) of existing cables. Innumerable transposing of working pairs on the M.D.F. is sometimes necessary and high supervisory and administrative costs over many months are involved to ensure a successful operation. Valuable resources in the form of skilled labour are diverted from other major and productive activities, and there is always the risk that an accident to plant can occur during such work. Major extension of cable entries represents a continual hazard whilst the work is being carried out, an uneconomic undertaking imposing unwarranted strain on operational staff, and unnecessary diversion of resources. Therefore, based upon previous experience and the fact that a Type 1 building in some instances will develop into a Type 2 building, the decision was made to specify a cable chamber for Type 1 even though this would increase the cost of the building initially.

Main Distributing Frame Area

This frame provides teminating and testing facilities for external plant cables to subscribers' premises and the internal cables to the telephone exchange equipment. It permits the connection of any telephone exchange number to any line pair. Fig. 5 shows a standard A.P.O. M.D.F. which, under qualitative maintenance requirements is segregated from the equipment room by a ceiling height partition. External plant cables are fed from the cable chamber underneath the frame, and are connected to link blocks on one side. The equipment cables are installed along the top of the frame and terminated on blocks, fitted with protective devices and located on the other side of the frame from the external plant cables. The M.D.F. is composed of a number of verticals 6¼ inches apart with each vertical capable of terminating 600 line cable pairs and 200 equipment number pairs. This ratio permits the adequate meeting of the design figures calculated from cable planning information and allows facilities for additional protective devices on spare line verticals to be accommodated if required by external line plant conditions. The M.D.F. structure demanded a ceiling height of 13 ft and a floor loading of 200 lbs./sq. ft (distributed).

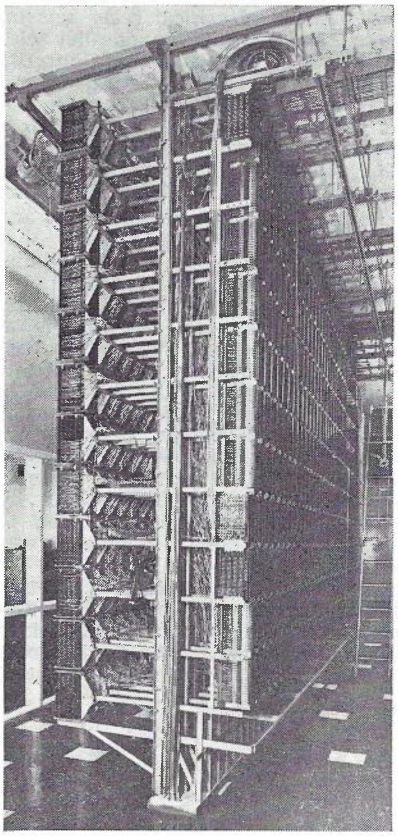


Fig. 5 — Standard A.P.O. Main Distributing Frame (M.D.F.).

The M.D.F. room is orientated to grow with the extension modules of the building with uncrating, store and workshop activities always catered for by utilising portion of the area reserved for M.D.F. growth. This was considered an economic plan and the workshop area was specified to be separated from the M.D.F. by a temporary timber framed wall to ceiling height and capable of relocation after a building extension.

Also included in the M.D.F. area is a test desk which is used for testing subscribers' apparatus, cable plant and telephone exchange equipment. The basis used was 1 test desk operating position per 10,000 lines which accounted for some degree of automatic robot testing now being introduced into A.P.O. exchanges. An auxiliary rack mounted test unit (with limited facilities) was specified to cater for periods of test overload which occur spasmodically, due to major cable interruptions and breakdowns.

Equipment Room

The equipment room width of 42 feet was specified on the basis of crossbar equipment with a traffic handling capacity of $m = 8$. The symbol $m = 8$ denotes the capacity of the equipment to handle subscribers calling and terminating rates of a particular magnitude. Another capacity, of $m = 6$ crossbar equipment, can be properly installed in the critical dimension of 42 feet and together, the $m = 8$ and $m = 6$ capacities will cater for the majority of subscribers likely to be served from equipment installed in standard buildings. Telephone exchange equipment is accommodated on racks which are installed in suites with access areas between suites for maintenance purposes. The 42 feet width dimension allows some flexibility in the pattern of racks which make up a suite when using $m = 6$ capacity equipment. An example is transmission (long line) equipment racks which can also be installed whilst still preserving optimum layout conditions for the crossbar apparatus. The clear height of the equipment room was specified as 12 feet 6 inches and this is sufficient for overhead intersuite runs of cable using troughing and ducting systems. The specified floor loading of 200 lb/per sq. ft. is greater than is actually required for crossbar equipment but this permits the flexibility of installation of other types of equipment racks if desired.

The equipment is extended in modular sections (or bays) of 10 feet. This dimension is an optimum, based on structural engineering considerations which give a small degree of overprovision of equipment space, resulting from extensions during the life of the building. The Department of Works cost studies determined that roof trusses and other structural components required by the 42 feet width dimension would be compatible with the 10 feet modular extension. The same cost studies also revealed that the minimum economic initial provision of modules would be two for the Type 1 and four for Type 2 giving a minimum capacity of 2000 lines for Type 1 and 5,000 lines for the Type 2 plans.

Telephone exchange equipment layouts are a changing requirement because the equipment is engineered to meet the particular characteristics of each exchange area and quantities of apparatus are dimensioned in accordance with traffic engineering mathematical analyses. In general terms, each installation of automatic exchange switching equipment contributes to a general pool of knowledge which, together with maintenance experience of various configurations, permits a progressive improvement in layout design. Nevertheless because certain patterns manifest themselves the A.P.O. from time to time, has developed reference layout plans (or typical patterns) from which it is possible to at least standardise on critical dimensions related to:

(a) length of suites;
(b) spacing between suites;
(c) width of passageways and aisles with respect to equipment rack sizes.

Typical crossbar exchange layouts were used for equipment area requirements as a specification for the standard plan development. These layouts were developed from earlier patterns based upon experience with crossbar plant and excluded subscribers meter racks. Changes in design of some of the equipment mounted on the racks can also vary the pattern of layout. Thus the 42 feet width should permit changes and allow the normal design improvement processes to apply during the life of the building.

Other features of the equipment room as specified were:

(a) A slight overpressure of the air inside the equipment with respect to other areas to minimise the entry of dust.
(b) Return air ducts should not create drafts or draw unclean air past sections of the plant from adjacent areas.
(c) Fixed windows were specifiied at a high level on external walls with the number limited to essential requirements. A likely development of the future will be the elimination of equipment room windows on external walls.
(d) Separate uncrating and general work area was necessary to reduce the dust nuisance in the equipment room.
(e) Entry into the equipment room should be supervised at all times to avoid unnecessary staff movement through the area. This was achieved by locating the main entry door from the equipment room into the maintenance control centre.

Ancillary Operational and Amenity Areas

Appendix 1 details the requirements for the major ancillary areas of power and air treatment and the amenity areas all of which are planned in size to meet the 20-year requirement. These requirements are in accordance with well-established engineering and personnel practices as set out in A.P.O. Engineering Instructions and internal policy memoranda based on equipment considerations and economy of operation. An example of this is the mounting of totally enclosed secondary batteries into cupboards and the provision of rectifiers (for a.c. mains conversion) in lieu of the previous standard equipment of motor generator conversion plant.

Air treatment was a major part of the study and resulted in the specification of temperature limits, relative humidity limits, and filtration requirements. A measure of the internal heat dissipation from crossbar to plant enabled a suitable design of plant to be achieved. These studies of course are only part of continuous investigations in the assessment of air treatment plant performance in the various States of the Commonwealth. Full air-conditioning is an 'optional' extra and the Type 2 plan provides space for a boiler and refrigeration plant if demanded by the particular location.

The amenity rooms were located at the front end near the entrance of the building. Provisioning was designed a little in excess of requirements to meet sporadic increases in staff during installation of equipment and other projects where additional staff use the amenities.

STANDARDISATION AND FLEXIBILITY

The main penalty for standardisation is usually loss of flexibility and therefore any study of this nature must be directed towards attaining a balance between the two. On the one hand a standard building plan can be highly efficient and economical, when used in a particular application for present day needs. At the same time however, it may be incapable of adaptation to meet other or unforeseen requirements. On the other hand a plan which meets all variations would clearly be uneconomic because features associated with very few situations would represent redundancy for the majority application. In the first example the introduction of flexibility is demanded as a corrective factor, whilst the second example demands its restriction. In both cases the degree of flexibility engineered into building plans influences the building economies and cost savings available under standardisation.

Therefore the degree of flexibility developed in the standard building design was influenced by considerations which attempted to avoid the two extreme situations illustrated above. An example of engineered flexibility occurred in the specification of the equipment room width for the standard plan. Planning studies of typical average calling and terminating telephone traffic rates of subscribers in areas covered by Fig. 1 revealed that the majority of these could be served by $m = 6$ capacity crossbar equipment which requires a smaller equipment room width than the equipment $m = 8$ capacity. The $m = 6$ capacity width dimension would have resulted in construction savings in this section of the building design. However, the planning studies revealed also that in some of the areas, $m = 8$ capacity equipment was a requirement either as a whole or during part of the planning periods. $M = 8$ capacity equipment demands a wider equipment room which in turn increased construction costs. However, the increase in cost to introduce this additional flexibility was considered justified in the face of the unacceptable alternative of installing $m = 8$ capacity plant to $m = 6$ design widths. This would have resulted in unsuitable layout configurations of equipment for such cases. Payment of installation penalties would have occurred every time additional equipment was installed plus maintenance penalties throughout the working life of the equipment. $M = 6$ capacity equipment can be accommodated economically in $m = 8$ equipment design widths without any such penalties. On the other hand, complete flexibility could have been obtained, at a higher cost again, by specifying the equipment room wide enough to accommodate the largest size crossbar equipment ($m = 10$ capacity). However, the higher cost (for complete flexibility) was not warranted because $m = 10$ capacity equipment is generally used in city and industrialised suburbs (represented by area G of Fig. 1) and there is only a remote chance that it would be used in a standard building.

Therefore the specification of an equipment room design width for $m = 8$ capacity plant represented the introduction of planned flexibility to increase the effectiveness and usage of the standard building but achieved at a small increase in building costs. The decision excluded both the alternatives of (i) the more economical but more restrictive application of $m = 6$ design widths and (ii) the least economical but totally flexible plan for $m = 10$ design widths.

Other features of the building design were planned on the basis of considerations such as those outlined above. Flexibility was introduced which in turn increased costs to some extent but at the same time, added that necessary commodity, the ability to meet limited unforeseen requirements. It is suggested that, because of the time commitment in the initial study, all factors which balance flexibility and building economics (short and long term) were not fully accounted for. In the light of experience gained from the use of this Standard Plan, subsequent reviews may be in a better position to achieve optimum conditions between standardisation and flexibility in the design.

Standard methods and practices are continually changing and at any point in time some established item of plant is under consideration for a redesign. This constitutes a form of penalty because such a redesign if unfinished, or not proven at the time of the review, is excluded, and the existing (and therefore to some extent unsatisfactory) design remains the basis for the next five year period of standardisation. This must be expected, although, providing the building design will permit, there is nothing to preclude the adoption of any redesigned item of plant or new technique at any time during the 5-year period. The keynote for the future is to design the building in such a manner that the inherent flexibility of building configuration will permit some degree of experimentation during the 5-year period. This is necessary and was foreseen as an essential requirement in the initial plan development in order that standard building design from the viewpoint of telecommunications engineering design standards can progress.

STANDARD BUILDING USAGE

Buildings will be programmed by specifying the type and number of equipment modules to meet the initial requirements. The Type 1 building will have its greatest application in country areas as accommodation for terminal and minor switching exchanges. Minor exchanges are exchanges which provide some tandem or through switching for terminal exchanges. On a Commonwealth basis approximately 50 buildings of this nature will be required annually over the next five years. It is emphaisised that features such as 200 lb per sq. ft floor loading will permit wider usage of the standard buildings to include those cases where it is necessary to also install limited quantities of long line equipment. Many minor switching centres will be under 2,000 lines in 20 years with an ultimate capacity under 5,000 lines. Tandem switching and transmission plant justifies the 2 modules demanded by the overall building economics, but the low subscribers' development focuses attention on the uneconomical aspects of a complete cable chamber. Under these circumstances, State Administration planning authorities, based upon the particular situation, could specify the cheaper form of cable entry using a cable slot. This is possible as the method of cable entry is a matter of individual design in conjunction with foundation requirements.

Type 2 building will be used more generally in metropolitan and extended local service areas (E.L.S.A.) In cases where the survey figures, at the 20-year date, are in the vicinity, or slightly in excess, of 10,000 numbers the decision to use a standard plan is a matter of judgment and experience of the A.P.O. State planning engineers, who are conversant with known trends and developments within the local conditions under study. The 10,000 line figure is not intended to be an inflexible upper boundary value. Because of this, it is difficult to estimate demand for the Type 2 plan in actual numbers during the next 5 years. For metropolitan application it is considered that approximately 25% of the telecommunication building programme could be met by standard buildings. The difficulty is further increased because initially, some sites owned by the A.P.O. may not readily permit construction of the standard building. In many ways site utilisation is one of the major planning considerations in a building proposal. Where the present site is unsuitable for the Type 2 building, there is no alternative to the design and specification of a particular building to suit the site. In the future the acquisition of sites should be steered by the standard building requirements. Within the A.P.O., everything practicable is done to achieve maximum use from a site in the long term to avoid restrictions in ultimate development. Once a telephone exchange is established, there is increasing economic pressure to continue to meet development from that location because the increasing cable and equipment investment makes it unattractive and uneconomic to change.

CONCLUSION

The development described in this article represents another but more positive step in the closer integration of building engineering and telecommunication engineering requirements as appled to the design of the most suitable accommodation for a particular type of telephone exchange requirement. In the past considerable progress has been made in the re-use of the principles of design where they have proved successful in a particular instance. This has led to repeated use on many occasions throughout the Commonwealth.

One of the particular objects of this development has been to achieve a saving in documentation time by a complete re-use of plans and specifications thus avoiding the time involved in redrawing sets of plans for a particular situation. It was realised that the full benefits of standardisation would only be gained if a particular type of telephone exchange requirement could be planned and designed in a single context, i.e., the requirements of the telecommunication equipment and the building as a protective envelope were integrated in a proper technical and economic manner. The close collaboration between the two departments during this study has, we believe, achieved this objective. The resultant standard plans of this initial cycle of development are an embodiment of current telecommunication engineering and building engineering techniques and experience. The progress already made by A.P.O. State Administrations was matched with the knowledge and experience of building engineering staff in the Department of Works who have specialised in the particular field of telecommunications building design. Through the agency of the Central Administrations of both departments the principles developed over the years were used as the basis for commencing this initial cycle of standardised telecommunication building plans.

In a different context however, standardisation can also mean stagnation. This can occur if a standard is not fully reviewed at set intervals to incorporate technological advances made during the previous period. In this respect, both departments will be pursuing a definite policy of continually reviewing all relevant developments which occur during the 5-year period and at the same time assessing any shortcomings observed through the usage of the standard building during that time. Changes in techniques and methods of telecommunication engineering, together with new and proven forms of building material and construction will no doubt be the main sources of change. Equally important will be the incorporation of innovations and ideas submitted by A.P.O. Plant and Planning personnel directly concerned with the operation, installation and maintenance of telecommunications equipment.

In the opinion of the authors, the most significant feature of the standard plans will prove to be the ability to focus and concentrate the attention of the different A.P.O. planning and plant section officers with Department of Works officers on to common ground and along common lines. This means that during the period between reviews, innovations, techniques and experience will be channelled towards the one objective of improving the design features of the standard plans thus ensuring that the next review will produce plans which incorporate all possible improvements. Therefore both departments are contributing to the aim of general productivity improvement by ensuring, in this particular field, that more satisfactory buildings will continue to be provided which are planned and built at lower costs and with better scheduling procedures. The final plans issued by the Directors-General represent, as far as possible, optimum arrangements to meet situation requirements at this stage. Both departments now have a charter to implement the use of these building designs wherever the requirement exists. If circumstances are such as not to permit the direct use of the standard plan, every endeavour should be made to apply the principles on which the plans are based.

ACKNOWLEDGEMENTS

The developments described in this paper were carried out by a working party composed of officers from the Headquarters Sections of the Department of Works and the A.P.O. The assistance of the many people who contributed their respective skills and experience towards the development of the final standard plans is gratefully acknowledged.

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APPENDIX 1

EXTRACTS FROM A.P.O. BRIEFING REQUIREMENTS

Planning Considerations

The Type 2 Building is designed to accommodate nominally 5,000 to 10,000 lines of telephone exchange equipment.

In general, a Type 2 Building will be used for terminal automatic exchanges where the development of the exchange area is beyond the capacity of a Type 1 Building in the 10-15-year period, but less than 10,000 lines at the 20-year date. Some additional flexibility is provided in the Type 2 Building as the ancillary rooms provided will support an Equipment Room of more than 10,000 lines (estimated 12,000-15,000). No firm upper limit is specified as future trends in ancillary space requirements or particular circumstances at any location may permit these areas to support equipment in excess of 15,000 lines. Furthermore, the M.D.F. has been located along the outside wall of the building to provide flexibility in the future in meeting changed planning concepts and unforeseen additional equipment capacity needs. In this location the M.D.F. area is more readily extended and provides more flexibility in the provision of a second cable entry, if required.

Normally, the Type 2 Building would be ordered with a minimum Equipment Room length of 4 modules (where one module represents 10 feet), as this is the minimum size Equipment Room which can economically be constructed in conjunction with the ancillary rooms to be provided. The ordering of additional Equipment Room length either initially or as an extension may be in any number of modules as required to meet development. In some exceptional circumstances, the Type 2 Building could be used with a smaller equipment room than the 4 modules to be constructed initially; this will depend on the initial size of the installation, the anticipated growth rate of the area concerned and other factors as discussed in the Director-General's memorandum of 24.6.1964, attached to the Working Party Report on the Economical Provision of Telecommunication Buildings. The principles embodied in the Working Party Report, together with the local background against which the requirements for a particular building are formulated should be applied to determine the optimum switch room length.

Site

The proposed standard plans for the Type 2 Building are based upon minimum site dimensions of 100 ft frontage and a depth of 130 ft for a 10,000 line building. (Two adjacent average suburban blocks of 50 ft x 150 ft will be sufficient for an exchange building of 15.000 lines.) When considering the location of the initial and ultimate building on a site the alternative of the standard plan in mirror image must be examined.

Many of the sites at present owned by the Department may not be suitable for the proposed plan so that consideration must be given to the possibility of acquiring either additional land to extend the existing site or a new site suitable for constructing the standard building.

If complete and thorough examination of all the facts proves a non-standard building on the existing site is fully justified, considerable effort will be saved and the preparation of plans expedited by following the general principles set down in the standard building design.

In future, sites should be purchased with the requirements for standard building design in mind. For a Type 2 Building, two blocks of land (50 ft x 150 ft) would normally be adequate, but a site should be chosen with a view to providing for long term expansion of the exchange and to ensure this, there should be adequate site remaining after 20 years to enable the exchange to at least double its capacity.

Complete details of the cable exchange entry and street cable manhole are not covered in these documents. Full briefing and supplementary drawings covering these items will be provided separately by the P.M.G.'s Department to suit the different conditions of each individual site. Where site conditions dictate, the "mirror image" of the plans may be used.

Equipment Room

The equipment room is designed for crossbar equipment and primary suite length for $m = 8c$ traffic capacity. A ceiling height of 12 ft 6 in is specified to permit intersuite runs of cable troughing over BDD racks.

No consideration was given to the provision of $m = 10$ size crossbar equipment as this is usually reversed for inner city locations, the buildings for which must be individually designed. The equipment room width of 42 feet will serve for both $m = 6$ and $m = 8$ equipment. The modules for the equipment room are 10 ft sections which is based upon structural building considerations and not suite spacings. This could allow some small degree of overprovision during extensions as a safety factor in meeting requirements.

The following areas were specified as design criteria for $m = 8$ equipment room areas:—

2,000 lines
42 ft x 20 ft
840 sq. ft

5,000 lines
42 ft x 40 ft
1,680 sq. ft

10,000 lines
42 ft x 70 ft
2,490 sq. ft

Drawing CSK-5783/Sheets 2 and 3 show typical equipment layouts in an equipment area 42 ft x 40 ft.

M.D.F. Area

Requirements for the M.D.F. area are based upon the use of a standard M.D.F. oriented to grow in the same direction as the equipment room. It was considered essential to provide a separate room for this activity from the equipment in conformity with qualitative maintenance principles. Uncrating and test desk facilities are also included in the general M.D.F. area as well as space for a clerical assistant.

The size of the M.D.F. was calculated on the basis of no protection on the equipment side with line pairs assessed at 2½ times the exchange numbers and 600 terminations per vertical on the line side. This figure was derived from experience gained in the States with suburban exchange subscribers reticulation systems and ample space is provided for unforeseen requirements by basing the length of the M.D.F. on line pair provision. Equipment side terminations are also 600 terminations high which therefore allows either for some protective devices to be included if required by the particular exchange location or extra line pair terminations if the 2½ times figure is exceeded.

To obtain maximum flexibility for extra line terminations on the equipment side of the M.D.F., a 6 in wide slot was specified in lieu of holes as the cable access between the cable chamber and M.D.F.

M.D.F. Lengths to serve particular equipment capacities are:—

Numbers	2,000	4,000	5,000	10,000
M.D.F. Length	5 ft	10 ft	12 ft	24 ft

Cable Chamber

The cable chamber is designed to provide a 48 duct entry from the street manhole and accommodation is provided for 48 cables by racking 24 cables each side of the cable chamber on 6 racks, each taking 4 cables.

(a) **Cable Chamber Dimensions:** The dimensions are 12 ft 3 in high, 10 ft 2 in wide (an alternative width of 7 ft 9 in can be used according to local custom) and the total length of the entry tunnel, cable rearrangement section and cable chamber proper is 69 ft 5 in. The various dimensions shown have been calculated as follows:

Height:	
6 racks, each 8½ in centre to centre + 8½ in from centre of bottom rack to floor.	4 ft 3 in
Turning area for main cables to potheads.	2 ft 0 in
Length of pothead	3 ft 0 in
Turning area for distribution cables to M.D.F.	3 ft 0 in
Total	12 ft 3 in

Width:		
Distance behind potheads on either side of Chamber.	1 ft 8 in x 2 =	3 ft 4 in
Stanchion Depth.	2 in x 2 =	4 in
Cable turning width for main cables.	6 in x 2 =	1 ft 0 in
Width of cable tray.	1 ft 2 in x 2 =	2 ft 4 in
Aisle width.	3 ft 2 in x 1 =	3 ft 2 in
Total		10 ft 2 in

Length:	
Access tunnel from front of building (6 ft 6 in width)	15 ft 11 in
Cable rearrangement length.	13 ft 6 in
Cable Chamber.	40 ft 0 in
Total	69 ft 5 in

(b) **Street Manhole and Entry to Exchange:** Due to the widely differing situations met in practice, neither a manhole nor exchange entry has been shown. In every case, the cable chamber exchange entry and street manhole will be designed individually for the particular site. Construction of the street manhole and cable exchange entry should be integrated with the construction of the cable chamber.

(c) **Entry to Cable Chamber:** An entry is provided at the rear of the chamber, and steps similar to a ship's ladder will be provided. An emergency exit is provided at the front of the chamber, opening into the area near the test desk. This escape manhole must be kept clear at all times.

(d) **Cable Gassing Equipment:** the cable gassing equipment is placed in the air-treatment and diesel plant room, a pipe leading from it to the flowmeters located on the M.D.F. room wall as desired.

(e) **Cable Chamber Drainage:** The cable chamber floor has a gradient of 1 in 150, sloping to the front of the building. A sump and appropriate type of pump will be provided where the cable rearrangement section of the chamber changes to the small access tunnel. The floor is graded from both sides into the centre of the chamber.

Uncrating and Storage

An uncrating area is provided in conformity with the principles of qualitative maintenance. This area is formed by an extension of the M.D.F. room and, if future expansion of the exchange warrants the extension of the M.D.F. into this area, then uncrating activities can be removed to the extended portion of the equipment room.

The monorail supporting frame for the equipment gantry is situated outside the building. This will allow its easy removal if the M.D.F. section of the building needs extension. The inclusion of a gantry is an optional item and should be included only as required.

A separate store room as such has not been provided. Portion of the M.D.F. room has been segregated for the storage of minor items only. Spare relay sets, as a general policy, will be either working (e.g., SLM spare equipment) or stored in spare relay set positions with battery connected. A minimum number of small components (e.g., resistors and capacitors) will be stored in free standing cupboards located in either the M.D.F. room or maintenance control room.

Maintenance Control Room

A separate area for this activity is considered essential and normally the area will be self-contained where maintenance staff can observe and study circuit conditions of the exchange equipment free from interruption. This is in line with service philosophy in the maintenance of crossbar equipment and it divorces these activities from the subscribers service work carried out on the M.D.F. and test desk.

Four racks have been accommodated in this area, together with a TRT and two tables, one of which is a plan table containing all relevant circuit diagrams for the equipment.

The four racks are:—

(a) Traffic measuring meter rack with a capacity for reading a maximum of 200 Erlangs.

(b) One traffic meter rack, e.g., TKM, AUM, AIM, etc.

(c) One service control rack containing service alarm, route alarm and RKR equipment, together with resettable meters.

(d) Provision for an extended alarm and TRT remote control rack. This rack will also provide for automatic data processing equipment as a development for the future.

It is considered prudent to provide a spare rack position for (d) above as current work in this direction should prove the introduction of A.D.P. within the next two or three years.

There is some doubt that one service control rack, as listed in (c) above, has the capacity to meet all service requirements for 10,000 numbers of equipment. This requirement is based upon current knowledge and techniques, but the trend in future developments may reduce the capacity of this rack to serve say 6,000-7,000 lines only. If future events limit the capacity then an additional service control rack would be necessary and consideration given to the removal of either the traffic meters or the Erlang meter rack outside the M.C.C. Such a decision would be the prerogative of the State Administration.

The basis of the maintenance and control equipment is set out fully in two publications — "Review of Crossbar Equipment Maintenance—August, 1963", and "A.P.O. Engineering Instruction — TELEPHONE Exchange M 7021".

Test Desk

One test desk will be provided for 10,000 lines and a test rack should then be installed to provide additional assistance up to 15,000 lines which is less than present standard provision. However, space has been provided for a two position test desk if required by local characteristics of the particular exchange concerned.

Meters

This area is based on the provision of 1,200 meters per rack with a 3 ft space between racks for the use of photographic equipment as a later development. A future development envisaged is an increase in capacity to, say 1,500 meters per rack and a rack redesign which will permit installation against a wall.

The installation of meters outside the equipment room avoids the necessity for meter reading officers and other personnel entering the switch room for the purpose of recording meter operations. The meter equipment is grouped with power and battery apparatus as a means of saving space in the exchange building.

Power and Battery

The area is designed for a total d.c. discharge figure of 800 amps. A main electric power supply board, fully automatic control cubicle for the standby diesel-alternator set and an exchange d.c. supply board are provided with the rectifier suite and a total of four 500 AH batteries can be accommodated in this area.

The figure of 800 amps should be sufficient for approximately 15,000 lines of m = 8 equipment (60 amps per 1,000 lines). The following figures are considered typical for other m capacity systems:—

m = 6a 35 amps per 1,000 lines
m = 6b 40 amps per 1,000 lines
m = 8a 50 amps per 1,000 lines
m = 8b 55 amps per 1,000 lines.

It is proposed that the initial requirements for the exchange will be met by standard rectifier units and exchange d.c. supply board, and later by the installation of an integrated a.c./d.c. conversion suite. These suites will meet the demand in excess of 400 amps.

Emergency A.C. Supply Details

The standard fully automatic N.S. (Normally Stationary) set for this application is an air-cooled diesel-driven brushless alternator of 44 kVA capacity at 0.8 power factor (35 kW), with separate floor mounted control cubicle. Should the requirements for the emergency electric supply exceed 44 kVA, a set of 60 kVA capacity, of similar size to the 44 kVA set, can be provided by the use of a turbo-charged version of the engine used on the standard unit. External dimensions of the N.S. set are 8 ft 6 in long x 3 ft 6 in wide x 4 ft 6 in high. The control cubicle is 3 ft 0 in wide x 7 ft 0 in high x 1 ft 9 in deep.

The N.S. set is mounted on a skid base and anti-vibration pads are provided. Care has been taken to eliminate possible leakage of fumes from the engine by the use of seamless flexible couplings on the engine exhaust and extension of the crankcase breather to the inlet manifold.

The cooling air inlet for the engine is via a common filtered air inlet provided for the mechanical plant room. The cooling air outlet is through a duct from the engine to the common outlet in the acoustically treated roof ventilator. The engine exhaust outlet is taken up through the roof, together with the boiler flue.

Masonry walls surrounding the area and sound attenuators fitted in the common air inlet and in the engine outlet duct, reduce mechanical noise outside the building to a reasonable minimum while the engine is running.

It is expected that no engine overhauls will be necessary under normal circumstances other than the usual services such as oil changes, checks of tappet clearance, head tightness, fuel injector tests, etc., due to the low running time, viz. 2,000 hours in 20 years.

A hundred gallon combined storage-service tank, wall or stand mounted, is considered sufficient for this class of plant.

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A COUPLING UNIT FOR TELEPHONE CONVERSATION RECORDERS

A. H. O'ROURKE, A.R.M.I.T., Grad.I.E.Aust. and H. O'CONNOR***

INTRODUCTION

In the latter part of 1966, the Postmaster-General announced that the recording of telephone conversations would be permitted after April, 1967, subject to certain conditions. The Post Office would make available for leasing by telephone subscribers, special recorder-connector units designed to permit various types of recording devices to be plug-connected to their telephone services. Recording of conversations by means of recorders not connected via the special unit would continue to be illegal and proceedings could be brought against offenders for breaches of the Telephone Regulations and Telephonic Communication (Interception) Act.

Many business and professional people and radio and television stations often have a real need to record telephone conversations, for example, orders telephoned by travellers to their head office, discussions required to be kept for reference between professional people and the recording of news and other information by newspapers and broadcasting services.

The C.C.I.T.T. considers that the admission of telephone conversation recording devices into a network is a matter for individual administrations but gives basic technical requirements recommended for such devices in its Recommendation P32 (Red Book Vol. 5, p23).

In the U.S.A., a warning tone must be provided with telephone conversation recording devices in accordance with Federal Communications Commission requirements. Certain machines approved for telephone conversation recording by the British Post Office and some European Administrations which have been submitted to the P.M.G.'s Department for type approval do not feature any arrangements for warning tone to the distant party, but simply include design features to ensure a low insertion loss when connected across a telephone line.

The unit designed and built by the P.M.G.'s Department ensures that a subscriber taking part in a telephone conversation is aware that it is being recorded because the connecting unit furnishes a distinctive signal at fifteen second intervals throughout the duration of the call. In this model, the signal is a pip tone of 1400 c/s lasting for 0.2 seconds. A photograph of the current unit is shown in Fig. 1.

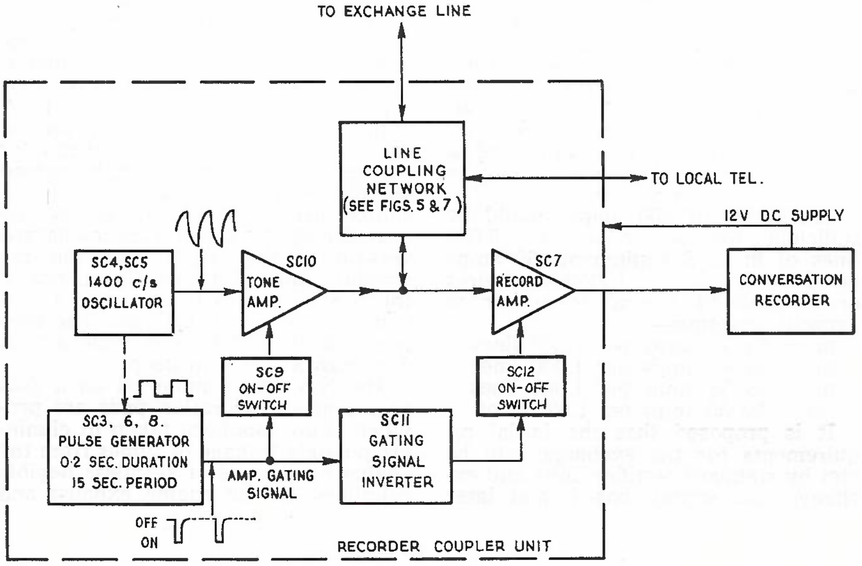

Fig. 2 — Block Diagram of the Unit.

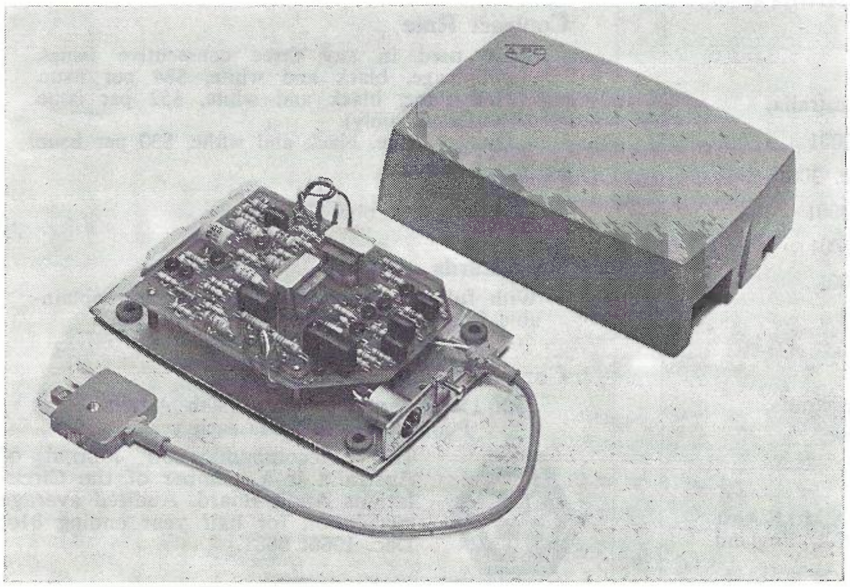

Fig. 1 — Unit with Cover.

GENERAL REQUIREMENTS

The general requirements to be met by the coupling unit are as follows:

(a) Provision of a "recorder outlet" to which a tape or conversation recorder may be connected.

(b) Provision of a warning tone, as described above, to the conversing parties.

(c) Reduction in level of the warning tone towards the local telephone.

(d) Reduction of the speech level from the local telephone to the recorder outlet, to provide some equalisation of the levels of the two sides of the conversation.

(e) Provision of a 12 volt d.c. supply to the coupling unit from the recorder being used.

(f) Blocking of the recorder outlet in the event of failure of the 12 volt d.c. supply, since this would also cause failure of the warning tone.

(g) The unit should have minimal effects on transmission and signalling in the telephone line.

(h) Solid state components to be used — no moving parts.

(i) The circuit design should permit manufacture at a moderate cost so that the unit can be provided at a reasonable rental.

GENERAL DESCRIPTION OF THE COUPLING UNIT

Block Diagram of the Unit

The block diagram (Fig. 2) shows the main sections of the unit with

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* Mr. O'Rourke is Engineer Class 2, P.M.G. Research Laboratories.

** Mr. O'Connor is Engineer Class 3, Workshops, Victoria.

the relevant transistors and waveforms. The transistors are numbered in accordance with the circuit shown in Fig. 3.

The individual sections are:—

(a) The line coupling network consisting of a three-winding transformer and impedance matching components.
(b) The oscillator, an astable multivibrator generating a 1400 c/s signal.
(c) The pulse generator which provides a gating signal for controlling the tone amplifier and record amplifier.
(d) The gating signal inverter for turning off the record amplifier when the tone amplifier is turned on.
(e) The tone amplifier feeding winding 3-4 on transformer TR1.
(f) The record amplifier which has two functions, the transmission of speech to the recorder via transformers TR2 and the prevention of recording of speech should the d.c. supply voltage fall below about 4 volts.

Connections Made to the Unit

The coupling unit has four main connections made to it (Fig. 4).

(a) From the local telephone
(b) From the exchange line.
(c) From the 12 volt d.c. supply in the recorder.

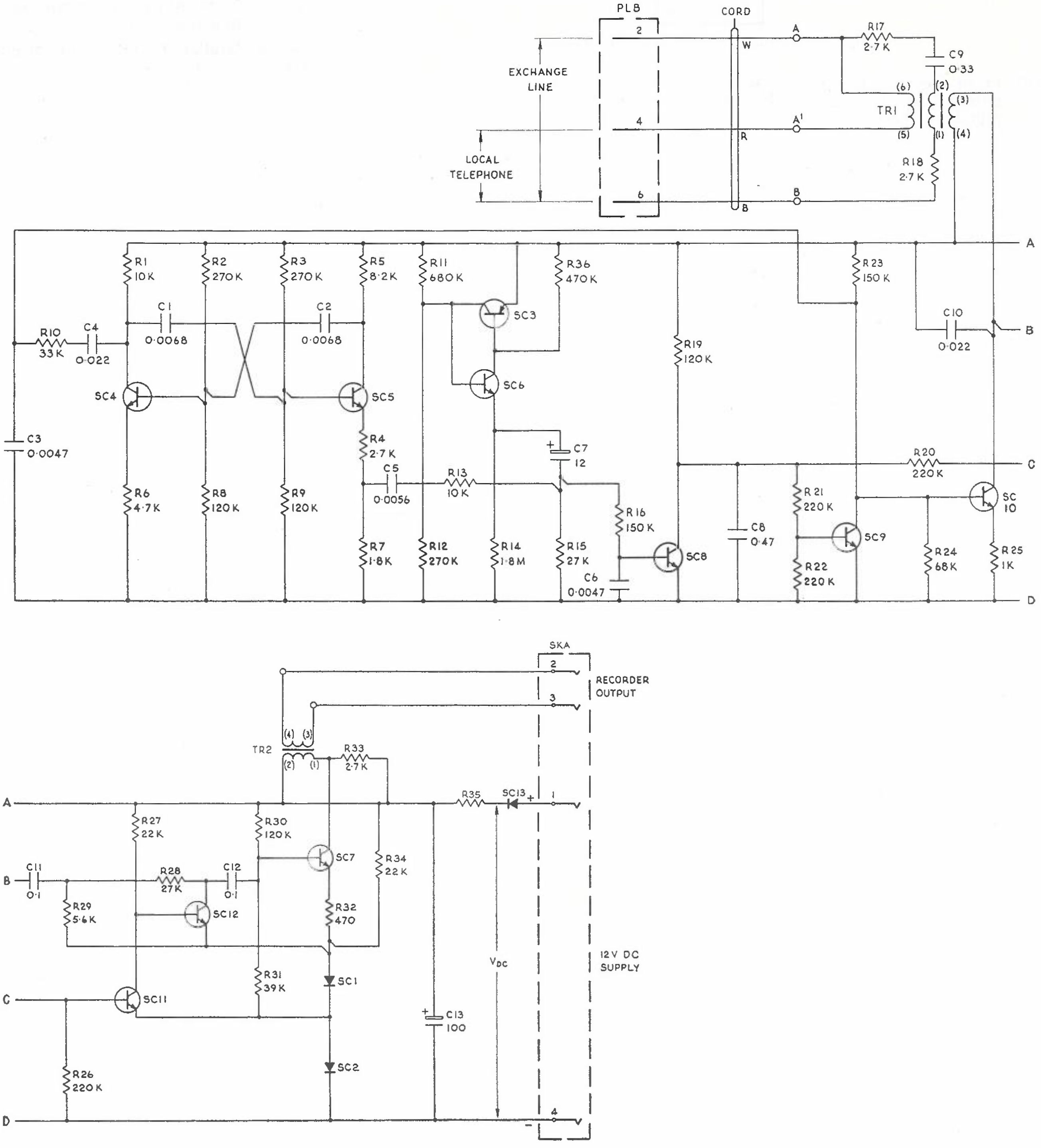

Fig. 3 — Circuit Diagram.

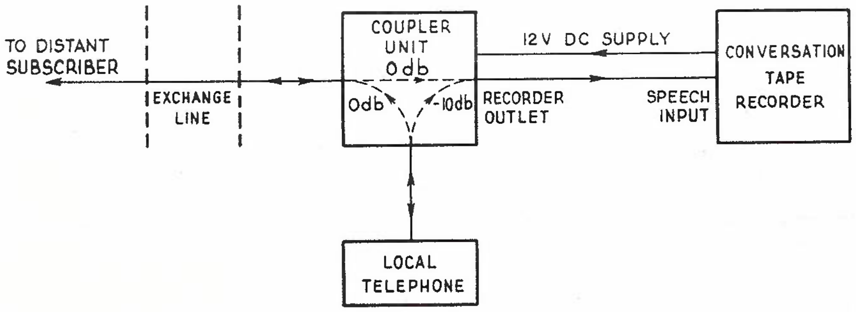

Fig. 4 — Connections at Subscriber's Premises.

(d) From the speech input of the recorder (the "recorder outlet" terminals of the unit).

The unit introduces an insertion loss of 0.4 dB, in both directions, in transmission between the exchange line terminals and the terminals of the local telephone, when measured with 600 ohm terminations. The shunt impedance (winding 1-2 of transformer TR1 in Fig. 4) across the telephone line is greater than 5400 ohms and the series impedance (winding 5-6) is less than 50 ohms. The series d.c. resistance of the latter is less than 10 ohms, consequently the unit has very little effect on feeding current and signalling.

The connection SKA of Fig. 4 is a Cannon type socket; PLB is the type 603 plug normally fitted to an 800 series telephone. The socket for PLB is connected to take an exchange line and a telephone service, and is arranged so that the telephone service may use the exchange line irrespective of whether the plug PLB is inserted or not.

Effect of Failure of 12 volt D.C. Supply

It is desirable that the coupler should block recording if for any reason the power supply to the 1400 c/s oscillator fails or is deliberately disconnected. In addition it is only necessary for warning tone to be transmitted when the recorder is actually in motion. For this reason the coupler has been made dependent on the recorder for its d.c. supply. If primary cells are used as the d.c. supply, a low supply voltage may eventually result. Consequently it is desirable that as the supply voltage falls, the blocking should occur before failure of the warning tone.

In the unit described, speech from the telephone line passes through an amplifier before reaching the recorder outlet terminals. The amplifier ceases to operate if the supply voltage falls below 4 volts whilst the warning tone will still be transmitted with a 3 volt supply. When the amplifier cuts off the gain falls by about 90 dB and the distortion becomes severe. This produces a level comparable with that produced by other stray couplings with the telephone circuits. In view of the requirement for simplicity in the unit it is considered that this provides reasonable protection against recording in the absence of adequate supply voltage.

DESIGN OF UNIT

Line Coupling Network

A three winding transformer is used to couple into the telephone line. The turns ratios are chosen so that the level of tone transmitted towards the local telephone is about 10dB less than the level transmitted towards the exchange line terminals under typical line conditions. Conversely during speech, the transmission path from the exchange line terminals to the recorder outlet terminals has about 10 dB less attenuation than the path from the local telephone terminals to the recorder outlet. The transformer thus provides some equalisation of the levels of two sides of the conservation at the recorder outlet.

The output impedance at this point in 600 ohms and with a high input impedance recorder, the attenuation between the exchange line terminals and the recorder outlet is approximately O dB on a voltage basis (see Fig. 4). The input impedance of the recorder is not critical but it should preferably be higher than 300 ohms.

There are a number of ways in which the coupling unit can be introduced into the telephone line.

Parallel or Bridging Connection of Oscillator: A simple method of coupling the warning tone into the telephone line is to use a high impedance circuit to inject the tone into the line. This has the advantage of simplicity, but has the disadvantage that the level of tone necessary to ensure adequate warning to the distant party, is uncomfortably loud in the local telephone receiver.

Parallel or Bridging Connection of Recorder: For recording the conservation, a bridging connection across the line does not provide any equalisation of the levels of the two sides of the conversation. These levels may differ by 30 to 40 dB on a connection having high attenuation.

Series-Parallel Coupling of Oscillator: By using a coupling network with series and parallel arms in the telephone line (such as shown in Fig. 5), the level of tone transmitted to the local telephone can be reduced. The warning tone is transmitted into the telephone line via a three winding transformer. The tone generator is represented by the generator symbol e_W.

Equations derived from the circuit of Fig. 5 are:

$$V_L = V_1 \frac{Z_L}{Z_L + Z_N} \quad \ldots\ldots (1)$$

$$V_S = V_1 \frac{N_3}{N_1} \ldots\ldots\ldots\ldots (2)$$

where V_L = a.c. voltage across the exchange line impedance Z_L

V_S = a.c. voltage across the winding in series with the local telephone

Z_N = network impedance

At the local telephone terminals, the open circuit voltage

$$e_T = V_L - V_S$$

$$= V_L \left(1 - \frac{V_S}{V_L}\right)$$

$$= V_L \left(1 - \frac{N_3}{N_1} \cdot \frac{Z_L + Z_N}{Z_L}\right) \quad \ldots (3$$

From equation (3) it can be seen that by a suitable choice of Z_N and the transformer ratio N_3/N_1 it is possible to reduce e_T, theoretically to zero. In this way the level of warning tone to

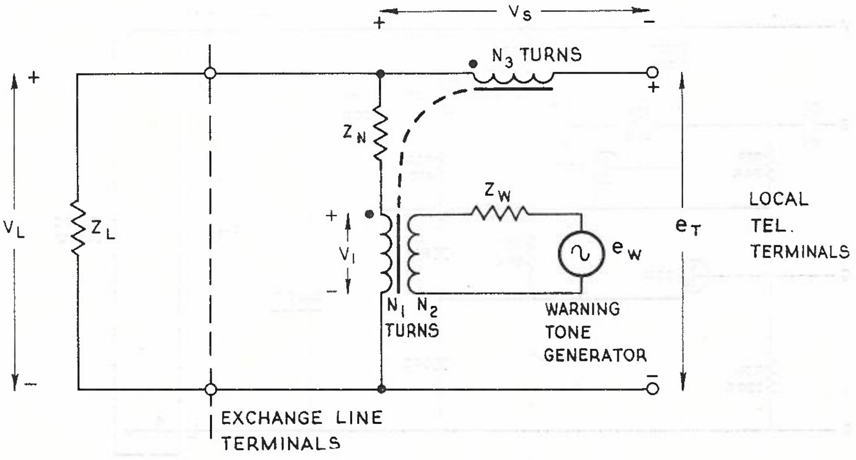

Fig. 5 — Series-Parallel Coupling into Telephone Line.

the local telephone can be reduced. The impedance of the telephone line looking towards the exchange is of the order of 600 ohms, but varies widely depending on the length and type of cable in use. Even at a given location the impedance will vary from call to call and this places a limit on the degree to which the tone level to the local telephone can be reduced.

Series-Parallel Coupling to Recorder: In a similar way speech from the telephone line can be coupled to the recorder so that the speech level from the local telephone can also be reduced. Fig. 6 shows a method using two coupling networks with separate transformers, one for the warning tone and one for the recorder. The problem of reducing the speech level from the local telephone is more difficult because more than one frequency is involved. If too much reduction is attempted, frequency distortion is introduced in the path from local telephone to recorder outlet.

Combined Coupling Network: An attractive economy is to use only one coupling network as shown in Fig. 7. This means a saving of one transformer which is quite important from the point of view of cost, but the method has, however, two disadvantages. Firstly, because of the high attenuation of warning tone through the coupling network — necessary to obtain low insertion loss in the telephone line—the level of tone to the recorder is about 20 dB higher than the speech level. This can be overcome by reducing the gain of the record amplifier during the time that the warning tone is transmitted. Secondly, the degree to which the level is reduced cannot be adjusted independently of the level reduction of the speech from the local telephone to the recorder.

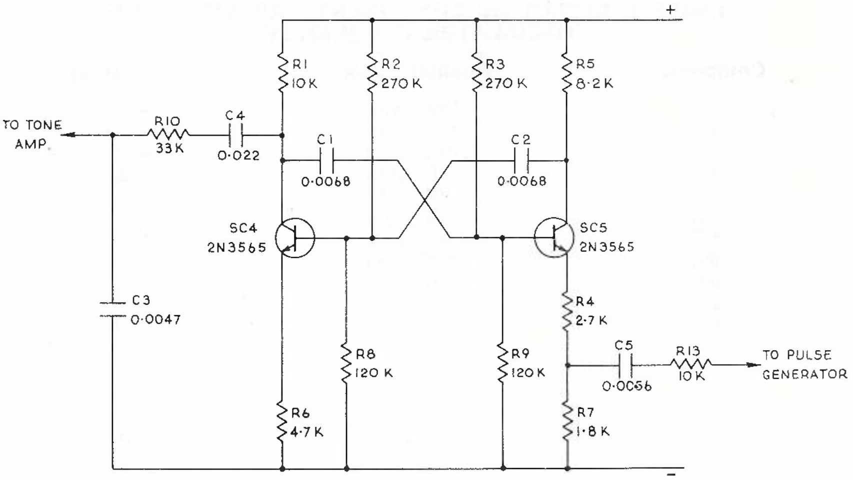

Fig. 8 — The 1400 c/s Oscillator.

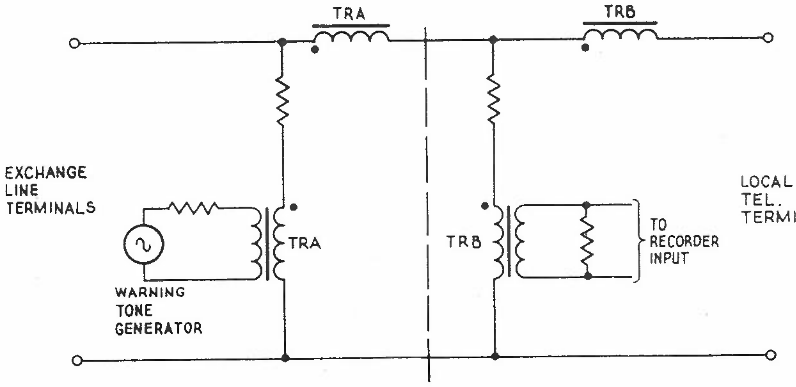

Fig. 6 — Arrangement with Separate Coupling Networks for Warning Tone and Recording.

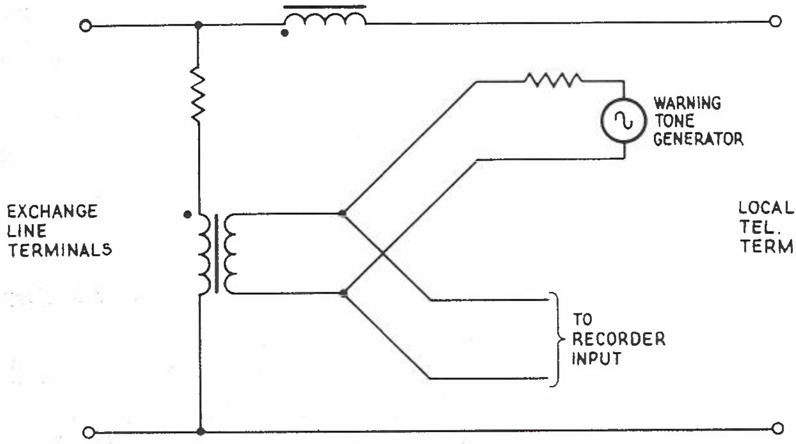

Fig. 7 — Combined Coupling Network.

However, this method of coupling into the line was adopted. The level reductions were about the same in both cases, varying 10-20 dB, depending on the impedance of the exchange line; this method appears to be a satisfactory compromise.

The 1400 c/s Oscillator

An astable multivibrator (SC4, SC5 of Fig. 8) is used to generate the 1400 c/s signal. The simpler saturating type of multivibrator was not used because of the existence of a stable state with both transistors saturated, and hence possible failure of the tone. This problem does not exist in the circuit of Fig. 8.

The output to the tone amplifier (SC10 in Fig. 3) is taken from the collector of transistor SC4; some low pass filtering is achieved with R10 and C3, the result being a slightly peaky sine-wave at the collector of SC10.

Pulses are also taken from the emitter load of SC5 via condenser C5 for use in the 15 second period pulse generator described below.

With all components having their nominal values the frequency of the oscillator is 1370 c/s at room temperature (23°C) with a 12 volt supply. The effects of variations in supply and temperature are discussed later whilst the effects of variations in component values are summarised in Table 1. Transistor variations produce negligible changes in frequency and leakage is small because silicon types are used. Changes in beta, the current gain, produce a variation of the impedance at the base, which appears as a resistance across R8 or R9. This merely alters the effective value of R8 and R9 and as can be seen from Table 1, this does not alter the oscillator frequency.

In most cases the effects of variation in component values will tend to cancel to a certain extent; however, to minimise variation, a component tolerance of 5% was adopted. If desired, the frequency can be adjusted

TABLE 1: EFFECT OF COMPONENT VARIATIONS ON OSCILLATOR FREQUENCY

Component	Nominal Value	Δf (c/s)
R1	10K ohm	—81
R2	270K ohm	—30
R3	270K ohm	—30
R4	2.7K ohm	+23
R5	8.2K ohm	—78
R6	4.7K ohm	+72
R7	1.8K ohm	+34
R8	120K ohm	0
R9	120K ohm	0
C1	.0068 μF	—59
C2	.0068 μF	—60

Δf = frequency change caused by 10% increase in component value.

over a range of about ± 200 c/s by varying the value of R5, with very little effect on the output waveform.

Pulse Generator

The circuit used to time the duration (200 milliseconds) and period (15 seconds) of the warning tone bursts is shown in Fig. 9. Considerable investigation was undertaken to determine the most satisfactory design for an R-C circuit with a time constant of approximately 20 seconds necessary for a 15 second timing circuit. One possibility was to use a 10 M ohm 2 micro farad combination which would permit the use of a plastic dielectric capacitor of reasonable size and cost. However, it was considered that the very low currents involved made a lower value resistor desirable. The combination used was 1.8 M ohm and 12 micro farad, the capacitor being an electrolytic solid tantalum type with 20% capacity tolerance. Manufacturers' data for these capacitors indicate that in the "worst case", leakage currents are not negligible at high temperatures, and for this reason the circuitry is arranged so that capacitor leakage current will not cause failure of the pulse generator, but will merely shorten the period. Units tested in the laboratory have shown negligible changes due to leakage even at 85°C. Plastic film capacitors up to 10 microfarad in small sizes are available but are somewhat expensive.

Transistors SC3 and SC6, PNP and NPN respectively, are connected as a PNPN switch. This arrangement behaves similarly to a unijunction transistor, but has lower power consumption, is more sensitive, and the transistors are cheap and readily available.

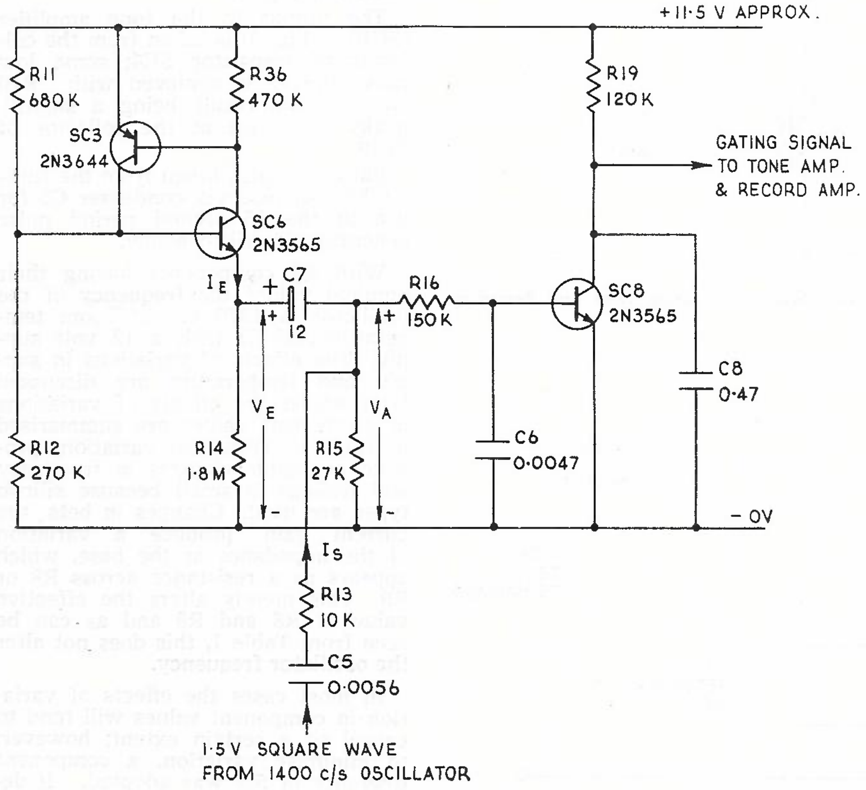

Fig. 9 — The Pulse Generator.

SC8 is used as a driving source for the on-off switching transistors SC9 and SC12 (see Fig. 2). An advantage of the circuit arrangement is that it causes a tone burst to be transmitted immediately the 12 volt D.C. supply is first switched on, that is, when recording begins. This happens provided the supply has been off sufficiently long—a short interruption in the supply may not alter the 15 second spacing of the tone burst.

Fig. 10 shows the output at the collector of SC8. Capacitor C8 lengthens the rise time — the reason for this is explained in the section "Record Amplifier". The initial tone burst is longer than subsequent bursts because capacitor C7 charges through a greater voltage range during the initial tone burst. A longer initial pulse however is probably an advantage in drawing attention to the recorder.

The three transistors SC3, SC6 and SC8 are all 'on' during the burst of tone, and all 'off' for the remainder of the time. The timing capacitor C7 is charged through the emitter current I_E of SC6. This current can be expressed as

$$I_E = \frac{V_E}{R_{14}} + \frac{V_A}{R_A} - I_S \qquad \text{(see Fig. 9)}$$

$$\text{where} \qquad R_A = \frac{R_{15}\ R_{16}}{R_{15} + R_{16}}$$

The first term of the right hand side is constant at about 6 micro-amps and the second term decreases exponentially from about 450 micro-amps towards zero as C7 charges. The third term I_S represents pulses of current of 150 micro-amps, of both polarities, injected via R13 from the 1400 c/s oscillator. When C7 becomes charged after about 0.2 seconds, SC6 and SC3 turn off allowing C7 to discharge through R14 and R15. After approximately 15 seconds, the potential on C7 is low enough to allow SC6 to turn on again, the cycle repeating continuously with pulses of 0.2 seconds duration every 15 seconds.

Tone Amplifier

The warning tone is transmitted to the telephone line, via transformer TR1, by a single transistor amplifier SC10 (see Fig. 3). The level transmitted is controlled by resistor R25.

When the pulse generator output transistor SC8 is off for 15 seconds, the tone switching transistor SC9 is driven to saturation, effectively shunting the 1400 c/s signal as well as turning off SC10, and the warning tone is not transmitted.

Record Amplifier and Low Battery Detector

The record amplifier has two main functions. The first is to restore the level of speech to a value suitable for input to a tape recorder at 'line' level, at an ampedance of 600 ohms. The second purpose is to prevent recording

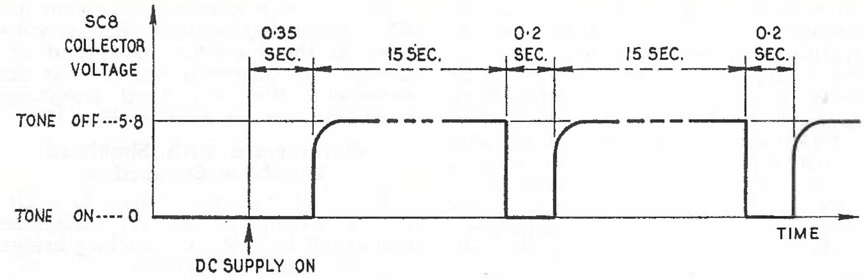

Fig. 10 — Output Waveform of Pulse Generator.

of speech if the d.c. supply voltage falls below about 4 volts — at this voltage the warning tone is still transmitted.

The amplifier employs one transistor SC7 and an output transformer TR2 **(see Fig. 3)**. Resistor R34 maintains a forward bias on diode SC1, so that when the supply voltage falls, the emitter junction of transistor SC7 becomes reverse biased thus cutting off the amplifier.

When the warning tone is being transmitted to the telephone line, SC8 is on, the gating signal inverter transistor SC11 is cut off and the record amplifier switching transistor SC12 is conducting, presenting a low collector-emitter impedance. Consequently the warning tone and the speech signals are attenuated by 40 or 50 dB, and the warning tone appears at the recorder outlet at a reduced level. When SC8 turns off at the end of the 200 millisecond period, the warning tone ceases, SC11 turns on, SC12 reverts to its non-conducting state, and speech signals are passed via C11 and C12 to the record amplifier SC7.

The 'time slot' cut out by SC12 is slightly longer than the duration of the warning tone, SC12 remaining on for about 13 milliseconds after the warning tone has ceased. This allows time for energy stored in TR1 to be dissipated, which would otherwise cause an annoying click to be heard in the recording. This is achieved by the use of two components, SC2 and C8. Fig 10 shows the effect of C8 on the waveform at the collector of SC8 when it turns off. The bias voltage across SC2 allows SC9 to turn on about 13 milliseconds before SC11 even though the bases of these two transistors are symmetrically tied to SC8 (see Fig. 3).

TABLE 2: DEFINITIONS OF SYMBOLS AND TEST RESULTS FOR 600 OHM TERMINATIONS

Item	Definition	Value	Comment
V_L	AC voltage at exchange line terminals		See Fig. 5, 11
V_T	AC voltage at local telephone terminals		See Fig. 11
V_R	AC voltage at recorder outlet terminals		See Fig. 11
V_S	AC voltage across series winding		See Fig. 5
V_{LW}	Value of V_L due to warning tone	— 10.6 dBv*	
V_{TW}	Value of V_T due to warning tone	— 30.7 dBv	
V_{RW}	Value of V_R due to warning tone	— 35.3 dBv	
V_{SW}	Value of V_S due to warning tone		
A_{LT}	Insertion loss in 600 ohm circuit	0.4 dB @ 1 Kc/s	Same in each direction
A_{LR}	$\frac{V_R}{V_L}$ Recorder outlet unloaded	— 1.4 dBx	See Fig. 11(b) 1 Kc/s
A_{LR}	$\frac{V_R}{V_R}$ Recorder outlet loaded 600 ohms	— 6.5 dBx	See Fig. 11(b) 1 Kc/s
A_{TR}	$\frac{V_L}{V_L}$ Recorder outlet unloaded	— 19.9 dBx	See Fig. 11(c) 1 Kc/s
A_{TR}	$\frac{V_R}{V_T}$ Recorder outlet loaded 600 ohms	— 25.0 dBx	See Fig. 11(c) 1 Kc/s
V_L 5%	Value of V_L giving 5% total harmonic distortion of V_R	+ 7.0 dBv	Mainly peak clipping (1 Kc/s)
V_L 10%	Value of V_L giving 10% total harmonic distortion of V_R	+ 9.1 dBv	Mainly peak clipping (1 Kc/s)
S/N	Record amplifier signal to noise ratio (range 2-40,000 c/s)	88.7 dBx	V_R at 5% distortion = + 5.3 dBv
I_{DC}	Power Supply current drain	4.6 mA	
p	Total warning tone harmonic distortion	11.5%	2nd = 2.9% 3rd = 10.4%
Z_R	Output impedance recorder outlet	512 ohms 12° inductive at 1 Kc/s	Depends on TR2
f	Frequency of warning tone	1366 c/s	
t'_A	Duration of initial tone burst	350 mS	Depends on rate of rise of V_{DC} at switch on
t_A	Duration of subsequent tone burst	210 mS	
T	Time between tone bursts	16.6 sec	

*dBv denotes reference level 1 mW into 1000 ohm.

Suppression of Warning Tone in the Amplifier

To prevent excessively loud bursts of warning tone being recorded, the record amplifier SC7 has its gain reduced during the time that the warning tone is transmitted to the telephone line. In this way the tone is reduced to a low level, sufficient however to provide recorded evidence that the warning tone was being used.

This method of reducing the tone level has a slight disadvantage in that during the times that the amplifier gain is reduced (0.2 seconds every 15 seconds) a syllable of the original conversation will occasionally be missed. However, listening tests indicate that this is rarely an inconvenience, since the same syllable would have been masked in the original conversation, and it would be expected that the listener would have asked for a repetition if any information has been lost.

Another possible method of reducing the tone level to the recorder is to use a narrow band-stop filter centred at 1400 c/s which could be switched in during the time the warning tone is transmitted. This method requires a stable oscillator frequency, stable filter components and a warning tone of low harmonic content. In view of this, gain reduction was considered more suitable for the type of unit required.

Performance with 600 ohm Terminations

The results of tests at room temperature (approx. 23°C) and with a 12 volt d.c. supply ($V_{DC} = 12V$) are shown in Table 2. The 600 ohm terminations were at the local telephone and exchange line terminals respectively (see Fig. 11). The unit was further tested (at 23°C) for varying supply voltages. The frequency of the warning tone stayed within ± 25 c/s for a supply ranging from 6 to 24 volts; when the supply dropped from 12 volts to 3 volts, the tone output level dropped 13 dB although tone was transmitted to line over the range 3 to 30 volts. At low supply voltage the level of both speech and tone to the recorder falls sharply and non-linear distortion rises. Thus at supply voltages below about 4 volts, recordings will be distorted and extremely faint.

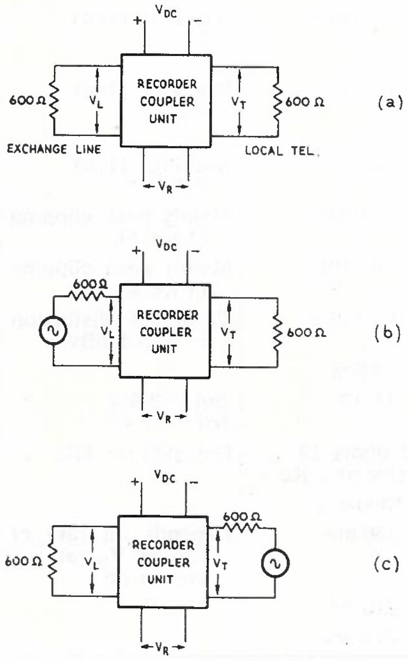

Fig. 11 — 600 ohm Test Circuits.

With the d.c. supply at 12 volts, the unit was tested over the temperature range 0-85°C. Changes in frequency, period, output voltage, etc., varied only slightly from those shown in Table 2.

Frequency response curves showing the relationship between the a.c. voltages at the recorder outlet and exchange line terminals and also at the recorder outlet and local telephone terminals can be seen in Fig. 12.

Performance with Simulated Telephone Connection

The unit was also tested in a circuit consisting of an 801 telephone connected to a 50 volt feeding bridge via an artificial subscriber's cable equivalent to 3.4 miles of 6½ lb/mile cable. The junction impedance was 600 ohms (See Fig. 13) and the results are shown in Table 3, the definitions being similar to those of Table 2. Frequency response curves applying to Fig. 13 are shown in Fig. 14.

TABLE 3: TEST RESULTS FOR SIMULATED TELEPHONE CONNECTION

Item	Value (dB)	Voltage (mV)
V_{LW}	— 9.5	340
V_{TW}	— 19.5	108
V_{SW}	— 12.0	
A_{LR} (Recorder outlet unloaded)	— 0.2	255
A_{TR} (Recorder outlet unloaded)	— 9.4	

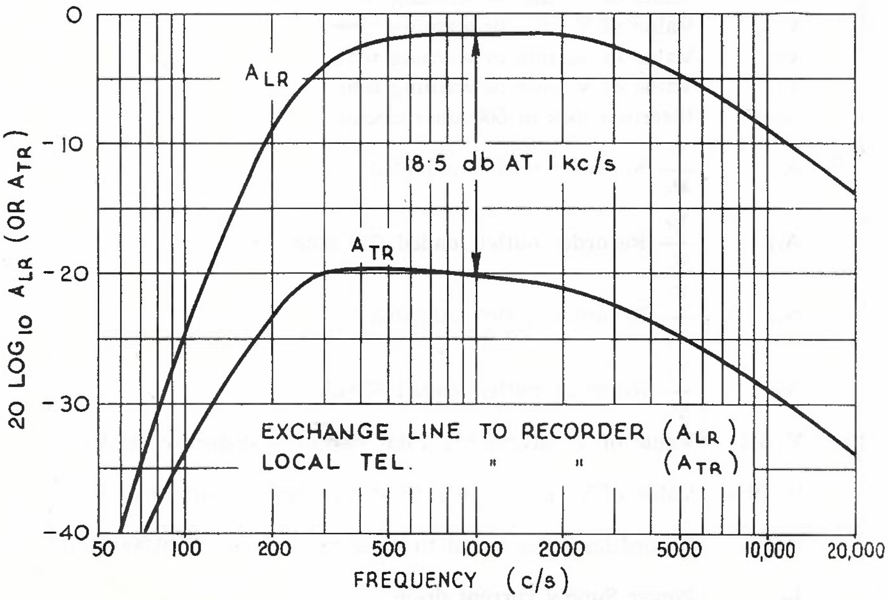

Fig. 12 — Frequency Response with 600 ohm Terminations.

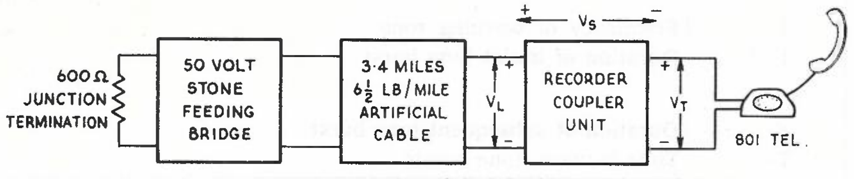

Fig. 13 — Simulated Telephone Connection.

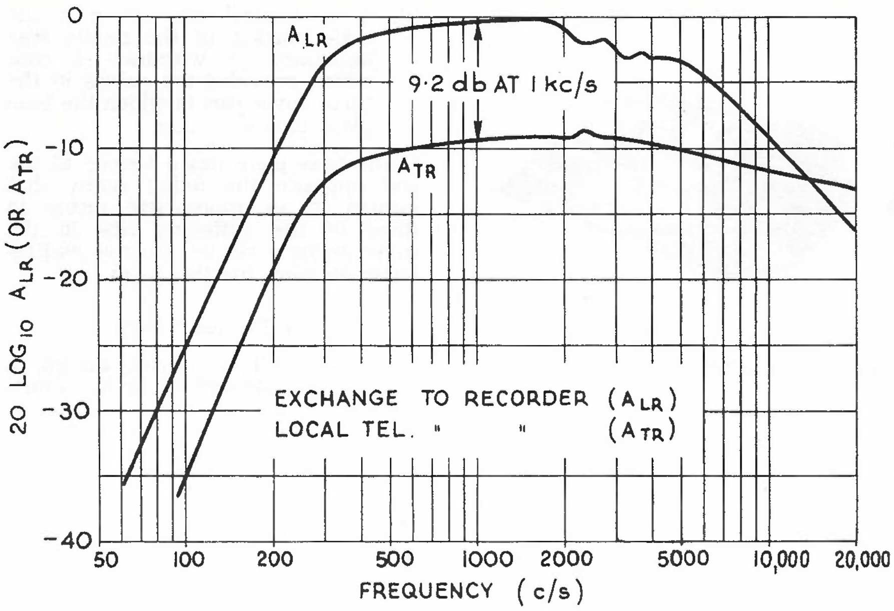

Fig. 14 — Frequency Response with Simulated Telephone Connection.

DEVELOPMENT OF PRODUCTION MODEL

On completion of the tests described in the preceding paragraphs, the circuit and technical details of the prototype unit were presented to the Design and Production Divisions of the Melbourne Postal Workshops. The Workshop's task was to develop a model suitable for economic quantity production, and subsequently to manufacture units for use in subscribers premises, business offices and similar locations, the units to have good appearance, physical robustness, reliability and to be readily maintained. The final model is shown in Fig. 1.

Volume production in the Postal Workshops is based on process type of labour and production line assembly methods and the manufacture of the units was a typical job. It was only necessary therefore, to resolve the work into simple units such that sophisticated machines and tools compensated for the lack of skill available at process worker level.

It was foreseen that a significant amount of investigation and development would be necessary to achieve the design objectives, and the standard technique known as Value Engineering (Ref. 1) was applied. The technique involved setting up a team of technical specialists to critically examine the function and cost structure of the unit. It involved also the assembly of relevant information, analysis, speculation, investigation and evaluation of the ideas generated within the team.

The result of the team's work was the decision to use two main features:—

(a) An Acrylonitrile Butadiene Styrene (ABS) plastic moulded cover together with a steel baseplate to enclose and protect the unit. (It might be added here that the exercise was primarily for a base and case to house the Recorder Connector, but it was always borne in mind that this housing if simple, attractive and within a certain size range, could be used for any of a number of similar units both for Departmental and Subscriber use).

(b) Printed wiring for the electronic circuit to minimize manufacturing and assembly costs.

The Cover

A consideration of the moulded plastic cover, together with the ultimate function of the unit — the requirement that its appearance should harmonise with subscribers existing equipment and particularly the colourphone, whilst retaining a simple but pleasing appearance — led to consultation with an industrial designer in the P.M.G.'s Department. As a result, it was decided to adopt a design which was considered to meet the requirements outlined above, its shape being formed by compound curves and a flat top surface having an Australian Post Office insignia. Other functional features included in the cover design are:—

One-screw fixing,

Moulded apertures for connector socket and line cord grommet,

Strength and rigidity by use of support ribs.

The male and female portions of the injection moulding tool manufactured in the workshops to produce the cover are shown in Fig. 15.

Some obvious and not so obvious facts about the tool are:

(a) The recessed surface of the female mould must be highly polished to achieve an acceptable finish on the product and be of negative draw for ease of ejection.

(b) The protruding spigots on the two mould halves are for attachments of water hoses connected to a temperature control unit which maintains the moulds at approximately 170°F.

(c) It would have been ideal to inject the ABS plastic in the flat face of the cover to achieve distortion free mouldings and easy filling of the mould but this of course would have left a blemish on the surface most seen by a user, therefore, centre lower edge injection was used; after the sprue was cut off the blemish was nearly imperceptible.

This led to some moulding difficulty which was overcome by close control of temperatures and injection speeds and pressures.

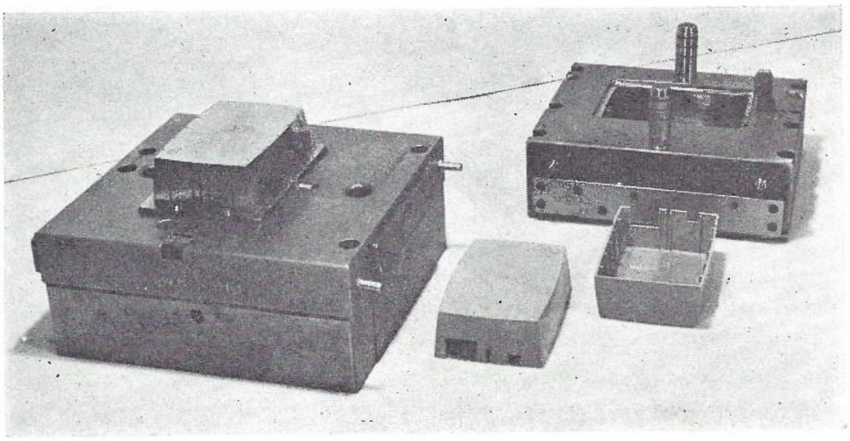

Fig. 15 — Injection Moulding Tool For Cover.

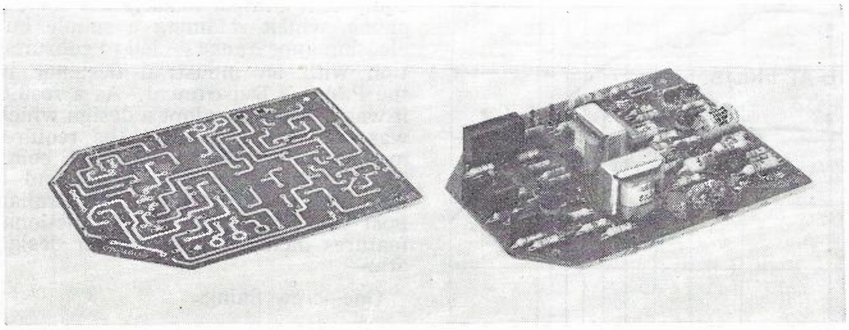

Fig. 16 — Circuit Board before and after Component Assembly.

Fig. 17 — Assembly Jig for Circuit Boards.

(d) A mechanical side action in the male portion of the mould was necessary to withdraw a core which provided the recess in the three cover ribs in which the base plate tongue locates.

The base plate has a tongue at the end opposite the fixing screw that locates in an appropriate recess in three of the stiffening ribs in the cover giving a simple, positive and reliable location for the cover.

The Printed Circuit

For the printed circuit design, a considerable amount of layout drafting was carried out, and several handmade prototype circuit boards were successively produced, each with its own refinements, until the present design was achieved. The use of components specifically designed for printed circuitry such as miniature block type capacitors, moulded plastic mounting pads for the transistors, preformed component leads, and quick-connect terminals for all external connections, has resulted in excellent producibility, ease of assembly and good access to the circuit for testing and maintenance. At the same time the component density has been kept high for this class of product, leading to a minimal space requirement for the circuit.

Fig. 16 shows an unassembled and assembled circuit board and components and Fig. 17 demonstrates the jig used for assembly.

It will be noted that the jig is in two sections and invertible so that steps in assembly of a card are:

1. Fix 4 cards in one half of jig and place components in position in accordance with stencilled numbering on the card. (Fig. 17).
2. Fold top half of jig, which has a foam plastic cushion insert, on to the circuit card and components.
3. Invert jig, solder wires protruding through the card and cut off wire residue. (Fig. 18.)

TRANSFORMER DESIGN PROBLEMS

The electronic circuit developed for the prototype used two coupling transformers of the ferrite potcore type, but because these were not suitable for direct mounting on a printed circuit board, it was decided after investigation, to use a miniature transformer currently manufactured by the workshops. This transformer was specifically developed for direct mounting on the printed circuit of the Technicians and Lineman's Buttinski Handset (Handset No. 4) and with modifications to the winding design and the laminated grain-oriented core, it was adopted for the Recorder Connector.

Transformer TR2 (see Fig. 3) required a large number of turns and considerable investigation was needed to determine the optimum former size, gauge of wire and type of lamination consistent with the required specifications. With machine winding of coils, it is always advantageous to use the maximum diameter allowable to limit breakages, and wire of 34 B & S gauge was eventually chosen. The transformer laminations used in the current model were of slightly different dimensions to those used in the Buttinski induction coil and it was found necessary to decrease the thickness of the former flanges at both ends. (See Fig. 19). This necessitated an alteration in the tooling for production of the former.

The former, moulded in glass-filled nylon, was mounted in a special jig to prevent distortion while being wound. A distorted former would have prevented the inter-leaved E and I laminations from having the correct spacing with respect to one another with a consequent increase in the reluctance of the magnetic circuit to the detriment of the overall performance.

CONCLUSION

The general requirements for a conversation recorder coupling unit have been outlined, and a design which meets these requirements has been presented. It has been shown that the requirements can be met using reasonably simple and inexpensive components. The unit has been designed primarily for use between two telephones but it is envisaged that there may be other applications such as quiz programmes on broadcasting and television stations.

ACKNOWLEDGMENT

The authors desire to acknowledge the work done by Mr. G. M. G. Casley of the P.M.G. Research Laboratories in designing the prototype unit.

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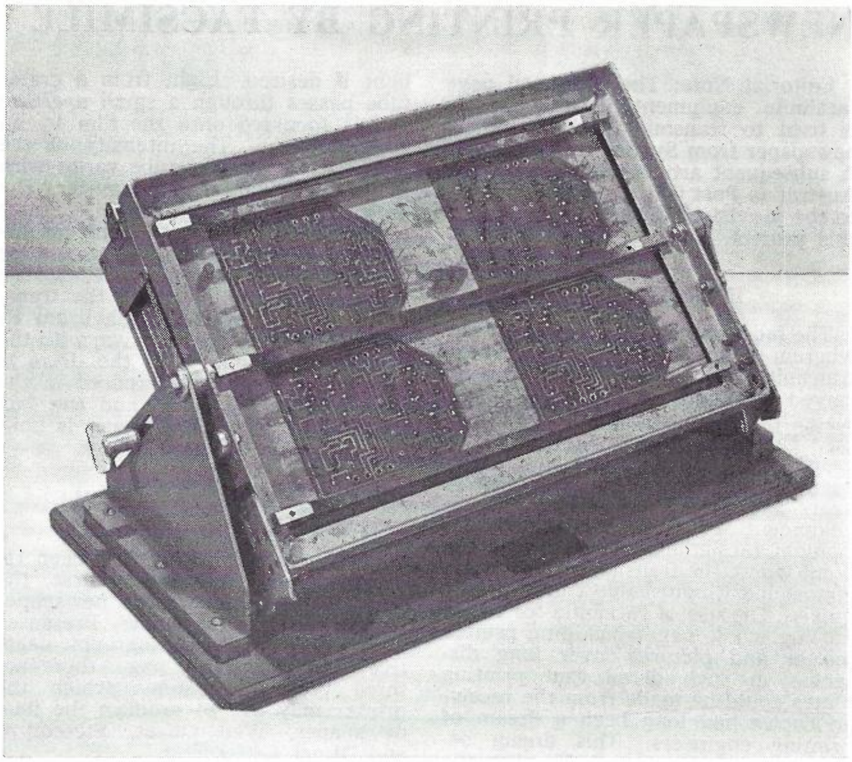

Fig. 18 — Underside of Circuit Boards.

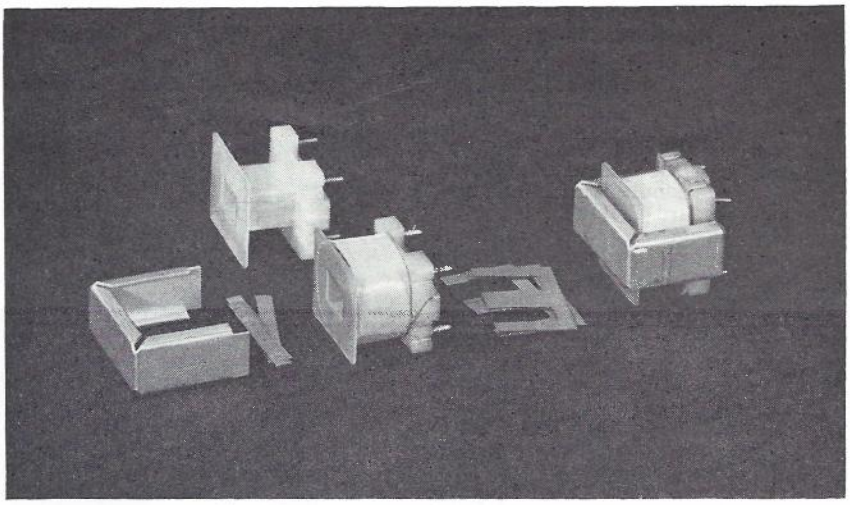

Fig. 19 — Component Parts of Transformer.

NEWSPAPER PRINTING BY FACSIMILE

*D. F. BANKS, H.N.C.**

Editorial Note: The Muirhead page facsimile equipment in this article is used to transmit 'The Australian' newspaper from Sydney to Melbourne. A subsequent article will describe the Australian Post Office work leading up to the provision of the circuit used on this project.

INTRODUCTION

The facsimile printing process is one wherein whole newspaper pages are transmitted by facsimile and the received negatives are used to make plates from which to print newspapers. Facsimile transmission of photographs for newspapers, of course, has been an established feature for many years and since the last war the development of this equipment, has brought facsimile reproduction to the point where the transmitted copies are almost indistinguishable from the originals. The use of facsimile for transmitting whole pages including printed matter and pictures, over long distances in such detail that printing plates could be made from the received copies had long been a dream of printing engineers. This dream became a reality in June 1959 when the ASAHI SHIMBUN of Tokyo started regular facsimile transmission of newspaper pages between Tokyo and Sapporo using facsimile equipment developed by Muirhead and Co Limited.

PRINCIPLE OF FACSIMILE TRANSMISSION

The principle of operation of Newspaper Page Facsimile is identical with that for standard facsimile transmission and reception. A proof, taken from the set page containing the type and screened half-tones, is wrapped around the drum of the transmitter and a small area brightly illuminated. An image of this area is projected through an objective lens and focussed onto a small screen. A rectangular aperture in this screen allows light from an element of the illuminated area of the newspaper to fall on the cathode of a photomultiplier cell, which produces an electrical voltage proportional to the amount of light falling upon it, which in turn is used to modulate the carrier signal sent to the receiver. During a transmission the drum is rotated and the optical system carrying the illuminating lamps and photomultiplier cell, is slowly traversed parallel to the axis of the drum. The entire newspaper page is thus scanned line by line in the form of a close spiral.

On the receiver, photographic film is wrapped around the drum contained in a light-tight box that permits the receiver to be operated in the daylight if desired. Light from a crater tube passes through a small aperture and is focussed onto the film by an objective lens. The intensity of the light from the crater tube varies with the signals from the transmitter. The optics unit which carries the crater tube and the optical assembly necessary to produce the minute scanning spot, is traversed slowly along the drum at the same rate as the transmitter optical system. The drum itself is rotated in synchronism with the transmitter drum. Thus the drum is scanned and the film exposed in the form of a close spiral and the facsimile copy of the newspaper is built up in a series of parallel lines.

METHODS OF FACSIMILE PRINTING

Once a facsimile copy has been received there remains of course, the problem of producing the newspaper from the facsimile copy. Presented with a high quality photographic negative of a newspaper page, there are three practical systems which the printer may use to produce the final newspaper, Web Offset, Stereotype and Direct Letterpress.

Web Offset System

In this method, the facsimile negative is printed down photographically on to a lithographic plate. Where the emulsion of the lithographic plate is exposed it is hardened and where no exposure has taken place the emulsion remains soft. After simple processing, where the softened emulsion is removed, the plate is fitted to a rotary press and printing commenced. During the printing process, the plate is brushed with ink and water. The water adheres to the background area but does not wet the hard and polished exposed characters.

The ink, being greasy, remains on the characters but will not 'take' on the wet background. The inked plate is then rolled in contact with a rubber roller called a blanket, which receives the ink image of the characters and subsequently transfers it to the newsprint paper. The inking, wetting and transferring process is repeated for each printing and the lithographic plate, which is not too robust, is never in contact with the relatively coarse printing paper.

Satellite printing plants using this system usually do not have even a

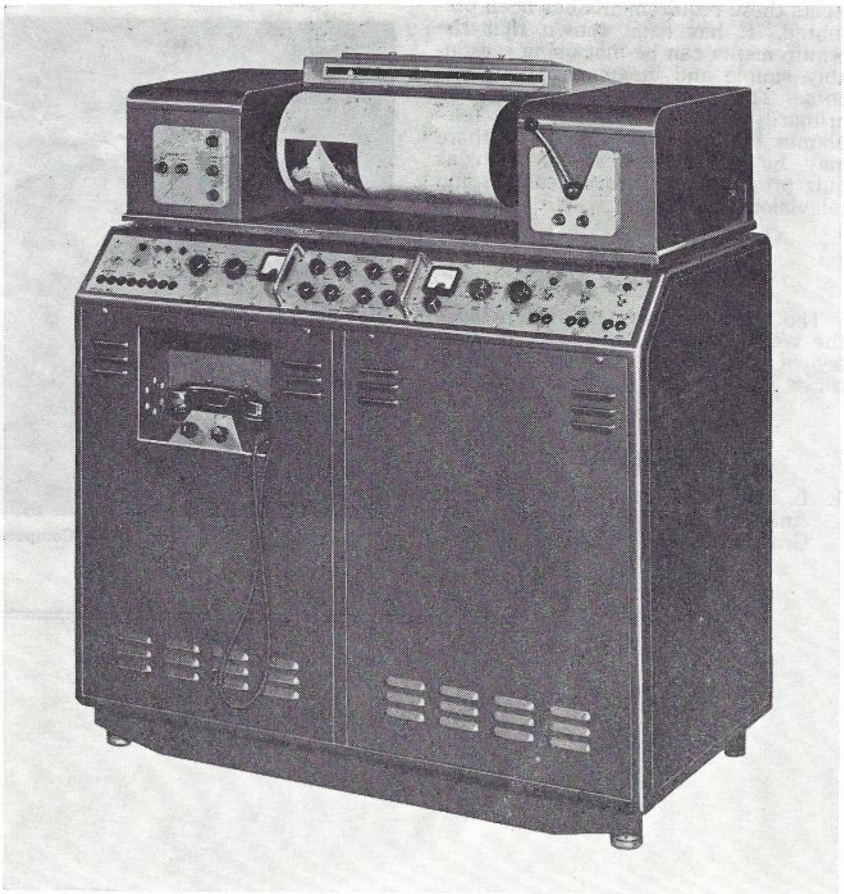

Fig. 1 — The Transmitter Unit of the Equipment Used by ASAHI SHIMBUN, Japan, 1959.

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* Mr. Banks is Senior Engineer Data Communication Systems, Muirhead & Co. Ltd., England.

single piece of type and start their process from the negatives produced by facsimile transmission. With this system, any news development occurring in the vicinity of the satellite printing plants are reported to the main publication centre where the news is edited and then transmitted back to the satellite plant by page facsimile. Thus a great weakness of this system is the delay in the inclusion of fresh news developments in various editions.

Other disadvantages of Offset printing include expensive Offset rotary presses and high newsprint wastage compared with the other two production methods. Web Offset rotary presses and lithographic plates suitable for large circulation newspapers are not yet fully developed. The production speed of Offset is considerably lower than that of Letterpress.

On the other hand, the biggest advantage of Offset printing is the high printing quality, especially in four colour pictures.

Stereotype System

In this system the facsimile negative is photographically printed on to a sensitized zinc plate. The plate is then processed and, as in the offset system, the unexposed areas of emulsion are removed. The exposed areas are next coated with an acid resist chemical which is subsequently hardened. This plate is then etched to a depth of approximately 0.020 in and a papier mache stereotype mat is moulded from it. The mat is then used to cast the printing half cylinders of heavy metal which are used on the rotary presses.

Although letterpress printing has been the established method of producing large daily newspapers the production of full page etched plates was not a practical system until 1953. For more than fifty years, the art of block-making on zinc plates had remained static and the time taken to etch even small plates was upwards of two hours. In 1953 however, the Dow Chemical Corporation of the United States of America produced an etching machine which was capable of doing the job in ten to twenty minutes. The invention of this and other so called powderless etching machines made letterpress printing by facsimile a workable system. Although originally designed for use with magnesium plates these machines have been satisfactorily adapted for use with zinc, a material which is much preferred by the printing trade.

The Stereotype printing system has certain advantages. Since the satellite printing plant receiving negatives by facsimile usually also has photographic process equipment they do not have to fear any unexpected disasters of losing the facsimile transmission circuits over long periods forcing them to suspend publication. Also it is possible to insert local news and advertisements without having to send the information to the main office. The Stereotype system is the best method to cope with large circulations for which the other systems have definite limitations in the plate making stage.

The disadvantage of this system is that with the retention of the typographic process it means that more personnel are required, resulting in added expense as compared with Offset printing plants. Moreover printing quality is the biggest problem which gives poorer picture quality and makes the printing of colour pictures very impracticable due to difficulties in registration of the separate colour pages because of the unstable nature of the papier mache mats.

Direct Letterpress System

The process is the same as the Stereotype system as far as the etched plate making stage. Now instead of producing the mat, from which the printing plates are cast, the etched plate is formed into a half cylinder and is used for the actual printing. This gives the advantage of using Rotary letter press as in the Stereotype system but without the disadvantage of poor registration, no mat is made, making colour printing more practicable. The printing quality lies between Offset and Stereotype.

The system suffers from the difficulty in the inclusion of local news and page layout changes as in the Offset system but the printing plates take longer to make than Offset and are more expensive to produce.

PROTOYPE EQUIPMENT

A basic principle of communication engineering is that information (in a technical sense) is equal to the product of bandwidth and time. A newspaper page contains a large amount of information and consequently requires either a large bandwidth or a long time for its transmission. Unfor-

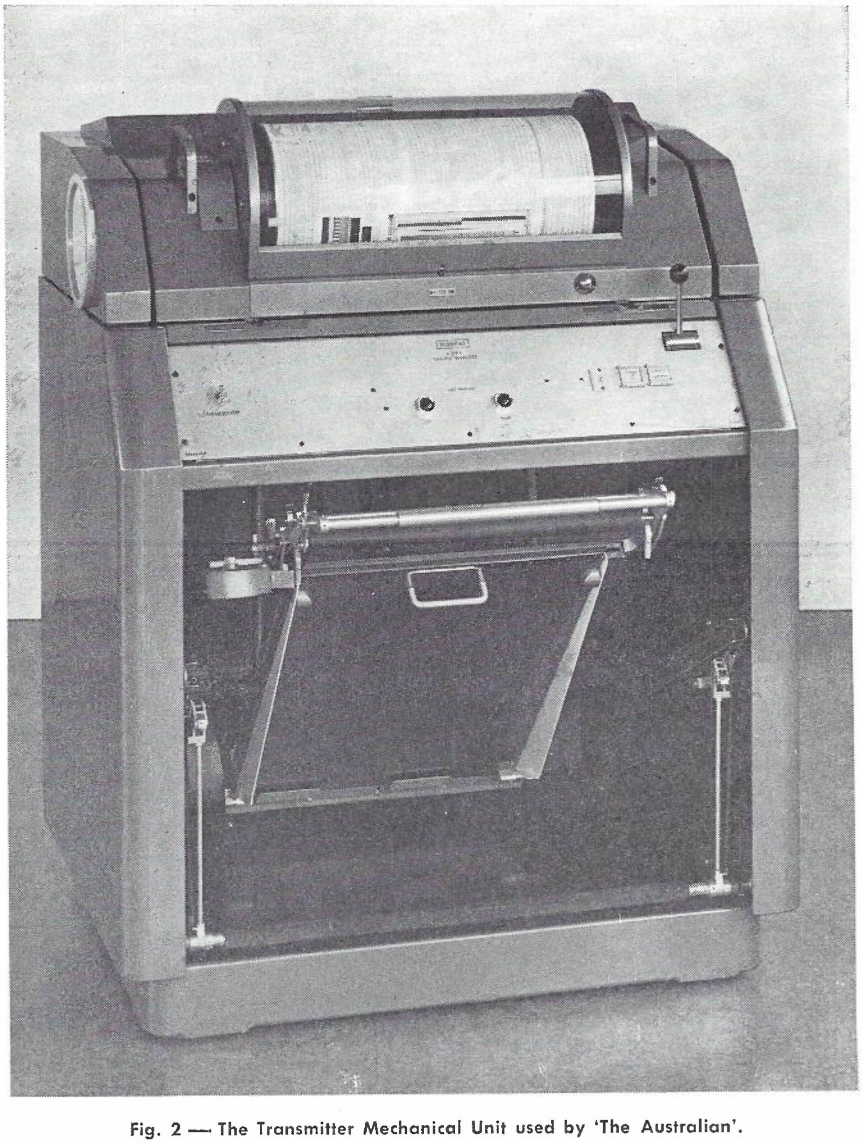

Fig. 2 — The Transmitter Mechanical Unit used by 'The Australian'.

tunately neither bandwidth nor time are freely available. Time is extremely valuable in producing a newspaper and bandwidth has to be paid for in money for circuit rental. Thus a compromise has to be made between the transmission time and a frequency band which is economical to rent.

At the time of the prototype equipment and the first practical newspaper page facsimile the compromise was settled, so far as bandwidth was concerned, on the 48 Kc/s group which is normally used for carrying twelve telephone channels in a carrier telephone system. The 48 Kc/s group can, however, be divided up in many ways to provide sub-channels for the simultaneous transmission of two or more newspaper pages.

By far the most difficult problem on the communication circuits available for newspaper page facsimile is that of delay distortion. This particular distortion is caused by the non-linearity of the phase shift versus frequency characteristics of the circuit and has the effect of delaying some frequencies with respect to other frequencies. The delayed frequencies are usually those nearer the edges of the frequency band where the various filters in the circuit come into operation. It is a fact that the delay distortion is a function of the circuit filters used and not of the line or radio path. The effect on the facsimile system of delay distortion is to produce two or more images at the receiving end. These secondary images are usually of lower intensity than the original or true image but are often of sufficient density to destroy the definition of small characters. The higher the speed of transmission and the finer the size of character to be transmitted the greater is the effect of a given delay distortion. It is possible to design suitable equalisers to reduce the delay distortion but at the time of producing the prototype page facsimile equipment little or no work had been made to equalise these wideband circuits.

The main purpose of the prototype equipment was to transmit and receive simultaneously four sheets of newspaper of size 24 in x 17 in over a distance of some two hundred miles of carrier telephone circuit. The circuit was to be rented on a time basis overnight. A 48 Kc/s group, 60-108 Kc/s was selected as forming the best compromise between transmission time and line rental costs. A battery of four transmitters and four receivers was planned to give the required facilities. A scanning density of 250 lines per inch was selected as being adequate for the smallest type faces to be encountered and the speed of scanning was determined at 156 rev/min or 2.6 lines per second. This gave a transmission speed per page of twenty-eight minutes. The video frequency generated by each transmitter was 8 Kc/s and transmission was by vestigial sideband amplitude modulated in four sub-channels of 11 Kc/s each. This left room for a further channel some 3 Kc/s in width which was used for sending a synchronising tone from one transmitter to its three partners and also to the four receivers for control of the drum speed of all machines.

The use of vestigial sideband transmission reduced the bandwidth somewhat at the expense of definition due to delay distortion of the filters within the page facsimile equipment, but since it was essential to meet the production schedule of eight pages per hour, the loss of definition was judged acceptable.

DEVELOPMENT OF MUIRHEAD PAGE FACSIMILE

In the early months of 1959 equipment which was a further development of early prototype machines was delivered to Japan. The standard of printing in Japanese newspapers was found to be extremely high and it was necessary to increase the scanning density to 300 lines per inch in order to define the intricate Japanese characters, many of which include black and white lines of only three thousandths of an inch in thickness.

A drum speed of 180 rev/min, or scanning rate of three lines per second, was decided upon and this gave a transmission time of twenty-seven minutes per page, each page measuring $21\frac{3}{8}$ in x $15\frac{1}{2}$ in. As with the prototype equipment, a 48 Kc/s group was chosen as the optimum in bandwidth, and in order to meet the schedule of four pages per hour, the machines were designed to operate in pairs, transmitting two pages simultaneously. For the sake of maximum definition and freedom from delay distortion each of the two sub-channels of 22 Kc/s was worked double sideband with a video frequency from each transmitter of 10.5 Kc/s. Subsequently, during the testing period, it was found beneficial to operate these channels asymmetrically, allowing a video frequency of 12.5 Kc/s which gave

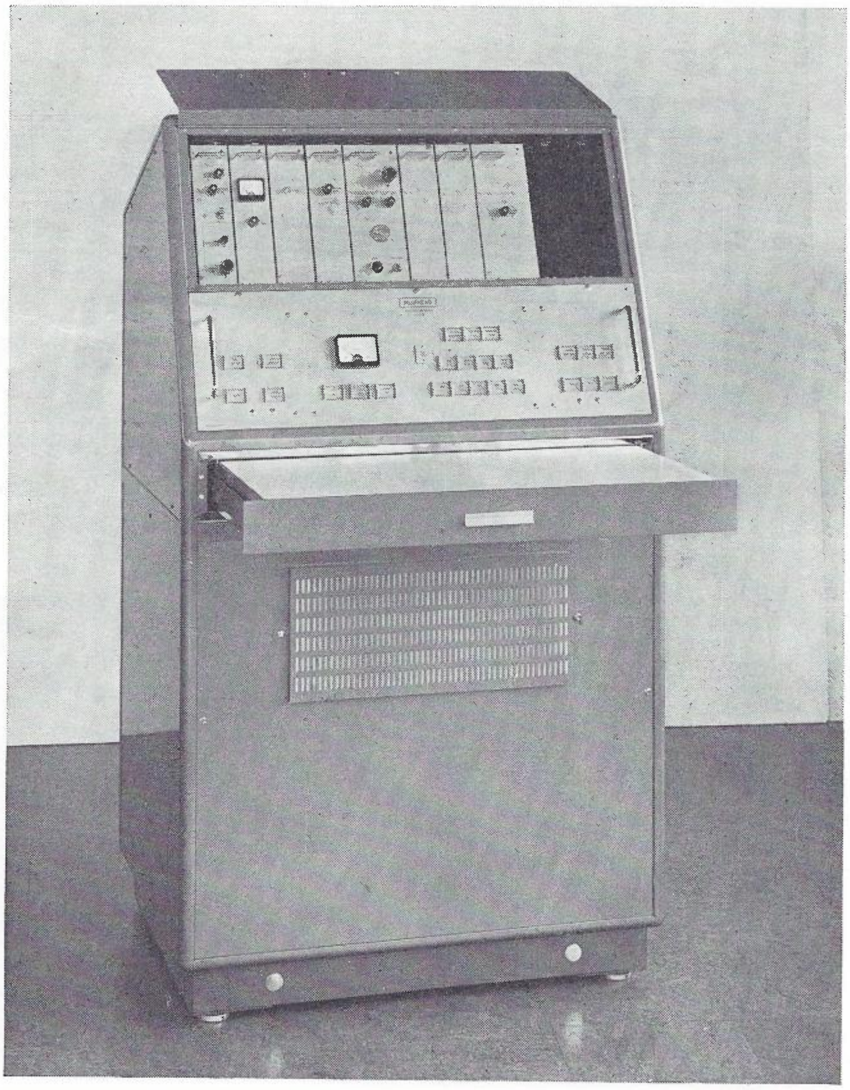

Fig. 3 — The Receiver Electronic Unit used by 'The Australian'. Top-Cover open to show access to modules.

increased definition of the complex Japanese characters.

To reduce loss of time through possible electronic failure and from operating and installation convenience, each transmitter and receiver were identical with its partner. This meant all machines were capable of operating on either of the two copy transmission channels and also enabled either transmitter to be used as the master in controlling the synchronisation. An operation advantage gained by this arrangement was that in each console the channel equipment not in use was available as spare equipment which could be switched instantly into operation when required. Synchronising of the drum speeds was achieved by transmitting a continuous tone from one transmitter to its partner and to the two distant receivers. The tone was generated by a tuning fork and then used to modulate a carrier at the lower end of the 60-108 Kc/s band adjacent to but separated from the two facsimile channels. This tone provided a convenient means of controlling the automatic gain control amplifier in the receivers and the circuit fail alarm circuits.

The ASAHI stated their regular Newspaper Facsimile production on the 1st June 1959 between Tokyo and Sapporo and the transmission path was via microwave. The Japanese P.T.T. had equalised the group delay distortion between 63 Kc/s and 102 Kc/s to approximately 40 micro seconds and at the speed of transmission being used this gave satisfactory results. During the next few years the Japanese P.T.T. improved the group delay equalisation by designing special through group filters and equalisers for exclusive facsimile use. The resultant differential delay between 63 Kc/s and 104 Kc/s was now 30 micro seconds.

In 1962 as a result of numerous enquiries for faster transmission times Muirhead and Company Limited developed a completely new style of Newspaper Page Facsimile type K-200-A and K-201-A which was delivered to America for the 'Wall Street Journal' in August, 1963.

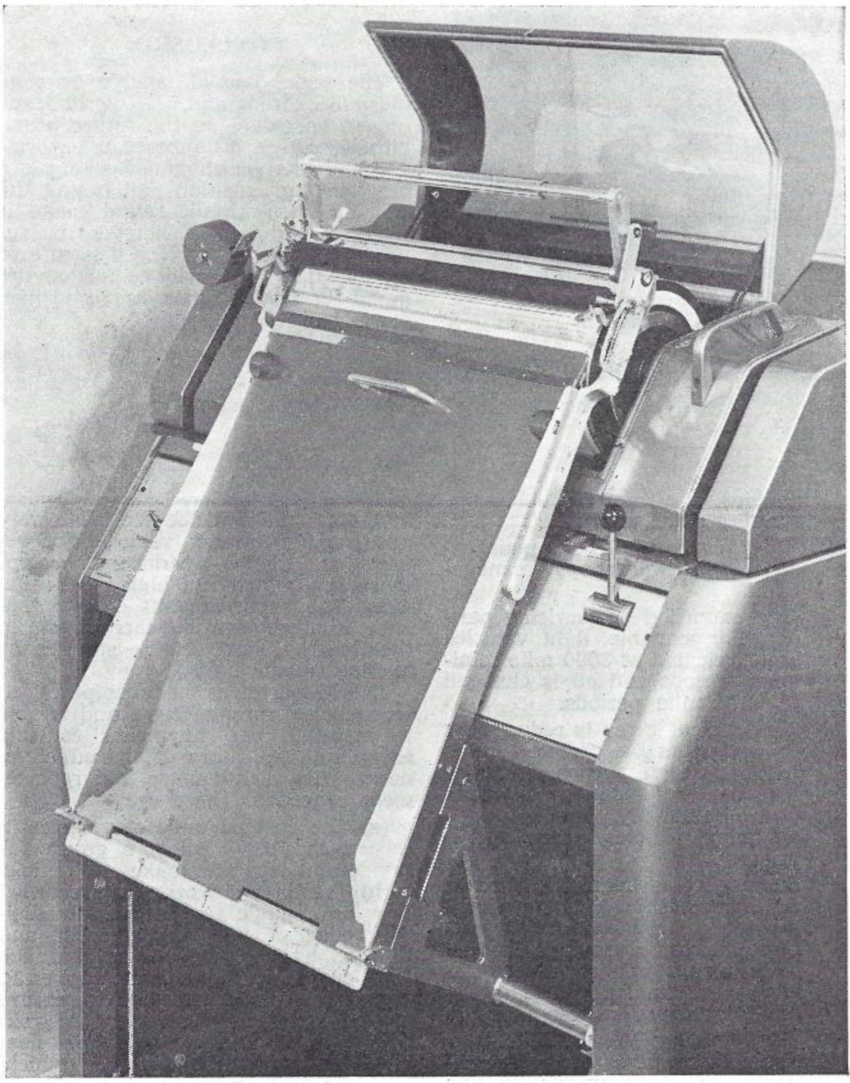

Fig. 4 — Close up View of Loading Fixture on Equipment Used by 'The Australian'.

The equipment was capable of transmitting a whole newspaper page in 5 minutes with a resolution of 1000 lines per inch. To achieve this short transmission time required a drum speed of 3600 rev/min. The surface speed of the drum, when running at 3600 rev/min, was approximately 80 m.p.h. some twenty times faster than the original equipment supplied to Japan. Consequently a complete new mechanical system was developed.

When rotating a drum at these high speeds great care must be taken to ensure that the copy remains in close contact with the drum, otherwise the accuracy of focus will be impaired. If the leading edge of the copy or negative should lift due to windage it can be torn off the drum with disastrous results. To overcome the difficulty of mounting the copy, and film tight on to the drum a special loading fixture was developed. The loading fixture enables the page or film to be loaded and automatically positioned on the drum with the minimum of handling. The complete operation takes less than one minute. The high resolution required by the 'Wall Street Journal' posed a further problem, that of maintaining the positional accuracy of the transmitter and receiver drums to very close limits. Any variation in relative position of the two drums gives rise to a 'step' or displacement of lines parallel to the drum axis. This type of displacement is called 'judder', 'jitter', or 'hunting'. A considerable amount of development effort and a high degree of mechanical precision was required to limit the effect of judder to a maximum displacement of 0.00015 in. In order to minimise the mechanical imperfection of rotation, the drum was mounted on air bearings, to reduce variation in bearing friction, and balanced dynamically. In addition an electronic control circuit was developed to reduce a tendency to judder. The control circuit was designed to sense a change in velocity of the drum and increase or decrease a braking load on the drum thus reducing the amplitude of any displacement.

With a drum speed of 3600 rev/min and a resolution of 1000 lines/inch the video frequency generated by the scanning head was approximately 750 Kc/s. The communication link to be used between the transmitter at San Francisco and the receiver at Riverside a distance of some 450 miles was a microwave video circuit. The bandwidth available for facsimile was 500 Kc/s to 4.5 Mc/s.

Although the 'Wall Street Journal' facsimile production is a working system and produces a very high quality satellite newspaper it is not a very practical operation for other organisations. The cost of renting a circuit of this type, if available, is so prohibitive as to make it uneconomical for most newspapers wishing to use facsimile printing.

In July of 1966 the latest K-200-D/K-201-D equipment was delivered to 'The Australian'. These machines are designed to operate in a 60 channel group 312-552 Kc/s and include many improvements to circuit design and operational facilities over the K-200-B/K-2O1-B installed in October 1965. This type of equipment was the first in the world to operate in a super-group. The transmitters and receivers are designed for either single or multiple installation. When a multiple arrangement is used, the machines may be remotely controlled by an external unit. The equipment is fully transistorised and modular type construction is used throughout.

The transmitter facsimile carrier is 500 Kc/s with vestigial sideband amplitude modulation. The vestigial filter is of constant phase design and the delay distortion is of the order of 2 to 3 micro seconds. The super-group circuit provided by the Australian Post Office is of exceptionally high quality; the delay distortion after equalisation is 5 micro seconds over the facsimile channel 328 Kc/s to 536 Kc/s. A choice of scanning density and drum speed is provided. The scanning densities are 400, 500, 600, 800 and 1000 lines per inch and the drum speeds are 1500, 2000, 2400 and 3000 revs. per minute and any drum speed may be used with any scanning density making it possible to transmit one page in 2.1 minutes.

The transmitters, initially in Canberra, are now situated in Sydney and the receivers in Melbourne. Prior to the facsimile installation, mats were moulded from the set pages in Canberra and transported by plane to Melbourne. The use of planes between the two centres although reasonably fast is not 100% reliable due to adverse weather conditions which could delay or even cause cancellation of a flight.

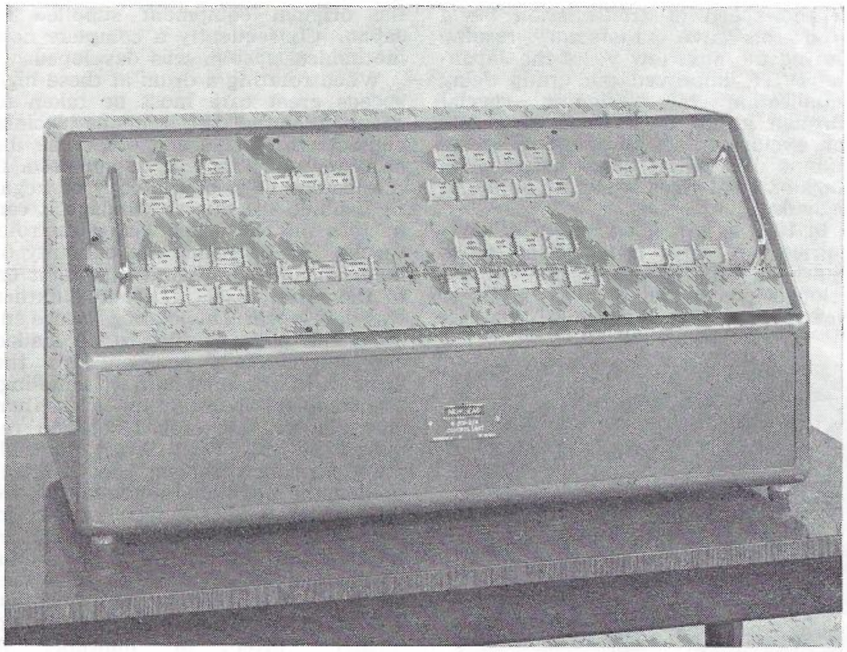

Fig. 5 — Remote Control Unit of the 'The Australian' equipment.

CONCLUSION

The wider use of newspaper page facsimile throughout the world leads one to speculate on the future possibilities. Large distances can be bridged and intercontinental working is a practical proposition although the economics of circuit rental make it rather prohibitive. Whatever the future development may be it is safe to assume that there will be further demand for faster transmissions in narrower bandwidths.

TECHNICAL NEWS ITEM

OPERATION OF THE MOTOR VEHICLE FLEET BY THE P.M.G. DEPARTMENT

The P.M.G. Department operates a fleet of over 10,000 vehicles ranging from small sedans to 50 ton transporters travelling a total of approximately 90 million miles per annum. In 1954, expenditure on fuel, tyres, repairs, maintenance and overheads (all costs excluding depreciation) amounted to $882 per 10,000 miles and by 1965/66 this cost had been reduced to $472 per 10,000 miles. This has been effected substantially by the following main factors:—

(a) The provision for each purpose of the smallest adequate vehicle.
(b) Replacement at comparatively early mileages (30,000 to 60,000 miles depending on type).
(c) The use wherever possible of standard vehicles.
(d) Design improvements in special bodies and equipment.
(e) Emphasis on vehicles with higher resale value (e.g. the use for many purposes of station wagons in attractive colours instead of panel vans).
(f) Close control of field maintenance and workshops management.
(g) The extension of servicing periods. For example, light vehicles are lubricated at 3000 mile minimum periods and oil is changed at 6000 mile periods.
(h) The cost of tyres is reduced by ensuring that the correct type is used for each purpose, and by investigating instances of rapid wear. Radial ply tyres are used on many vehicles where appropriate.
(i) Standard grade petrol is used in the fleet, vehicles being tuned for the appropriate octane rating. Substantial savings in fuel costs result. The road performance with standard fuel is satisfactory, and no adverse effect on maintenance cost is apparent.

The basic concept of early replacement recognises that production line labour is much more efficient than maintenance labour, early disposal minimises maintenance and it is rarely necessary to return vehicles for repairs at central workshops except those few which run high total mileages. The small amount of maintenance required can be carried out in the field by local service stations or by field repair units.

The Department has computerised its vehicles' running costs and is able to maintain two important controls as overall indicators of the effectiveness of its maintenance and replacement practices. These are:—

(a) The cost per mile of vehicles in each 10,000 mileage group for each separate make of vehicle.
(b) Trends in downtime are recorded as a guide to the overall efficiency of fleet management and as a check to ensure that the degree of maintenance applied to the fleet is sufficient to ensure a satisfactory standard of reliability. The average for fleet downtime is below 4%, which, for fleet operation, is considered a satisfactory figure.

PREPARATION OF PRINTED WIRING ARTWORK

*A. H. BADDELEY, B.Mech.E., B.E.E., A.M.I.E. Aust.**

INTRODUCTION

Although printed wiring techniques have become well established in Australia during the last decade, there are many engineers who, because of a lack of familiarity with a few basic essentials, feel hesitant to specify the use of printed wiring in their routine work. Printed wiring constitutes a useful tool for even small quantity manufacture and this article will endeavour to encourage the non-users to learn to avail themselves of it.

THE ETCHED-FOIL PROCESS

From the welter of diverse methods which were tested in the fifties, printed wiring has settled mainly on the etched-foil technique, especially for jobbing work in the electronics field. Most people will be familiar with the appearance of etched-foil boards. These are the ones which we find in many modern electronic instruments and in nearly all portable transistor radio receivers. They consist of a copper-foil wiring pattern cemented to a relatively thick (usually 1/16 in) base laminate, the copper acting as the interconnecting medium between the other discrete components of the circuit.

This complicated wiring pattern is all that remains of a continuous copper foil layer which initially covered the whole area of the base laminate. The unwanted areas of copper were etched away, i.e. they were removed by the chemical action of an etchant, usually a solution of ferric chloride or ammonium persulphate. During this etching process, the areas of copper foil required for circuit conductors were protected by a coating called the 'etchant resist', which was subsequently removed before the component pigtails were soldered to the copper.

Fig. 1 illustrates the succession of operations which result in the manufacture of a printed wiring board by the etched foil method, using a photo-sensitive etchant resist.

The first step is to coat the blank board, on its copper foil side, with a thin layer of a photo-sensitive compound. This layer is applied by spraying, dipping or whirling and it is then allowed to dry thoroughly. Next, a negative transparency is placed in contact with the coating in a suitable printing frame and the assembly is placed under a bright source of actinic light. Clear areas of the negative let through sufficient light to render the underlying areas of coating insoluble in a subsequent developing operation. After development, the board is placed in an etching tank or etching machine and the now unprotected areas of copper are chemically removed. The board is then washed and, after the remaining areas of resist coating have been removed by abrasive or solvent action, the board is ready for machining and assembly.

The method of manufacture outlined above is only one of three popular methods. It is suited to work where fairly high accuracy is required but, for large scale production where low cost is more important than high accuracy, it is probably better to use a screen-printed resist.

Screen-Printed Resist: Screen-printing, using stainless steel screens for dimensional stability, of polyvinyl chloride lacquers on to copper-clad laminates provides a good method of depositing a reliable etchant resist. Photographic methods are usually employed for clearing those areas of the screen where lacquer must pass through on to the copper foil, but, in this case, a positive transparency is required instead of a negative.

Electroplated Resist: Noble metals, electrodeposited on to the copper foil, can be used as a means of protecting the desired circuit areas from etchant attack. A thin layer of acid gold (0.0002 in is enough) is resistant to ferric chloride and does not need to be removed after the etching process. In fact, it serves to prevent tarnishing of the copper during storage and it facilitates soldering later on.

As will be seen from Fig. 2, a positive transparency is required for this method.

Transparencies: We have seen that, no matter which of the above methods is employed by the etching shop, we need either a positive or a negative transparency of the desired circuit in order to arrange for its manufacture. Most commercial manufacturers prefer to receive their order complete with the transparency, although they are all set up to produce the negative or positive, as necessary, from any suitable artwork layout which may accompany the order.

The main purpose of this article is to explain how one goes about the task of preparing a suitable transparency for presentation to the printed wiring etcher.

BASIC TYPES OF ARTWORK

The transparencies, positive or negative, are all derived from drawings or from analogous representations of the final circuitry configuration. The term 'artwork' is used to describe the whole range of drawings, etc., from which working transparencies can be produced. In some special cases, the artwork itself can be used as the working transparency.

There are two basic methods of making up suitable artwork. The first

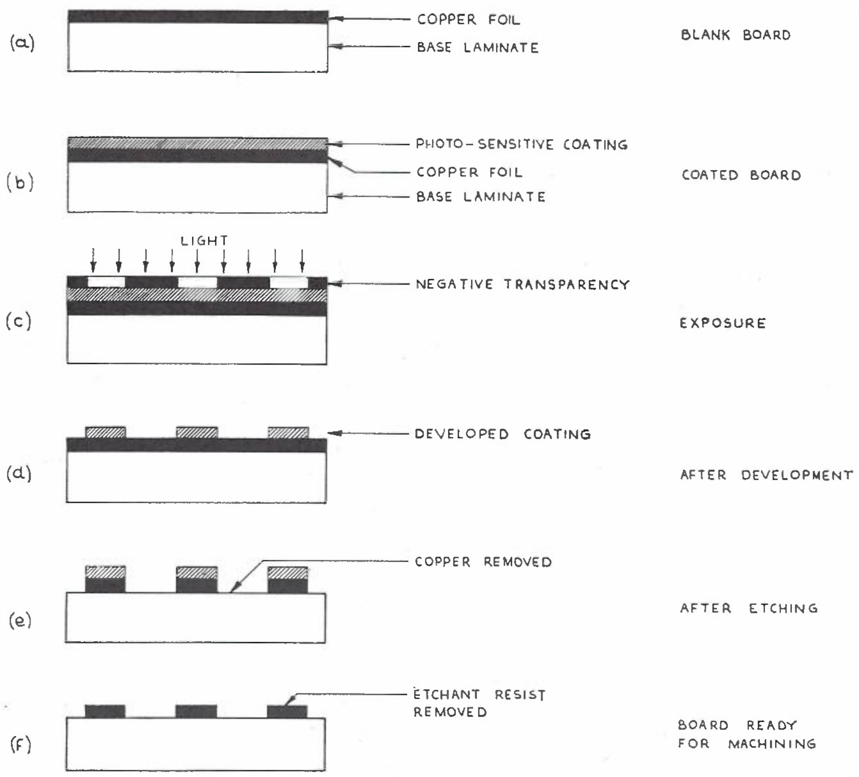

Fig. 1 — Successive Operations in the Manufacture of a Printed Wiring Board by the Photo-Etching Method.

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* Mr. Baddeley is Engineer Class 3, P.M.G. Research Laboratories. See Vol. 16, No. 3, Page 283.

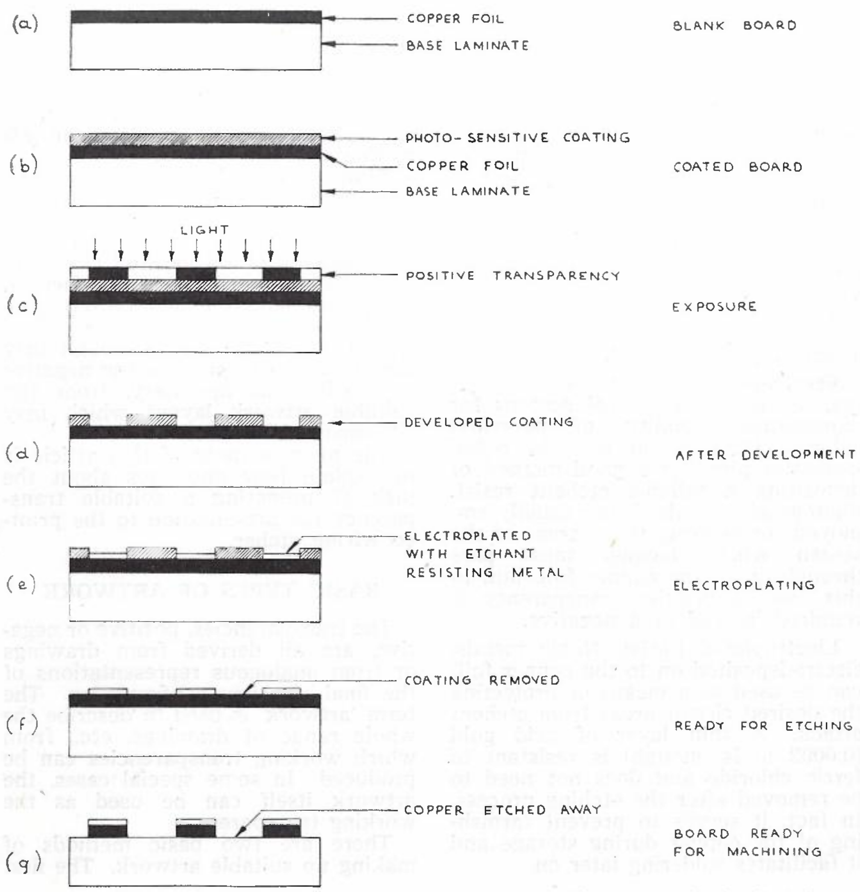

Fig. 2 — Manufacture of a Printed Wiring Board by the Electroplated-Resist Technique.

involves laying out the conductor areas on a clear or white background. The second involves stripping either the conductor areas or the non-conductor areas from an initially opaque background.

Laid Out Artwork

Ink Drawing: In the first category, are included black ink drawings on white base materials. These can be photographed in a copying camera to produce a suitable negative. If a photo-positive transparency is needed, the negative can be contact printed on to cut film.

Whenever possible, such drawings would be prepared several times full size in order that the subsequent photo reduction can reduce the amount of any drafting inaccuracy. Special types of white drafting board have been produced commercially for this type of work; the boards incorporate a grid of blue lines which do not appear as dark lines on a blue-sensitive film but which facilitate the setting out of conductor patterns. It will be explained later that all conductor terminations should lie on the intersections of a grid.

Frontal lighting, in the form of tungsten photo-floods or quartz-iodine lamps, must be provided for copying ink drawings or any opaque white base. The amount of contrast obtainable in the negative depends on how non-reflective the ink is. Better contrast can be obtained by preparing the drawing on a clear plastic drafting sheet and by back-lighting it.

Taped Artwork: As an alternative to ink drawings, opaque adhesive tapes may be used on a clear plastic or glass sheet. Several manufacturers now sell suitable tapes in various widths, as well as terminal pads, bends, tee connectors, fillets, elbows, ovals. etc., all of these being supplied in self-adhesive form. The tapes are available in dispensers which facilitate the application and 'steering' of the tape. The other accessories are supplied on backing tapes, from which they are stripped and transferred to the artwork layout as required.

The ease with which taped artwork may be altered makes this type of layout very suitable for jobs where changes in wiring are expected or where several printed wiring boards with minor variations from one to another are required.

As with ink drawings, taped layouts are usually prepared several times full size and are reduced to full size during photo-copying. Fig. 3 shows taped artwork being prepared, on a polyester ('Mylar') sheet base, over an illuminated work-table. Fig. 4 is an illustration of a process camera of the type often employed in copying printed wiring artwork.

Stripped Film Artwork

In the second basic type of artwork, there is initially an opaque area, from which selected portions are removed to give either a representation of opaque conductors on a clear ground or clear conductors on an opaque ground. The latter is more usual.

The raw material is a polyester ('Mylar') film which carries, on one side, an adherent red layer which can be peeled off. The areas to be peeled off are predetermined in the following manner. The draftsman, technician or

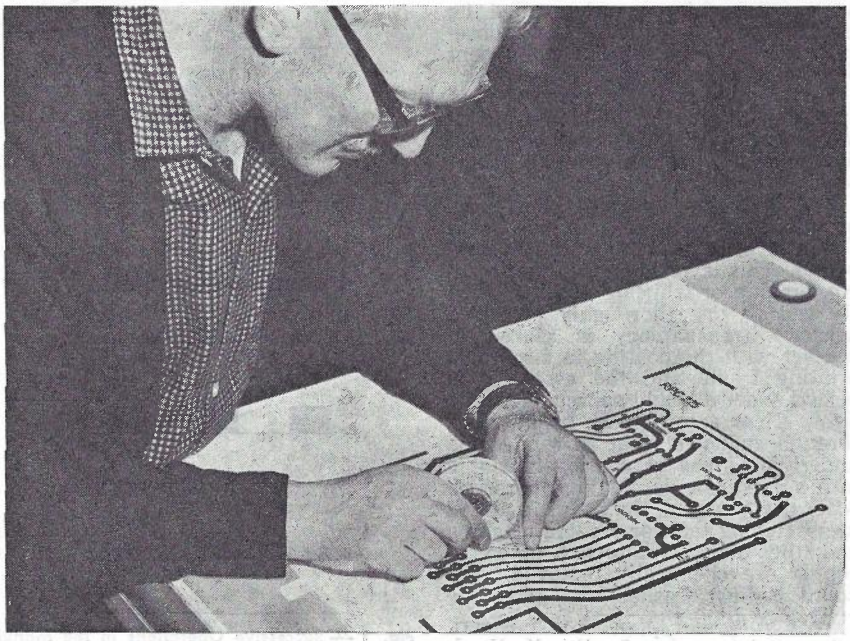

Fig. 3 — Laying down Taped Conductor Paths from a Tape Dispenser.

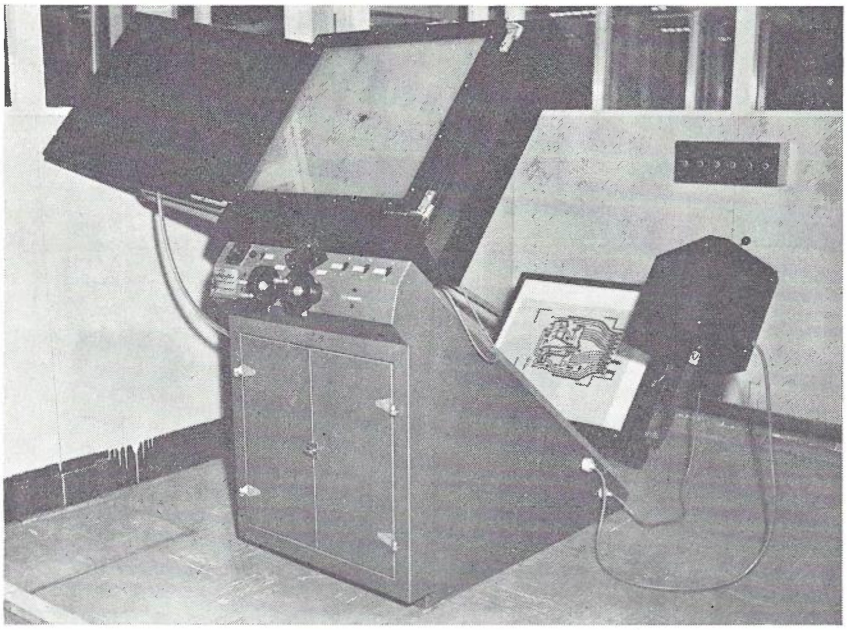

Fig. 4 — A Typical Process Camera Suitable for Photo-Reduction of Printed Wiring Artwork.

artist scribes around the area to be removed, using a chisel-pointed tool. Parallel lines can be scribed by special double bladed, spring loaded tools. Concentric circles can be cut by means of special drop compasses. Next, the draftsman lifts up the edge of the enclosed area of red coating. Tweezers can then be used to peel off the selected area of coating.

For work of very high accuracy, there are machines called Co-ordinatographs which can scribe the lines required more precisely than any manually-controlled tool could do.

As a guide to where to scribe the strippable coating, a pencil outline of the circuitry can be drawn on the opposite face of the polyester film beforehand. If the transparency which is being prepared is a negative of the circuit, then this pencil draft will be seen, from the drafting side, as a correct representation of the circuit orientation (i.e. it is not a mirror image). The circuit appears as a mirror image of the desired printed wiring during the stripping operation which must be carried out from the other side of the sheet.

It may seem simple not to worry about which way round the transparency is prepared and to choose the 'right way up' during the actual exposure of the circuit board, but, as in ordinary photographic contact printing, one obtains the most accurate results only when the "emulsion side" is in contact with the job. For this reason, negative transparencies should always be cut as mirror images and positives should always be cut in the original orientation.

CONDUCTOR LAYOUT

Having considered the more popular methods of preparing the conductor configuration on a suitable medium, it is necessary to consider the other aspects of conductor layout, for example, those which determine the spacing, width, separation and termination of the conductors.

Hole Positions

Most of the electrical components which will be mounted on any printed wiring board have pigtail leads which, at the assembly stage, will be passed through holes drilled or punched in the board and be soldered to the conductors. In order that the drilling of such holes may be facilitated, it is strongly recommended that the holes be positioned on the intersection points of a standard Cartesian grid of 0.1 inch pitch in both directions, as specified in Australian Standard No. C.326—1961 (Ref. 1). For finer work, a basic grid of 0.025 in pitch has been established.

There are other advantages to be gained from using the basic 0.1 in grid. For example, it eliminates the need for separate dimensioning of all hole positions on manufacturing drawings of the printed board. Most electronic component manufacturers now place the electrical terminating leads in positions which suit the basic grid.

The accuracy with which the positions of drilled holes may be expected to conform to the nominal grid positions is indicated by Clause 4 of the Australian Standard (Ref. 1) which states, in effect, that the tolerance on positional error, over a grid length of x inches, is ± (3 + x) thou., or ± 0.005 in, whichever is the greater.

Conductor Widths

Conductor widths are usually chosen on a basis of current carrying capacity for a given temperature rise, although it may be necessary, in the case of very narrow conductors, to relate minimum design width to the narrowest conductor which can be reliably produced by the prevailing etching process. The Australian Standard (Ref. 1) suggests an absolute minimum of 0.015 in for normal work.

Most copper-clad boards sold in Australia have copper surface densities of 1 oz per square foot or 2 oz per square foot. The thicknesses of these copper foils are 0.0014 +0.0004/—0.0002 inches and 0.0028 +0.0007/—0.0003 inches, respectively. Because of its higher cost, 2 oz copper will not be used by the board manufacturer unless it is specified. Therefore, in designing conductor widths, the engineer should assume 1 oz per square foot copper unless he intends to specify 2 oz. Curves showing safe

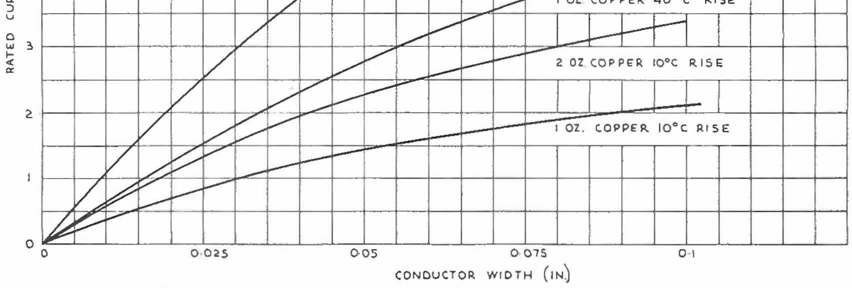

Fig. 5 — Safe Current Ratings of Etched-Foil Conductors.

current ratings of etched foil conductors versus conductor width are given in Fig. 5. These curves are derived from tabulated recommendations in Reference No. 2 and represent safe current ratings.

For taped artwork, one must use conductor tapes whose width is equal to the designed conductor width multiplied by the linear ratio in which the artwork size exceeds the final size of the job. There will be, therefore, a secondary limitation on conductor width imposed by the restricted choice of tapes of different widths. Tapes are available commercially in widths of 1/64 in, 1/32 in, 1/16 in, 3/32 in, 1/8 in, 3/16 in, 1/4 in, 1/2 in, 1 in and 2 in. Flexible matt black tapes are most commonly used, although some writers express a preference for red translucent tapes because these have more cleanly cut edges and because it is convenient to be able to see through the tapes to inspect underlying grid lines, etc. The red tapes are, of course, opaque to blue light; hence they reproduce as would black on a blue-sensitive film.

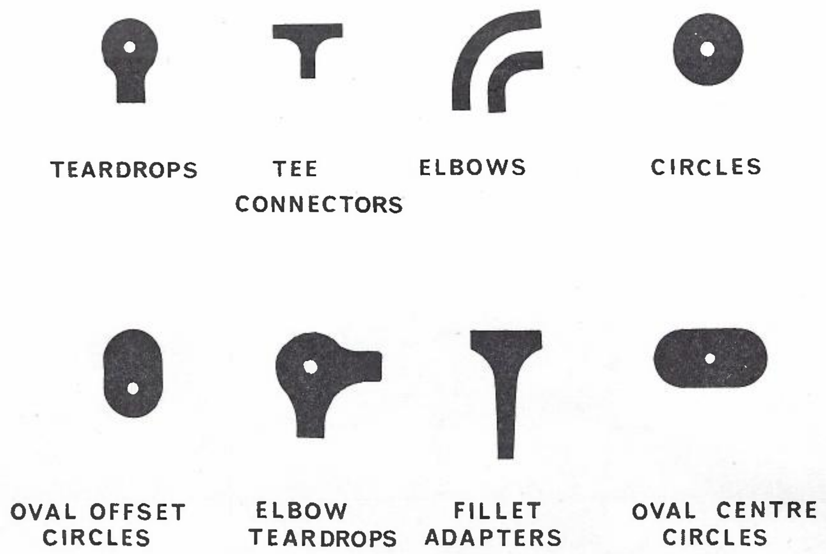

Fig. 6 — Self-Adhesive Die-Cut Shapes Available from Tape Manufacturers.

Terminal Lands

The factors which determine the best choice of terminal land diameter are as follows. One must first select a hole size which suits the pigtail diameter. The hole diameter should be a standard one if possible. Then one must allow a suitable annular width to accommodate an adequate solder fillet, say 0.030 in.

If the printed wiring layout is to be made for only a very limited number off, it is likely that they will be drilled manually and positioned under the drill by eye. In this case it is an advantage to leave a small etched-out circle in the centre of each terminal land in order to centre the drill later on. However, when the drill or punch is located independently of the lands, as it would be in a large production run, it is better not to provide the concentric clear area in the terminal land.

In selecting hole sizes, the number of different sizes should be kept to a minimum, in order to eliminate delays in drilling. It has been found, in the P.M.G. Research Laboratories, that most pigtails and other leads can be accommodated satisfactorily in one or other of three hole sizes. The relevant drill sizes are No. 55 (0.052 in), No 60 (0.040 in) and No. 70 (0.028 in). The outer diameters of corresponding terminal lands would therefore be 0.112 in, 0.100 in and 0.088 in, although one is again restricted in choice of diameter when using the die-cut circles and terminal lands sold by the firms which market conductor tape. Reduction of the annular width of copper below the figure of 0.030 in recommended in the Australian Standard (Ref. 1) should be contemplated only if the designer is sure of obtaining very accurate boards of good solderability. Badly soldered joints will result also if the hole diameter is more than 0.010 in bigger than the diameter of the pigtail.

As well as marketing die-cut circles and annuli, the tape manufacturers usually sell other aids to printed wiring layout, such as those shown in Fig. 6. These shapes facilitate the production of fillets and smooth bends which, by eliminating sharp corners, reduce the likelihood of fracture of the conductors under vibration.

Conductor Separation

For general purposes, the Australian Standard (Ref 1) recommends a minimum conductor separation of 0.030 in edge-to-edge. This figure should not be reduced, especially if the board is to be dip or wave-soldered. Smaller separations would certainly present bridging troubles under these conditions.

The permissible separation distances should be related to the voltage between the adjacent conductors and, in this regard, U.S. Military standards indicate that the 0.030 in separation should be increased, especially for uncoated boards, for voltage differences exceeding 150 volts. For voltages from 150-300, a separation of 0.050 in is recommended. For over 300 volts difference, the recommended figure is 0.100 in or 0.0002 in per volt, whichever is the greater. These figures refer to d.c. voltage differences or to peak-to-peak a.c. voltage differences.

GENERAL LAYOUT

Edge Distances

In many cases, the distance between the edge of a board and the nearest conductors will be dictated by the fact that the board will be overlapping some part of the supporting structure. Here, the abovementioned separations required by voltage considerations will apply, with due allowance being made for tolerances on the relative positions of board and chassis.

Where the edge of the board does not lie close to any other parts, it is not recommended that conductors be run closer than about 0.12 in. This is because the cut edge of the board cannot be completely sealed against moisture ingress and the moisture presents a source of breakdown of insulation resistance.

Register Marks

A competent designer of printed wiring boards will discuss the machining of his boards with the production engineers before he starts to prepare the artwork. He will usually find that the production department needs some reference marking on the board to indicate where the board must be accurately positioned during drilling, punching or blanking.

Although the location and shape of register marks may vary considerably from one shop to another, it is important for the designer to be aware of the need for register marks and of their desired location before he attempts to lay up his artwork.

Reference Dimensions

It has been explained already that most artwork is prepared several times bigger than full size. Reduction to full size is carried out photographically and it is usual for copying camera ratios to be set by scaling the image on the ground glass focusing screen, at least in the case of jobbing work. Therefore, it is very helpful to the photographer if an accurately delineated dimension on the artwork (but not on the actual board area) is marked with its correct reduced size. For instance, on a four-times full size layout, an accurate 12 in gauge line would be labelled '3 in ref' for the guidance of the photographer.

This reference dimension need not be used when accurately calibrated copying cameras are available. Experienced photographers, using cameras with graduated setting scales for the lensboard and copy holder, can reproduce a known copying ratio without reference to the particular artwork, but the designer should check the accuracy of the photo-reduced transparency before it is sent to the board etcher.

Planning the Wiring Layout

After over a decade of concentrated development of the etched foil technique, there does not seem to be, even now, a short-cut method of deriving a printed wiring configuration from a schematic circuit diagram. It is just a case of patient cut-and-try. Certainly a clean schematic with a minimum of crossed conductors is a help but the designer usually ends up with upwards of half a dozen sheets of paper representing various stages of development of the final layout.

Crossovers in printed wiring can be effected only by passing one conductor underneath the body of an electrical component. As a last resort, a wire jumper connection, suitably sleeved, can be used, but the jumper contributes nothing else to the functioning of the circuit and it should be avoided if at all possible. If several jumpers are to be used in a circuit, at least they should all be of equal length, in order to reduce the effort involved in bending them to shape.

Similarly, all pigtail components of similar body size (e.g. all $\frac{1}{4}$ watt resistors) should have a uniform centre-to-centre distance for their turned-down leads. This is good practice, not only from the point of view of standardisation, but also because it enhances the appearance of the board.

The axes of resistors, etc. should, for the sake of appearance, follow the grid lines and the ends should be lined up wherever possible. It looks far better to have neat rows of components and wriggly printed wiring than to have neat runs of printed wiring and wriggly rows of components.

All resistors, capacitors, etc. should be laid flat on their sides wherever possible. This makes for a more robust mechanical assembly. The practice of standing components on end, in order to conserve board area, is not recommended because it can nearly always lead to overstressing of the copper to base-laminate bond. Components exceeding 14 grams in weight should be anchored to the board by some means other than their electrical terminals. This figure should be reduced to 7 grams for airborne equipment.

Only one component pigtail should go into any one hole. In the absence of a plated-through-holes service, through connections in double sided boards can be made by means of small eyelets. Funnel-head eyelets are preferable to rolled-head eyelets. It is not considered good practice to associate the feed-through eyelets with ordinary component terminations, because the eyelets need to be soldered to the component-side foil. If it became necessary to remove the pigtail component for any reason, the soldered joint between the eyelet and the component side foil could be damaged and repair would be difficult.

'Picket Fence' Areas

If a printed wiring board is to be dip- or wave-soldered, precautions must be taken, during the design stage, to avoid having large continuous areas of copper foil in the layout. Copper is an excellent thermal conductor, whereas most of the base laminates are not. When the board suddenly comes in contact with a large mass of solder, the copper reaches solder temperature very quickly, but the base laminate does not. The copper tries to expand relatively to the base laminate and high stresses are placed on the copper-to-base adhesive and blistering can result. This effect can be avoided by creating gaps in each of the large areas of copper to form a 'picket fence' of conductors surrounded by a narrow strip of copper defining the outer perimeter of the area.

Apart from this need to protect the board against thermal shock, copper should not be removed unnecessarily during etching. Provided that adequate clearances between adjacent conductors are maintained, the less copper to be removed the better; this conserves etchant solution and so reduces costs.

Edge Connectors

When the edge of the board is being designed to plug into a mating socket, tabs will be arranged in the artwork layout to suit the connector manufacturer's specification. In general, it will be necessary to electroplate these tabs. If the electroplated-resist method of etching is being employed, the tabs will be plated at the stage where the resist is deposited. If, on the other hand, the board is to be etched before the tabs are electroplated, it is often necessary to incorporate, in the artwork, a strapping connection to unite all of the tabs for plating purposes. This strapping connection lies outside the board area proper, and is sawn off after plating, the cut edge being then lightly chamfered where it enters the socket.

Board Identification

From the designer's point of view, it is an advantage to have an identifying number or title on each board. In any large establishment, a logical numbering system should be formalised so as to avoid the possibility of board numbers being duplicated by different designers. These numbers should be incorporated into the artwork so that they appear either as copper letters on clear ground or as etched-out letters on a copper background. Transfers of the 'Letraset' or 'Instantype' variety are useful for this purpose.

From the point of view of the board etcher, it is worthwhile to include, on each layout, a name, monogram or other symbol which will immediately identify the firm or organisation which owns the board design. In this way, the manufactured boards are easily identified in the etching shop, even though their associated job cards may have become mislaid.

Other lettering which can be included advantageously in the artwork comprises voltages, polarities, terminal designations and orientation marks for transistors, diodes, micro-circuit blocks and electrolytic capacitors.

Mounting

The artwork layout should take account of the way in which the board is to be mounted. Supports for 1/16 in boards should be no more than 4 in apart. When allocating space around mounting holes, do not forget that plain washers will usually be placed under screw heads.

All components which dissipate substantial quantities of heat should be fitted with suitable radiators or "heat sinks".

If possible, mount pigtail components with their axes in the vertical direction when the board is mounted in the vertical plane. This helps to dissipate heat by convection and reduces dust collection.

CONCLUSION

In the foregoing text, the author has tried to indicate the main aspects to be considered in the preparation of printed wiring artwork. Of course, there is a lot of information which the designer must collect from commercial supplies in relation to any specific job. He must find out what sort of components, terminals, connectors, feed-throughs and mounting hardware are to be used and then he must choose appropriate land shapes and mounting hole sizes for each before he can start to prepare the artwork, but it is hoped that intending users of printed wiring who wish to create their own artwork will have derived some help from the suggestions contained in this article.

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PROTECTION OF TELEPHONE CABLES FROM ATTACK BY INSECTS

G. FLATAU, F.R.M.I.T.[*]

Editorial Note: This paper was presented at the Fifteenth Annual Wire and Cable Symposium at Atlantic City, New Jersey, December 1966.

INTRODUCTION

Recorded instances of insect attack on telephone cables date back to long before the turn of the century. However, this problem has in the past 20 years assumed a new dimension because of two reasons. Firstly, telephone networks of significant size have vastly extended in the tropical and sub-tropical regions, particularly in developing nations, i.e., into those climates where the insect fauna is far more extensive and voracious. Secondly as economic advantages caused the introduction of plastic sheathed cables in place of metal sheathed ones, chewing or boring insects have encountered materials which are often easier to penetrate.

In Australia the hazards of insect attack have already been faced for many decades, because of our unique circumstances of having a highly developed telephone network of long standing, covering a continent spanning 30 degrees of latitude, ranging from the tropical North, through sub-tropical and temperate regions to the cool alpine climates of parts of the South. The vast majority of damage by insects in Australia is due to termite and ant attack on underground cables, whilst borers, grubs, beetles and cockroaches have never been more than isolated nuisances. It must be emphasised that insect damage to cable at no stage has caused more than a relatively small proportion of total cable faults, 5% being about the maximum in the worst year, but these faults represent a considerable financial cost, and in particular an expenditure which it is felt can be avoided by the protective measures now being developed. It is probably also a reasonable assumption that any successful measures developed to protect against termite attack, stand a good chance of being equally effective against almost any other insect order presently causing cable damage. This should be kept in mind in the following sections, which deal with investigations to secure protection from termite and ant attack.

THE HABITS OF TERMITES AND ANTS

Termites and ants are both social insects, that is they live in well organised colonies where every individual has its specific duties, and performs these selflessly for the good of the community. Termites, often called "white ants", and the true ants are not related, belonging to completely different orders of the insect world. Termites are far more primitive, one species prevalent in Northern Australia having not altered in 40 million years. Both families contain many genera and species, but most of these are of little economic importance living contentedly on plant materials etc., and it is only a few genera which are either responsible for cable damage, destruction of timber, etc. or are household pests. The following genera have been definitely connected with attacks on cable or wiring in Australia:

TERMITES:
- MASTOTERMES (See Fig. 1)
- COPTOTERMES
- NASUTITERMES

ANTS:
- PHEIDOLE (See Fig. 2)
- PHEIDOLEGETON
- IRIDOMYRMEX
- MONOMORIUM

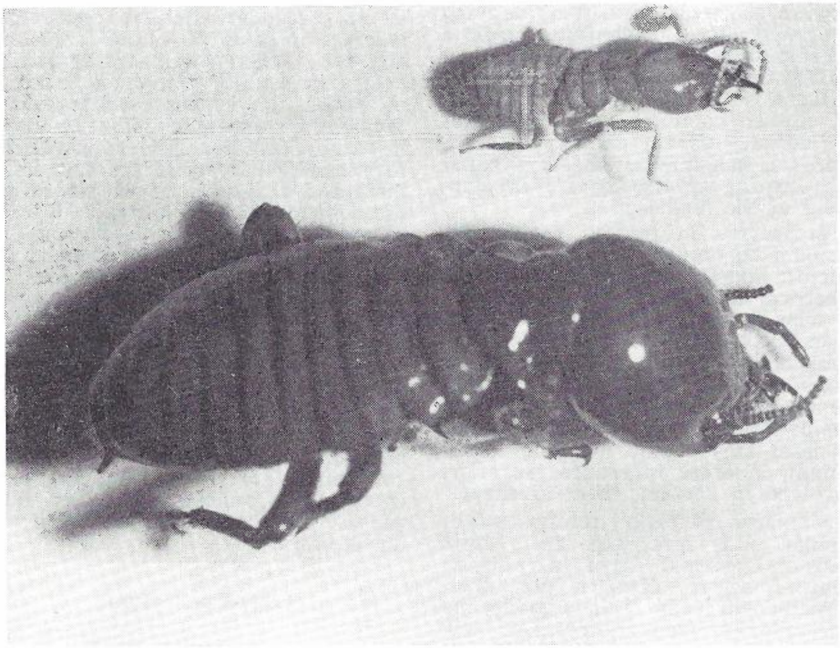

Fig. 1 — Comparison in Size of Mastotermes and Coptotermes (1½ in. — 5/32 in.) soldiers.

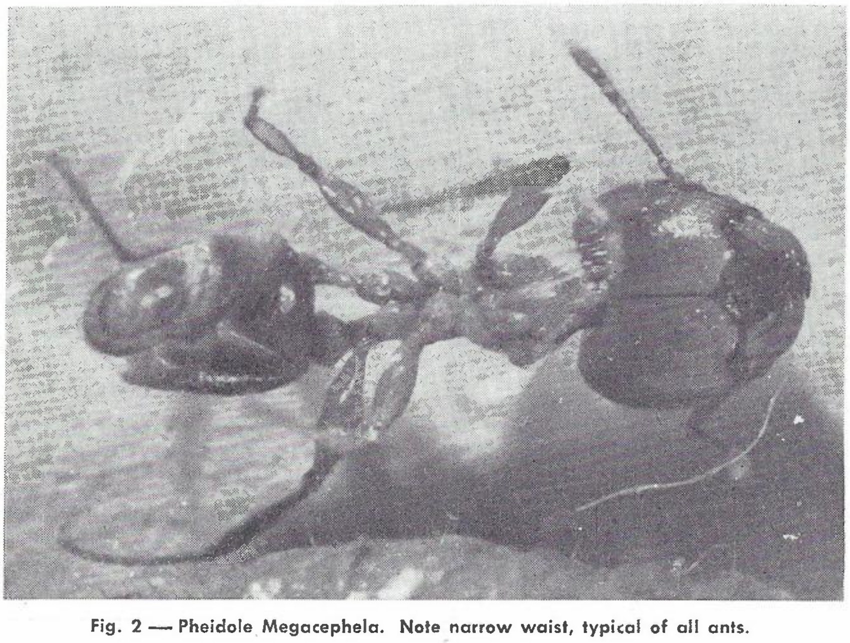

Fig. 2 — Pheidole Megacephela. Note narrow waist, typical of all ants.

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[*] Mr. Flatau is Principal Officer, P.M.G. Research Laboratories.

In reports from other parts of the world (Ref. 1, 2) these names appear again and again with perhaps two or three additions. Although the species differ with geography, this only represents morphological differences of interest to the entomologist.

Colony sizes vary from type to type and with age, but it is not unusual to encounter populations of the order of millions. The nest locations also vary not only between species, but also according to climate. For instance many species of Australian termites are mound builders in the tropics and subterranean in the temperate zones. Each nest contains one or more queens, who functions as an egg-laying "machine" producing thousands of eggs per day for many years (Fig. 3). Most species have soldiers, who protect the nest. However all colonies are mainly populated by workers, who forage and feed everybody and look after the eggs and young. It is generally the workers who cause our troubles.

The question frequently asked is why termites and ants will attack unpalatable and non-nutritious materials such as lead or plastic? Nobody can give a clear-cut answer, but it does appear likely that the insects attack out of curiosity in their unending quest for food. Contributory factors would be the interruption of a food path by a cable, and perhaps the use of the sheathing material for nest construction. From time to time theories are advanced about insects being attracted by conductors of a particular polarity, by certain colours, by cables carrying music or high frequency transmissions etc. etc., but there seems to be no real proof for such assumptions. We know that termites are more prone to attack cables laid in ducts during summertime, but this is due to the fact that the higher humidities retained in a duct as compared to the soil outside, meet the comfort requirements of these insects.

Most termites and ants are to be found within two to four feet below the soil surface, whilst at times they will tunnel much deeper, some species are also to be found high above ground inside tree trunks.

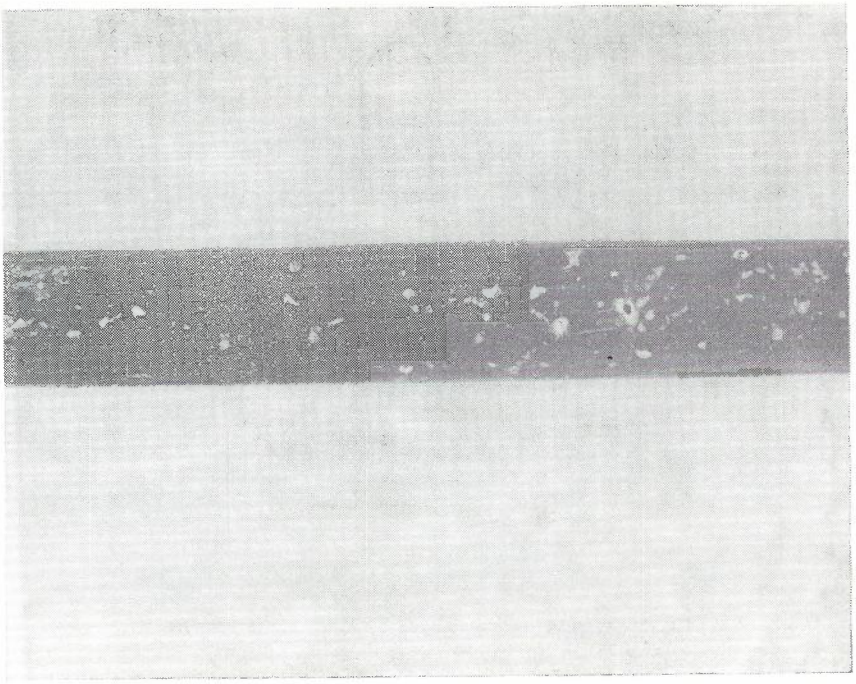
Fig. 4 — Low Density Polythene Sheath Attacked by Pheidole Megacephela Ants.

TYPE AND EXTENT OF DAMAGE

Damage from insect attack varies over a wide range in both the size of the individual perforations and the length of cable attacked. For instance the ant PHEIDOLE MEGACEPHELA produces circular holes no larger than 1/32", but often extending over hundreds of yards (see Fig. 4), whilst the giant termite MASTOTERMES DARWINIENSIS usually concentrates its attack over a few feet of length, but leaves holes as large as 1-2 square inches (see Fig. 5). The elapsed time after laying a cable, until serious damage was noted, has varied from weeks to years, although the claim is often made that the worst attacks occur within 12-24 months of installation. As a general rule, termites are likely to attack lead or plastic sheathed cables, whereas ants are mainly a hazard to plastic cables. (The ant MONOMORIUM DESTRUCTOR is the only recorded exception to this rule in Australia.)

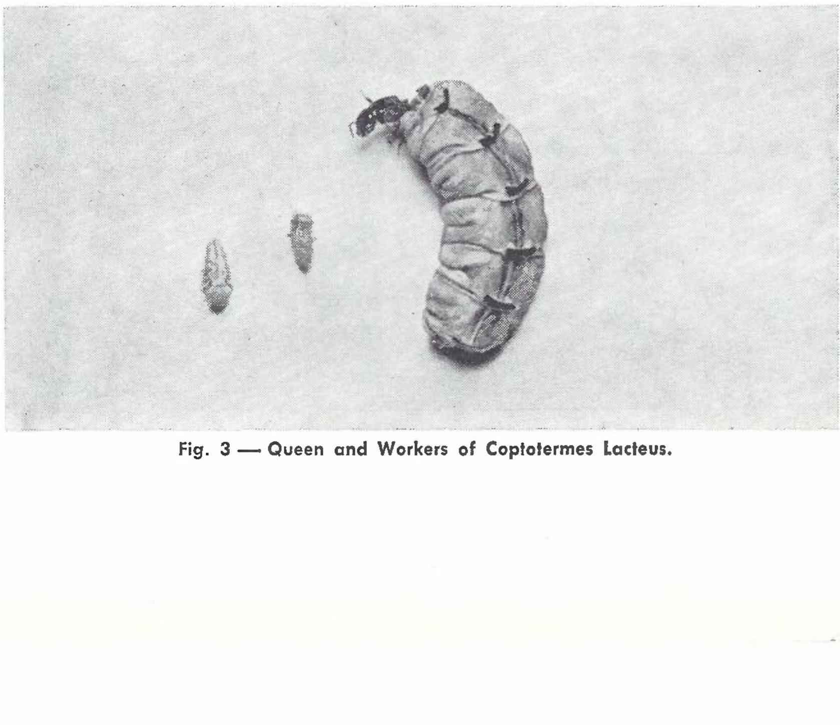
Fig. 3 — Queen and Workers of Coptotermes Lacteus.

In Australia the hazard of termite and ant attack progresses as a general rule as one moves from the temperate South to the tropical North, but localised climatic factors play their part to often confuse this simple picture. No direct correlation between soil types and fault incidence has been found, except that semi-arid or desert areas are less affected. (By the same token these areas also contain little buried cable plant, which means that statistically no conclusion can be reached.)

The most pertinent factor is of course the degree to which insect and ant attacks contribute to the overall fault spectrum. The latest fault statistics indicate that the number of cable faults caused by insects are of the order of 1-2% of all sheath faults, although this percentage is probably raised to 3-5% when only plastic sheathed cable is considered. Admittedly these figures are small, when compared to some other sheath fault categories, such as mechanical damage. But the fact remains that insect attack causes something like 3,000 individual cable faults per year in our network, and probably an appreciable number of additional attacks occur which might not be recognised until years later when water entering the cable causes a fault condition. Even then this fault, especially if it is traced to a joint might be attributed to a different cause, such as faulty workmanship!

There are also definite indications that the rate of attack is steadily increasing, especially that portion due to ant attack in the Northern States. It is evident therefore that any methods which will substantially reduce

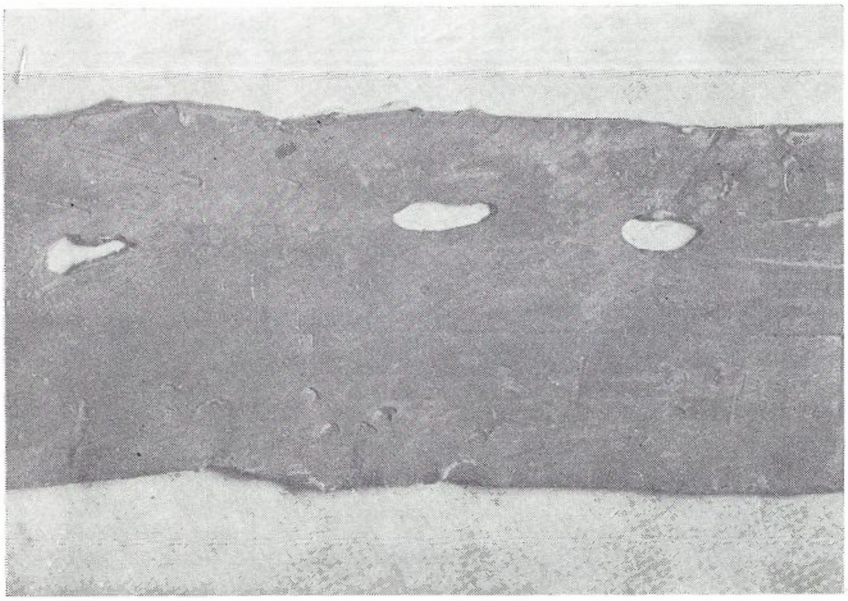

Fig. 5 — Lead Sheath Damaged by Mastotermes Termites.

damage by insect on cables, will represent a worthwhile annual saving, both financially and in labour required for repair.

PROTECTIVE MEANS

The choice of any protective measures is circumscribed by a number of clear requirements. Briefly these are:

(a) The protection must remain effective over the life of the cable, which means usually 20-30 years.

(b) The method must represent a sufficiently low health hazard to operating staff or manufacturing staff, so as not to impose excessive precautions during handling of the cable.

(c) The cost of protection must be kept low (if it can be incorporated during cable manufacture, the process should be reasonably simple and capable of application with existing tools or machines).

All methods tried in the past or currently under investigation have generally attempted to follow the above rules, although possibly not enough attention was paid to toxicity hazards in some early trials. Basically all protective methods fall under one of two headings:

(i) A cable sheath of an intrinsic hardness greater than that of the insect mandible.

(ii) The use of a chemical repellant to dissuade the insect from approaching the cable.

The first alternative, i.e., a hard, resistant sheath, is attractive as it readily meets condition (b) above, and condition (a) can probably be fulfilled by a correct choice of metallurgical or plastic formulation. However, the cost of such sheath compared to the conventional metal or plastic sheath might be appreciable, especially if it involves a composite sheath construction. Keeping this in mind, what sort of hardness is required? Taking the termite mandible as a basis of comparison, it has been shown by scratch tests (Ref. 3), that the insect mandible is harder than lead, but will not scratch copper, brass or aluminium. When it comes to plastics the position is somewhat confused, as some plastics of a hardness (on the Barcol scale) lower than lead appear to be superior in their resistance. The implications are that in the case of plastics the desired property is not just metallurgical hardness, but rather a combination of hardness and toughness. The likely explanation for this lies in the manner in which a termite will "bite" a sheath, which is a gouging or tearing action (Fig. 6). The ability of a material to deform rather than break or tear on the application of mandibular force thus presents the insect with a far more difficult task, and one which it will perhaps give up after a few futile attempts.

Turning to the other alternative, that of a repellant, it must be clearly understood that this can not necessarily be equated with a poison. In the case of termites and ants in particular, a poison would be useless because of the large number of attackers involved. If the cable sheath is just poisonous, each insect will die after one or more bites, but the chances of a sheath perforation are extremely high, whilst the insect population is merely reduced by a small number, which can be made up by the colony in a matter of a few days or weeks. For this reason one requires a true repellant, one which discourages the insects from approaching the cable, because they sense danger or something unpleasant. Repellant treatment of the area surrounding the cable, or by incorporation in or on the cable sheath is generally an economical proposition, but raises problems with regard to life expectancy and health hazards. It is essential that the repellant be capable of resisting climatic influences over many years, in particular that it be not carried away by leaching action following heavy rains. The material chosen must be carefully evaluated for toxicity and dermal hazards, and adequate protective safeguards for persons handling the

Fig. 6 — Termite Mandible Markings on Lead Sheath.

cable must be implemented. In the case of buried cables in country districts it is important to be certain that the repellant used will present no hazard to grazing cattle nor contaminate crops in the vicinity. In most places stringent regulations now exist, governing the type and concentrations of insecticides permitted to enter the soil.

EVALUATION OF PROTECTIVE METHODS

Historically the initial efforts in this field were aimed at providing protection from insect attack for underground lead sheathed cables. Soil treatment with creosote was tried in the 1930's with only limited success, and the incorporation of a chlorinated naphthalene compound in the petroleum jelly pulling compound some years later was also found unsatisfactory. The dusting of cable ducts with arsenical compounds was tried, but apart from the health hazard, appeared also to have only limited persistence. The commercial introduction of more powerful insecticides seemed to offer promise of more effective soil treatment, but some trials with D.D.T. were most disappointing. In fact the only method which proved fully satisfactory was steel-tape armouring, and this technique is generally employed by us on cables in the worst affected areas, in particular where Mastotermes termites are present. Where attacks on armoured, lead sheathed cables have taken place, the cause has been the opening up of the helical wound tape either due to manufacturing faults or due to the application of excessive stresses during laying operations, permitting the termites to gain access to the underlying lead sheath. Whilst effective, this is a costly solution, and hence is used only to a limited extent.

By about 1950 it was becoming evident that plastic sheathed and insulated cables would soon offer definite financial and manipulative advantages, especially in the smaller size cables used in local distribution practices. Hence it was decided to commence field trials of plastic sheathed wires and cables in various areas of Australia where termite infestation was known to be severe. The method of test which was adopted, consisted of laying down test plots containing sufficient samples to permit withdrawal of each type under test after 1, 2 and 3 years' exposure, recovery of each lot being made in such a manner as not to disturb the remainder. Each individual sample, approximately 15" long, was sheathed in, or attached to, a 12" long termite susceptible timber peg. The pegs were buried in a square matrix to a depth of 13", with a separation of 18" between neighbours in rows and columns. Timber connecting laths, were buried 1" below the surface, contacting each peg in a row, and the outside two columns. Plain wooden control pegs were also included at various points of the matrix, as a means of checking termite penetration during the course of the test, without having to disturb any samples. In laying down a test plot, it was essential to create the minimum disturbance of the surrounding soil, so as not to drive the insects away, and to protect the plot from grazing cattle, curious humans and also bush fires.

We were fortunate in being able to enlist the help of the Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.), whose Division of Entomology had developed a method of testing materials against attack by some species of termites under laboratory conditions. (See Ref. 4.) These tests have consistently been found to agree with our findings in the field, although unfortunately the most powerful termite species, Mastotermes, cannot be maintained under laboratory conditions.

The first series of field tests during 1951-1954, clearly indicated the susceptibility of low density polythene or plasticised P.V.C. to termite attack, but did show that the degree of attack decreased with increasing hardness. The incorporation of either lead naphthenate or pentachloro-phenol (1%) in polythene was found to be ineffective.

A more extensive series of trials based on the experiences gathered till then were conducted during 1959-1964, using the same test methods as above, but also including a site in New Guinea. (See Ref. 5.) In addition to tests against termites, tests for resistance to ants were also conducted. In the latter case lengths of 30-40 yards were buried 12"-18" deep with only the ends protruding, in areas where ant attack had previously been observed. Insulation resistance measurement between conductor and soil were made regularly over a $2\frac{1}{2}$ year period; low resistance indicated the onset of attack, the final results being normally short-circuit conditions. The ant species involved in all coses was PHEIDOLE MEGACEPHELA. A brief summary of the results is given in Table 1.

TABLE 1.

Sheath Material	Additive or Other Protection	% of Samples Attacked by Termite or Ants (Sample size 12-160)
Polythene M.F.I.2	1% Dieldrin	5.4
Polythene M.F.I.2	0.5% Dieldrin	9.1
Polythene M.F.I.2	0.25% Dieldrin	25.0
Polythene M.F.I.2	1% Aldrin	18.2
Polythene M.F.I.2	0.5% Aldrin	36.4
Polythene M.F.I.2	0.5% Gammexane	13.3
Polythene M.F.I.2	0.2% Gammexane	13.3
Polythene M.F.I.2	5% lead Pentachlorophenol	27.2
Polythene M.F.I.2	0.015" nylon 6 or 6-6 jacket	4.0 (all due to ants)
Polythene M.F.I.2	nil	30.2
Polythene M.F.1.0.3.	1% finely divided silica	25.0
Polythene M.F.1.0.3.	0.1% finely divided silica	21.0
Polythene M.F.1.0.3.	nil	18.7
P.V.C.	1% Dieldrin	15.7
P.V.C.	0.25% Dieldrin	18.2
P.V.C.	0.5% Gammexane	11.1
P.V.C.	0.2% Gammexane	17.7
P.V.C.	1% Chlorinated aryl sulphonamide	23.6
P.V.C.	0.015" nylon 6-6 jacket	0 (not tested against ants)
P.V.C.	nil	38.2
Epoxy resin	nil	0
A.B.S. pipe	nil	0

It is evident that none of the additives tried could be classed as effective, especially when one compares the maximum exposure time of three years with the expected life times of cables in service. The trials confirmed that P.V.C. is less resistant than polythene and that Dieldrin was superior to the other repellants tried. The figures for the silica additions are startling, as they show the best result with untreated controls! The explanation for this probably lies in the fact that as silica is added to the polythene, the surface texture becomes rougher, and hence enables the insects to more easily gouge out pieces of the sheath. It is interesting to note that nylon jacketing was found completely resistant to termite attacks, a fact which has been confirmed in trials held by C.S.I.R.O. and other authorities in Australia, but there was some damage due to ant attack. The reasons for this performance variation are not perfectly clear, but could be due to the difference in biting action between termites and ants. At the same time it is important to emphasise that the nylon used in the above trial had a tendency to blister or de-laminate from the underlying polythene, probably due to excessive water absorption. A blistered nylon would present a much simpler barrier to the insect mandible, and in fact there is a good chance that the actual attacks might have occurred at points where the nylon had cracked. These considerations have resulted in a change to a nylon with much lower water absorption, in the nylon jacketed cable presently on trial.

A new series of field trials has been underway since 1964, in which the previous findings have caused us to investigate several sheathing materials of greater toughness. Early results from the field, coupled with laboratory test results on some samples by C.S.I.R.O., are summarised in Table 2. All tests to date refer to termite resistance only, and do not extend beyond one year of burial.

Heavy attack has occurred on polythene and PVC control samples, and also on some commercial cables of overseas origin, which were submitted in the hope of being "termite-proof". A few other promising polymer materials or additives are on trial, but have had insufficient exposure time as yet, for any examination to be made.

Work is still continuing with soil treatment, and in one area has lately met with good success. Here a method has been devised, of spraying the soil during cable laying operations, using a ½% Dieldrin emulsion in water at a rate of about 80 gallons of solution per 1000 yards of trench. Fault statistics indicate that this treatment has produced a very significant reduction in cable faults due to insect attack. It is still doubtful if this type of treatment will be equally effective in the high rainfall tropics, where previous attempts at soil treatment with Dieldrin or Lindane met with little success. Only further work can resolve this point, and at the same time the continued use of this practice in the original area will show whether the method is likely to have the desired long lasting effectiveness.

For cables laid in ducts, a method has been developed where 2% Dieldrin dust is blown into the duct by means of an air compressor and injection hose unit. About 9 lbs. of the powder is used for a 500 foot long, 4" diameter duct, and strict precautions to protect operating staff are enforced. This technique has been used in only a limited area, and then mainly in response to termite damage to a cable in a duct, at the time of installation of a replacement cable, but the results are stated to be very satisfactory in preventing re-infestation.

Since 1958 a committee under the auspices of the Plastics Institute of Australia has been investigating the problem of termite and ant resistance of plastics. This committee, composed of both users and manufacturers, has met regularly and collated the available information as well as enlisting the aid of the C.S.I.R.O. Division of Entomology in an extensive laboratory and field testing programme (Ref. 6). The findings to date (Ref. 7) have been in general agreement with our own results, but in addition have been extended to various plastic materials not currently used for telephone cable insulation.

TABLE 2

Slight to moderate attack:	High density polythene (0.96 gm/ml) Polypropylene Polythene wrapped with jute yard impregnated with grease, outer covering of PVC tape. Polythene, wrapped with tanalith impregnated jute wrapping.
Very slight attack (surface graze marks only):	Polythene + 1% silica Polythene + 5% silica Polyurethane
No attack:	*Polythene covered by 0.004" helical brass tape, low grade polythene outer sheath. Polythene sheath, 0.030" Nylon 11 jacket.

* Some attack on the outer sheath has occurred, but the latter is only present for mechanical reasons during laying.

SUMMARY

As a result of the testing carried out in Australia over the past 15-20 years, an attempt has been made below to classify cable sheathing materials into four groups, as far as their resistance to insect attack is concerned:

(a) Fully resistant materials: steel, brass, copper, aluminium, bronze, polycarbonate, acetals.
(b) Highly resistant materials: rigid P.V.C., high density polythene, nylon, PTFE, polyesters.
(c) Moderately resistant materials: lead, polypropylene, polyurethane, some natural rubbers, A.B.S.
(d) Non-resistant materials: low density polythene, plasticised P.V.C., cellulose acetate butyrate, synthetic rubbers.

This classification must be regarded as approximate only, as the susceptibility to insect attack can vary extensively not only amongst insects from different orders, but even amongst species within the one genus. Furthermore the insect resistance of a given material can be significantly changed by alterations in chemical composition of physical properties, such as the type or concentration of plasticiser, anti-oxidant etc.; the intrinsic hardness or degree of surface finish. The addition of a repellant or hard filler to the sheathing material can also change the material's position in the classification, although to date no such formulation has fully come up to expectations. However as new insect repellants are developed they will certainly have to be evaluated, as this particular approach to the problem is by far the most economically attractive.

Until one of the acceptable synthetic materials has been proven to give near-complete protection to attack from insects, either due to the intrinsic properties of the material itself or by inclusion during manufacture of some additive, two other solutions are available. The one most favoured at present, because it has proved itself in practice, is the incorporation in the sheath structure of a continuous metal barrier, for instance a brass, bronze, steel or copper tape suitably protected from corrosion. If this method is uneconomic, consideration should be given to an outer plastic jacketing, such as Acetal, Nylon or Polycarbonate. In suitable circumstances soil treatment with insecticide emulsion or dusting of the cable ducts seems to hold considerable promise.

No general solution for the protection of telephone cables from insects is yet in existence, but present knowledge is now far enough advanced to be able to specify cable sheathing materials which will stand an excellent chance of resisting attack under the most hazardous conditions. The final selection will usually be a compromise between economic and performance factors, and hence a knowledge of the probability of attack in a given area is required, when such decisions are to be made.

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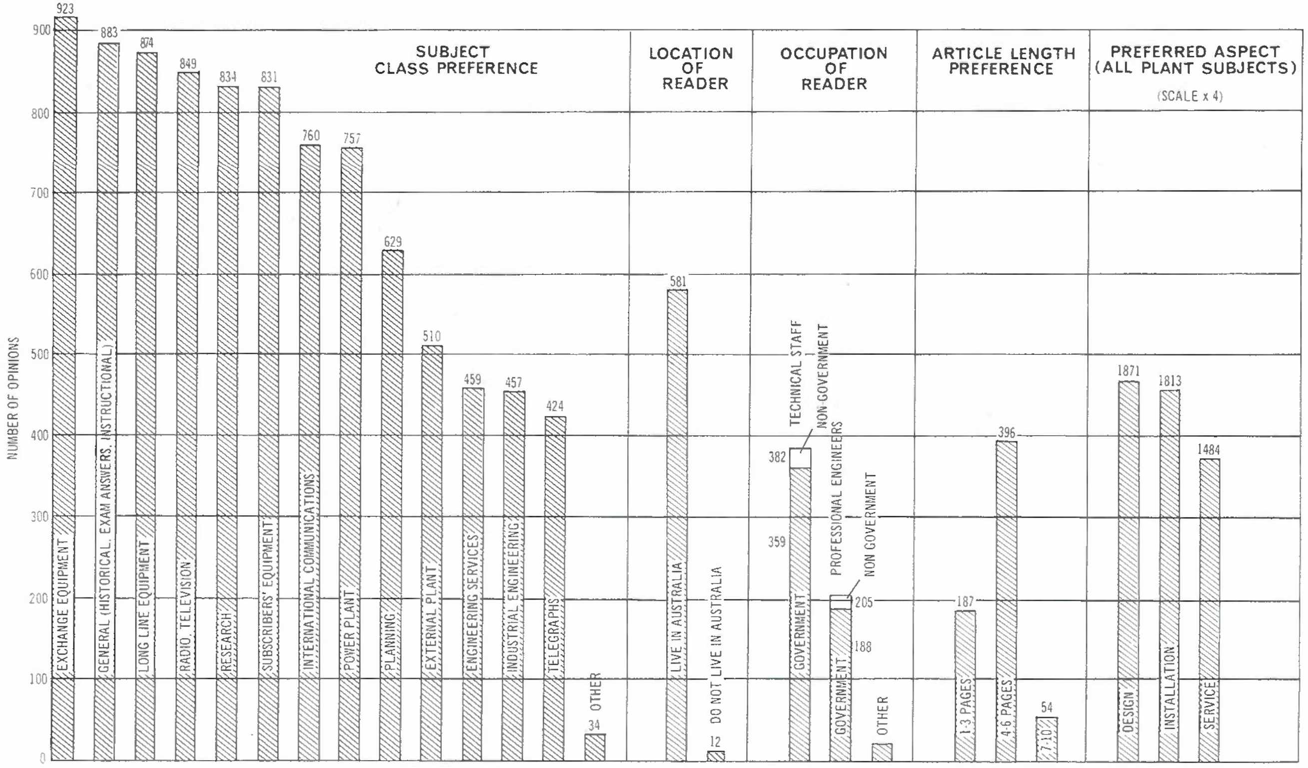
READER SURVEY

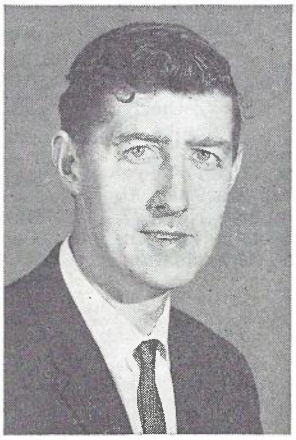
The following chart gives the results of the Reader Survey sent out with the October 1965 issue of the *Journal*. The co-operation of readers who returned the questionaire forms and the excellent work performed by agents and Society members who assisted in analysing the replies is gratefully acknowledged.

READER SURVEY, OCT, 1965



OUR CONTRIBUTORS

R. S. COLQUHOUN



A. H. O'ROURKE

H. O'CONNOR

P. C. C. WAY

R. S. COLQUHOUN, author of the article "Bush Fire Disaster — Southern Tasmania", is Supervising Engineer, Country Section, Tasmania. He joined the Postmaster-General's Department in New South Wales as a technician-in-training in 1938. After subsequently qualifying as an Engineer he was appointed as Group Engineer, Newcastle, where he was associated with the restoration of communication services following the serious Hunter Valley floods of 1949. In 1953 he was promoted to the position of Divisional Engineer, Burnie, Tasmania and in 1965 was promoted to his present position. Mr. Colquhoun is an Associate Member of the Institution of Engineers, Australia.

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A. H. O'ROURKE, co-author of the article 'A Coupling Unit for Telephone Conversation Recorders', served with the R.A.A.F. as a radar mechanic between 1942 and 1946 and joined the Postmaster-General's Department in 1949 as an adult technician-in-training, subsequently qualifying as a senior technician. Before completing a diploma course in radio engineering in 1958, he spent a number of years on technical work with different Commonwealth Departments. These positions included the production of geiger counters and associated equipment used in the search for uranium at the Bureau of Mineral Resources, and, at the laboratories of the Australian Atomic Energy Commission, the maintenance and construction of electronic instruments necessary for nuclear research. Mr. O'Rourke spent a further period at the Chemical Physics Laboratories of C.S.I.R.O. before rejoining the Postmaster-General's Department in 1960 as Engineer Grade 1. He was employed as a group engineer in the Metropolitan Service Section, Melbourne, before being appointed in 1965 to his present position as Class 2 Engineer in the Research Laboratories. He is a Graduate Member of the Institution of Engineers, Australia.

H. O'CONNOR, co-author of the article 'A Coupling Unit for Telephone Conversation Recording,' commenced as a telegraph messenger in the Postmaster-General's Department at Wangaratta, Victoria in 1935. In 1938 he became a junior mechanic and between then and 1951 when he qualified as an engineer at the P.M.G.'s Department Open Examination, he served five years in the Armed Forces and various periods as a senior technician, technical instructor and supervising technician. He gained experience in the Country Branch as a Class 1 Engineer, and experience in the Services Branch as a Class 2 Engineer in Materials Testing and Technical Training Divisions. Mr. O'Connor has been a Class 3 Engineer at the Postal Workshops in either a Production or Design Division since 1957.

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P. C. C. WAY, co-author of the article 'Rapid Testers for Step-by-Step Exchange Equipment', is an Engineer, Class 4, in the Metropolitan Branch N.S.W., Postmaster-General's Department. Mr. Way joined the Department as a Junior Mechanic in 1936. After completing a Departmental Cadetship in 1943 was appointed Engineer External Plant, Metropolitan Area, Sydney. Proceeded as Group Engineer to Wagga Wagga Division in April 1947, subsequently being appointed Divisional Engineer, Wagga Wagga in 1950. On returning to Sydney in late 1960, acted as Supervising Engineer, Southern Region (Country) until 1962. During 1962 joined Metropolitan Equipment Service as Engineer, Class 3, seeing service in two Divisions, Newtown and City, until 1964 when appointed as Engineer Class 4 in charge of Metropolitan Equipment Service. When the Metropolitan Branch Regional organisation was introduced in January 1966, took up present position as Engineer Class 4, Metropolitan Region (East).

Mr. Way is an Associate Member of the Institution of Engineers (Australia). For the past four years has been Secretary of the Telecommunication Society, N.S.W. Division. Has also been co-ordinator of N.S.W. material for publication in TELEGEN since its inception. He has been actively engaged in affairs of the Australian Postal Institute, being currently Senior Vice-President, N.S.W. Division, Chairman Sports and Social Committee.

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G. FLATAU, author of the articles 'Protection of Telephone Cables from Attack by Insects' and 'Reliable Contacts and Connections in Telecommunication Plant', joined the Postmaster-General's Department as a physicist in the Research Laboratories in 1951, and became Senior Physicist in 1960. His work has been concerned with the study of materials and components used in telecommunication plant, their behaviour under environmental stresses and the investigation of failure phenomena. Mr. Flatau made overseas study tours in 1957 and 1966. Since 1965 he has been Principal Officer in charge of the Physics and Polymer Sub-section in the Research Laboratories.

G. FLATAU

E. A. GEORGE

P. H. SPAFFORD

D. F. BANKS

E. A. GEORGE, co-author of the article, 'Standard Buildings for Automatic Exchange Equipment,' is an Engineer Class 3 in the Installation and Service Standards Sub-section of the Telephone Exchange Equipment Section at Headquarters. Prior to joining the Department in 1950 in Sydney, as an Engineer Class 1, he served an apprenticeship in the Signal and Telegraph Branch of the New South Wales Government Railways, and later as an Assistant Electrical Engineer on telecommunications equipment design. He gained his Electrical Engineering Diploma in 1949 at the Sydney Technical College. Mr. George was an Engineer Class 1 on subscribers' installation work and later, an Engineer Class 2 on P.A.B.X. and exchange installation activities in Sydney. In 1956 he was transferred to Metropolitan Internal Plant activities and was engaged on the development of network plans and major projects in the Sydney, Canberra and Wollongong networks. During this time, he was associated with the preparation of Departmental functional requirements for major building proposals including multi-storey building designs for Haymarket, Potts Point and Wollongong exchanges. In 1963 Mr. George was promoted to his present position and since then has directed the activities of a Sub-section engaged on the promulgation of exchange installation standards. He has been a member of a number of Headquarters Working Parties, many of which were of a joint consultative nature with other departments. He is an Associate Member of the Institution of Engineers and a Member of the Royal Institute of Public Administration.

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P. H. SPAFFORD, co-author of the article, 'Standard Buildings for Automatic Exchange Equipment,' is Principal Buildings Officer in the Works Programming and Buildings Sub-section of the Services Section at Headquarters. Mr. Spafford joined the Department in 1928 as a technician-in-training. He was later promoted as Cadet Draftsman in the drawing office in Adelaide and completed his course at the South Australian School of Mines in 1936. Mr. Spafford was lated promoted to the position of Draftsman Grade 2 in Melbourne in 1939, and subsequently transferred to Central Office in 1941 to take up a position as Sectional Draftsman. During the early days of the formation of the Buildings Branch Mr. Spafford was seconded for duty in this Branch as a Buildings Officer. He rose through the various ranks of this Branch to Principal Buildings Officer, to which position he was appointed in 1957. In his position as manager of the Buildings Section at Headquarters, Mr. Spafford has been closely associated with all the major building proposals implemented throughout the Commonwealth over a long period. He has worked in close association with executive architects in the Department of Works both at Headquarters and the State Branches. He has been a member of many committees and working parties both inter-departmental and intra-departmental on matters dealing with the Department's major building programme. He is an Associate Member of the Royal Institute of Public Administration.

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D. F. BANKS, author of the article, 'Newspaper Printing by Facsimile', has been responsible for the installation of facsimile systems throughout the world. He was one of the design team for the Sydney - Melbourne version and came to Australia to commission its installation. On his return he was promoted to his present position of Senior Engineer, Data Communications Systems. He holds the Higher National Certificate in Electronics.

ANSWERS TO EXAMINATION QUESTIONS

Examination Nos. 5631, etc. — 1st July, 1967 and subsequent dates, to gain part of the qualifications for promotion or transfer as Senior Technician (Telecommunications), Postmaster-General's Department.

TELECOMMUNICATION PRINCIPLES

QUESTION 1

(a) In the circuit in Fig. 1, the resistor Rx is adjusted until the current drawn from the battery is 100 mA. Assuming negligible battery resistance, calculate the value of resistance to which Rx has been adjusted.

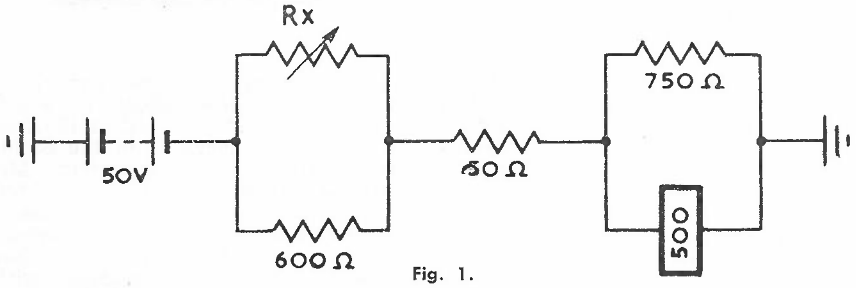


Fig. 1.

(b) Calculate the power being dissipated by the 500 ohm relay coil.

ANSWER 1

(a) The resistors are arranged in two parallel arms joined in series by series resistance of 50 ohms. The total resistance (R) is —

$$R = \frac{600\ Rx}{600+Rx} + 50 + \frac{500 \times 750}{500+750}$$

$$= \frac{600\ Rx}{600+Rx} + 50 + 300$$

$$= \frac{600\ Rx}{600+Rx} + 350 \quad \dots\dots\dots\dots (1)$$

Also $R = \frac{E}{I} = \frac{50}{100} + \frac{1000}{1}$

$$= 500 \text{ ohms} \quad \dots\dots\dots\dots (2)$$

Therefore

$$\frac{600\ Rx}{600+Rx} + 350 = 500$$

$$\frac{600\ Rx}{600+Rx} = 150$$

$$600\ Rx = 150 \times 600 + 150\ Rx$$

$$450\ Rx = 150 \times 600$$

$$Rx = \frac{150 \times 600}{450}$$

$$= 200 \text{ ohms}$$

(b) The resistance (Rca) to current flow in the circuit offered by the parallel arm containing the relay coil is—

$$Rca = \frac{500 \times 750}{500+750}$$

$$= \frac{500 \times 750}{1250}$$

$$= 300 \text{ ohms}$$

The voltage drop (Eca) across the parallel arm containing the relay coil is—

$$Eca = I.Rca = \frac{100}{1000} \times 300$$

$$= 30 \text{ volts}$$

The voltage drop across the parallel arm containing the relay coil (Eca) is the same as the voltage drop across the relay coil (Ec).

$$Eca = Ec = 30 \text{ volts}$$

Power (P) dissipated in the relay coil (Rc) is

$$P = \frac{Ec^2}{Rc} = \frac{30 \times 30}{500}$$

$$= 1 \cdot 8 \text{ watts}$$

Alternative Method

(a) The voltage drop (E50) across the 50 ohm resistor is—

$$E50 = I\ R = \frac{100}{1000} \times 50 = 5 \text{ volts}$$

The resistance (Rca) to current flow in the circuit offered by the parallel arm containing the relay coil is—

$$Rca = \frac{500 \times 750}{500+750}$$

$$= 300 \text{ ohms}$$

The voltage drop (Eca) across the parallel arm containing the relay coil is—

$$Eca = I.Rca = \frac{100}{1000} \times \frac{300}{1} = 30 \text{ volts}$$

Total applied voltage (E) is equal to the sum of the voltage drops around the circuit—

$$E = Erx + E50 + Eca$$

(where Erx is the voltage drop across the parallel arm containing the unknown resistance Rx).

$$E = Erx + 5 + 30$$

$$= Erx + 35$$

The applied voltage E = 50 volts

Therefore

$$Erx + 35 = 50$$

and Erx = 15 volts which is also the voltage drop across both the 600 ohm resistor and across Rx.

Current flowing in the 600 ohm resistor (I 600) is

$$I\ 600 = \frac{Erx}{600} = \frac{15}{600} \times \frac{1000}{1}$$

$$= 25 \text{ milliamps}$$

Current flowing in Rx is

$$Irx = I - I\ 600 = 100 - 25$$

$$= 75 \text{ milliamps}$$

Therefore

$$Rx = \frac{Erx}{Irx} = \frac{15}{75} \times \frac{1000}{1}$$

$$= 200 \text{ ohms}$$

(b) Power (P) dissipated in the relay coil (Rc)

$$P = \frac{Ec^2}{Rc} = \frac{30 \times 30}{500} = 1 \cdot 8 \text{ watts}$$

EXAMINER'S COMMENT:

Candidates who failed to obtain full marks in this question often did so through attempting to work out the problem mentally instead of setting out each step. This resulted in faulty reasoning. For example, a number of candidates made their calculation on the basis that current splits over two parallel paths in direct proportion to the resistance of the path (e.g. $I \propto R$) when in fact it is inverse proportion to the path resistance (e.g. $I \propto 1/R$).

QUESTION 2

(a) It is required to INCREASE the RELEASE TIME of a relay by external modification of its circuit. State four ways in which this can be done, naming the additional component(s) and/or contacts and how they are connected.

(b) Explain with the aid of sketches how a NORMAL operating relay can be converted to a SLOW OPERATING-NORMAL RELEASE relay.

ANSWER 2

(a) Any four of the following —

- (i) Parallel capacitor — capacitor connected in parallel to coil winding,
- (ii) Parallel resistor — resistor connected in parallel to coil winding,
- (iii) Parallel rectifier — rectifier connected in parallel to coil winding so as to provide a path for the current due to the induced e.m.f. when the relay circuit is opened,
- (iv) Short circuited winding — additional short circuited winding on relay,
- (v) Short circuited winding through a MAKE contact — additional coil on relay with a contact which makes when the relay is operated and gives a short circuited winding when the relay circuit is opened.

(b) A complete answer to this part of the question will be found in the Course of Technical Instruction Miscellaneous Note MG 101 — Relays, Page 5.

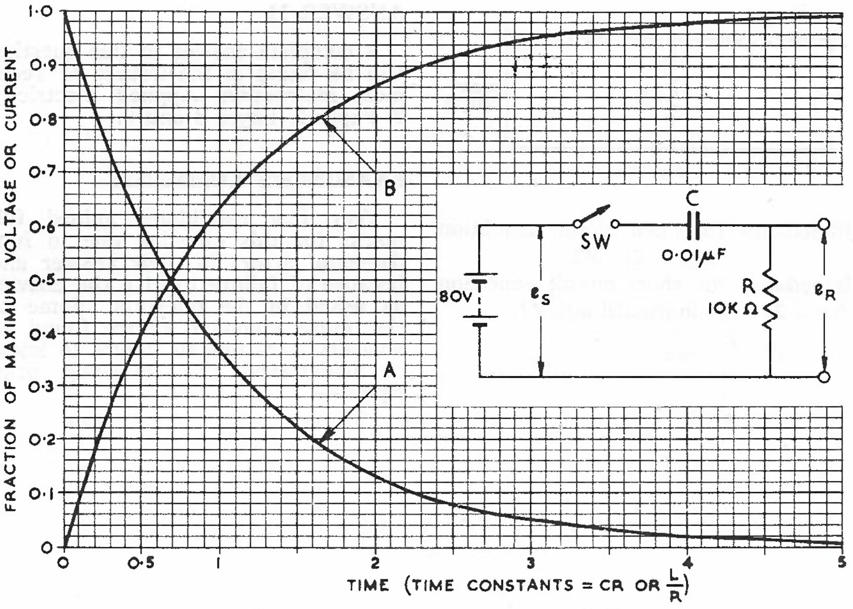
EXAMINER'S COMMENT

Part (a) was generally well answered.

Part (b) was poorly answered by many candidates and the answers given often showed that they did not understand WHY their answers to Part (a) were correct. Candidates generally should give more consideration to the ways in which currents due to induced e.m.f.'s in electro-magnetic circuits can be used to advantage.

QUESTION 5

(a) Using the universal time constant chart and the circuit shown in Fig. 2, find the value of voltage (e_R) across the resistor after the switch has been closed for 250 µS. (All estimations, readings and calculations must be stated in your answer.)



UNIVERSAL TIME CONSTANT CHART

Fig. 2.

(b) Draw the shape of the pulse produced in the circuit showing the values of e_R.

ANSWER 5

A complete answer to this question will be found in the Course of Technical Instruction Course Paper CP 308, Introduction to Pulse Techniques, Page 22.

EXAMINER'S COMMENT:

A large number of candidates lost marks because of their failure to state all estimations and readings as well as calculations in their answer as asked for in the question. Also candidates lost marks for incorrect use of the time scale of the Universal Time Constant Chart. The time in microseconds for which the circuit was closed was often used instead of the number of time constants when reading the chart.

QUESTION 6

(a) Describe briefly what is meant by the term 'Relaxation Oscillator'. Name the three classes of relaxation oscillators and briefly state the characteristic of each.

(b) In the space below, draw the circuit of a typical BINARY type of two stage oscillator which can be used for the generation of square waves or pulses.

ANSWER 6

(a) An oscillator circuit whose output wave form is nonsinusoidal is classified as a relaxation oscillator. The relaxation oscillator uses resistance-capacitance or resistance-inductance components in the feedback circuit to provide the switching action.

The three classes and characteristic of each class of relaxation oscillator are as follows:—

(i) **ASTABLE** or "free running" which produce a continuous output with or without external synchronising signals.

(ii) **MONOSTABLE,** "one shot" or "start-stop" which stay in a stable state until an external signal is applied and which return to the original state in a fixed time interval after the signal is removed.

(iii) **BISTABLE,** "flip-flop" or "binary" which have two different quiescent or stable states and remain in either one until changed to the other state by an external signal.

(b) A typical circuit of the BINARY or BISTABLE multivibrator is given in the Course of Technical Instruction Miscellaneous Note MG 211, Transistor Oscillators, Page 15.

EXAMINER'S COMMENT:

A number of candidates did not attempt this compulsory question. Part (a) was well answered by most candidates who did submit an answer. Many candidates gave a typical circuit of an ASTABLE multivibrator instead of the required BINARY type.

QUESTION 9

(a) What is the meaning of the expression dBm? State its relationships to the expression dB.

(b) Calculate the following:

(i) The power ratio represented by an amplifier of 15 dB.

(ii) The input power to an amplifier of 15 dB gain if the output power is 4 watts.

(iii) Express 8 milliwatts in dBm.

(iv) Express -9 dBm in milliwatts.

ANSWER 9

(a) The dBm expresses the power level of a steady single frequency as a number of decibels ABOVE or BELOW the specified reference level of 1 milliwatt. The dBm is independent of both frequency and circuit impedance.

The dB expresses the ratio of two powers in a logarithmic manner. The dB and dBm functions overlap when one of the power levels in the dB ratio is 1 milliwatt, since the dBm reference is 1 milliwatt.

(b) (i) NdB = 10 log of power ratio

Therefore, 15 = 10 log of power ratio

$$\text{Log of power ratio} = \frac{15}{10} = 1.5$$

$$\text{Power Ratio} = \text{Antilog } 1.5$$
$$= 31.62$$

(ii) In this case,

$$\text{Power Ratio} = \frac{\text{Output Power}}{\text{Input Power}}$$

because the Output Power is larger than the Input Power due to the amplifier in the circuit.

Therefore,

$$31.62 = \frac{4}{\text{Input Power}}$$

$$\text{Input Power} = \frac{4}{31.62}$$
$$= 0.1265 \text{ watts}$$
$$= 126.5 \text{ milliwatts}$$

$$\text{(iii) NdB} = 10 \log \frac{P1}{P2}$$
$$= 10 \log \frac{8}{1}$$
$$= 10 \times 0.9031$$
$$= 9.031$$

Therefore 8 milliwatts = +9dBm

$$\text{(iv) NdB} = 10 \log \frac{P1}{P2}$$

In this case the -9 dBm signifies that the level is BELOW the reference level of 1 milliwatt.

Therefore,

$$9 = 10 \log \frac{1}{P2}$$

$$0.9 = \log \frac{1}{P2}$$

$$\frac{1}{P2} = \text{antilog } 0.9$$
$$= 7.9343$$

$$P2 = \frac{1}{7.9343}$$
$$= 0.125 \text{ mW}$$

Answers (i) 31.62
(ii) 126.5 milliwatts
(iii) + 9 dBm
(iv) 0.125 milliwatts

EXAMINER'S COMMENT:

(a) Many candidates lost marks for failing to state the relationship between dB and dBm in their answer as asked in the question.

(b) The main errors made by candidates in answering this part were reflected in their lack of understanding of the meaning of dBm as being a power level ABOVE or BELOW the reference level of 1 milliwatt. These candidates correctly calculated that 8 milliwatts was equal to 9 dBm but wrongly assumed that correspondingly -9 dBm was equal to 8 milliwatts also.

Some candidates did not appear to understand the meaning of the term power ratio as applied to this question.

QUESTION 10

With reference to the equivalent circuit of a transmission line shown in Fig. 3.

(a) Draw the equivalent 'T' Section of the line.

(b) State what length of line the circuit represents.

(c) What Secondary Constant of the line does Z_O represent?

(d) Using the formula

$$Z_O = \surd Z_{OC} \times Z_{SC}$$

where Z_{OC} = Open circuit Impedance

Z_{SC} = Short circuit Impedance

express Z_O in terms of Z_1 and Z_2.

(e) Calculate the value of Z_O of an attenuator where $Z_1 = 20\ \Omega$ and $Z_2 = 80\ \Omega$.

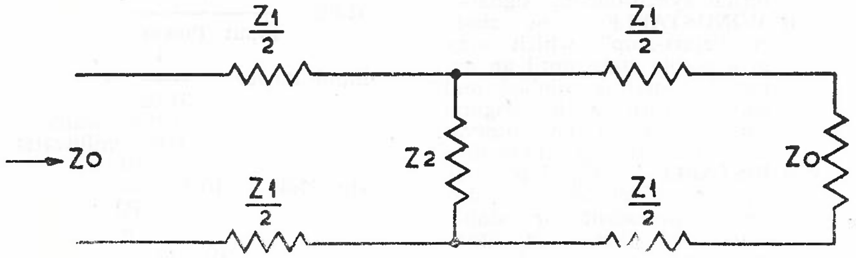


Fig. 3.

ANSWER 10

(a) See Fig. 4.

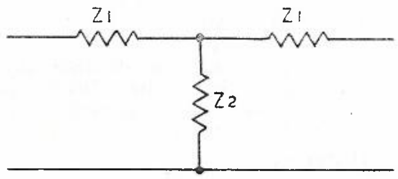


Fig. 4.

(b) Any length from a few feet to infinity.

(c) Characteristic Impedance.

(d) Referring to Fig. 4, the circuit conditions for Zoc and Zsc are as shown in Fig. 5a and 5b.

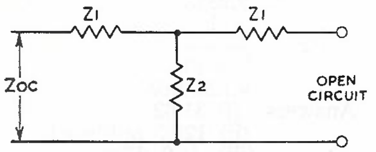


Fig. 5a.

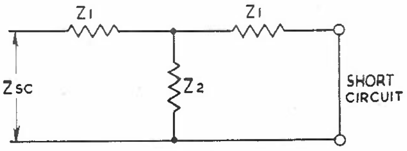


Fig. 5b.

Impedance for open circuit condition

$$Zoc = Z1 + Z2$$

Impedance for short circuit condition

$$Zsc = Z1 + (Z1 \text{ in parallel with } Z2)$$

$$= Z1 + \frac{Z1 \times Z2}{Z1 + Z2}$$

$$Zo = \sqrt{Zoc \times Zsc}$$

$$= \sqrt{(Z1+Z2)\left(Z1 + \frac{Z1 \times Z2}{Z1+Z2}\right)}$$

$$= \sqrt{Z1^2 + \frac{Z1^2 \times Z2}{Z1+Z2} + Z1.Z2 + \frac{Z1 \times Z2^2}{Z1+Z2}}$$

$$= \sqrt{Z1^2 + Z1.Z2 + Z1.Z2\left(\frac{Z1+Z2}{Z1+Z2}\right)}$$

$$= \sqrt{Z1^2 + 2Z1.Z2}$$

(e)

$$Zo = \sqrt{Z1^2 + 2Z1.Z2}$$

$$= \sqrt{(20)^2 + 2 \times 20 \times 80}$$

$$= \sqrt{400 + 3200}$$

$$= \sqrt{3600}$$

$$= 60 \text{ ohms}$$

QUESTION 11

(a) Draw the typical vector diagrams of the circuit in Fig. 6, showing graphically the method by which the phase angle can be calculated. ($E_L > E_C$.)

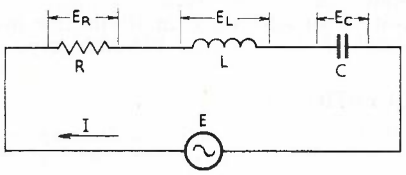


Fig. 6.

(b) Show with the aid of vector diagrams how the IMPEDANCE DIAGRAM can be obtained for the circuit.

ANSWER 11

A complete answer to this question will be found in the Course of Technical Instruction, Applied Electricity 2, Paper 2, Pages 8 and 9.

EXAMINER'S COMMENT:

Very few candidates gained full marks for this question due to fundamental errors in their answer and because of failure to give the answer as asked in the question. Some of the more common errors found in answers were due to failure to know or understand the following principles:—

(i) Vector rotation is assumed to be anticlockwise in direction and this indicates leading or lagging phase relationships.

(ii) $E_L > E_C$ means that E_L is greater than E_C.

(iii) Current lags the voltage in inductive circuits.

(iv) Phase Angle is the angle θ in degrees and is not Tan θ or Cos θ.

(v) Voltages in a SERIES circuit are referred to a common current reference vector.

QUESTION 12

A PARALLEL circuit contains 20 ohms resistance, 10 ohms inductive reactance, and 30 ohms capacitive reactance. An alternating voltage of 6 volts is applied to the circuit.

(a) Draw the circuit diagram.

(b) Calculate:

(i) the impedance;

(ii) the phase angle.

(c) Draw a vector diagram to show the current distribution in the circuit.

ANSWER 12

The complete answer to this question will be found in the Course of Technical Instruction Book, Applied Electricity 2, Paper 3, Page 7.

EXAMINER'S COMMENT:

Many candidates attempted to solve the problem as though it was a SERIES circuit even though they correctly drew the diagram as a PARALLEL connection of components. It is strongly recommended to candidates when answering questions of this type to always draw the vector diagram first keeping in mind the following principles:—

(i) In SERIES circuits the current vector is the common reference vector.

(ii) In PARALLEL circuits the voltage vector is the common reference vector.

If this is done, formulae do not require to be remembered as they can easily be derived from the vector diagram.

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Answers to Examination Questions

	Examination		Journal	
	Date	**No.**	**No.**	**Page**
Senior Technician Telephone Section 2 — Long Line Equipment	July, 1965	5364	1	78
Senior Technician Telecom Principles	July, 1966	5482	1	79
	July, 1967	5631	3	258
Telephone Equipment	July, 1966	5482	1	80
Senior Technician Telegraphs Telegraph Equipment	July, 1966	5483	2	173

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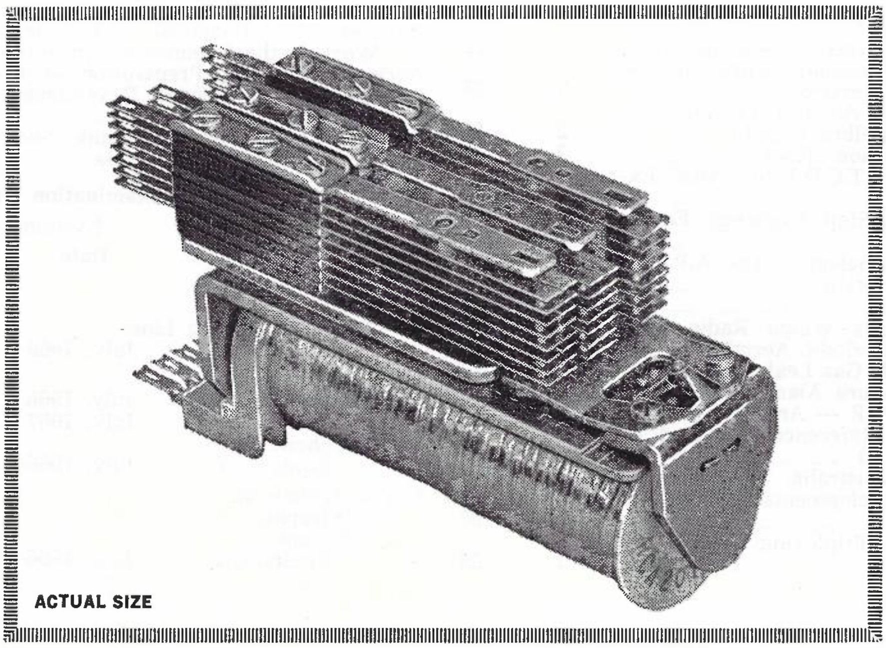

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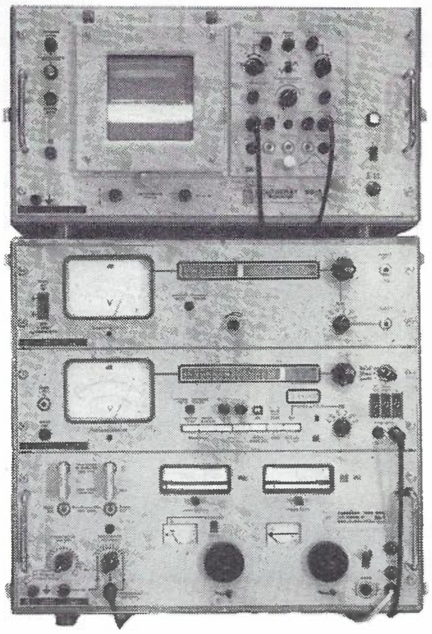

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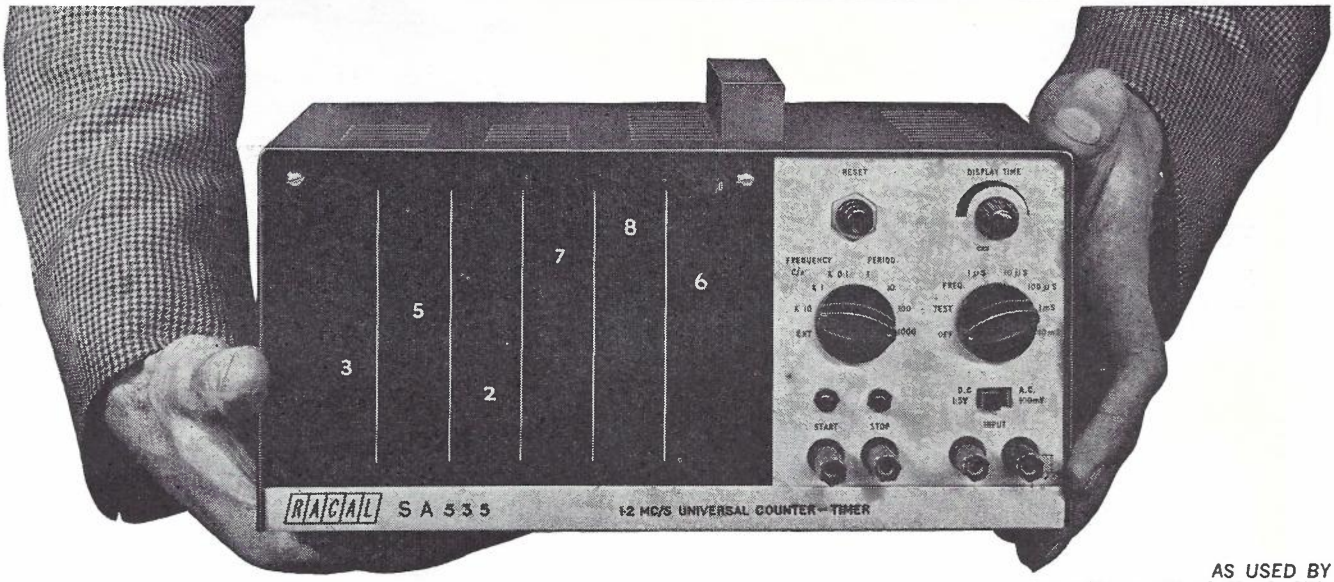
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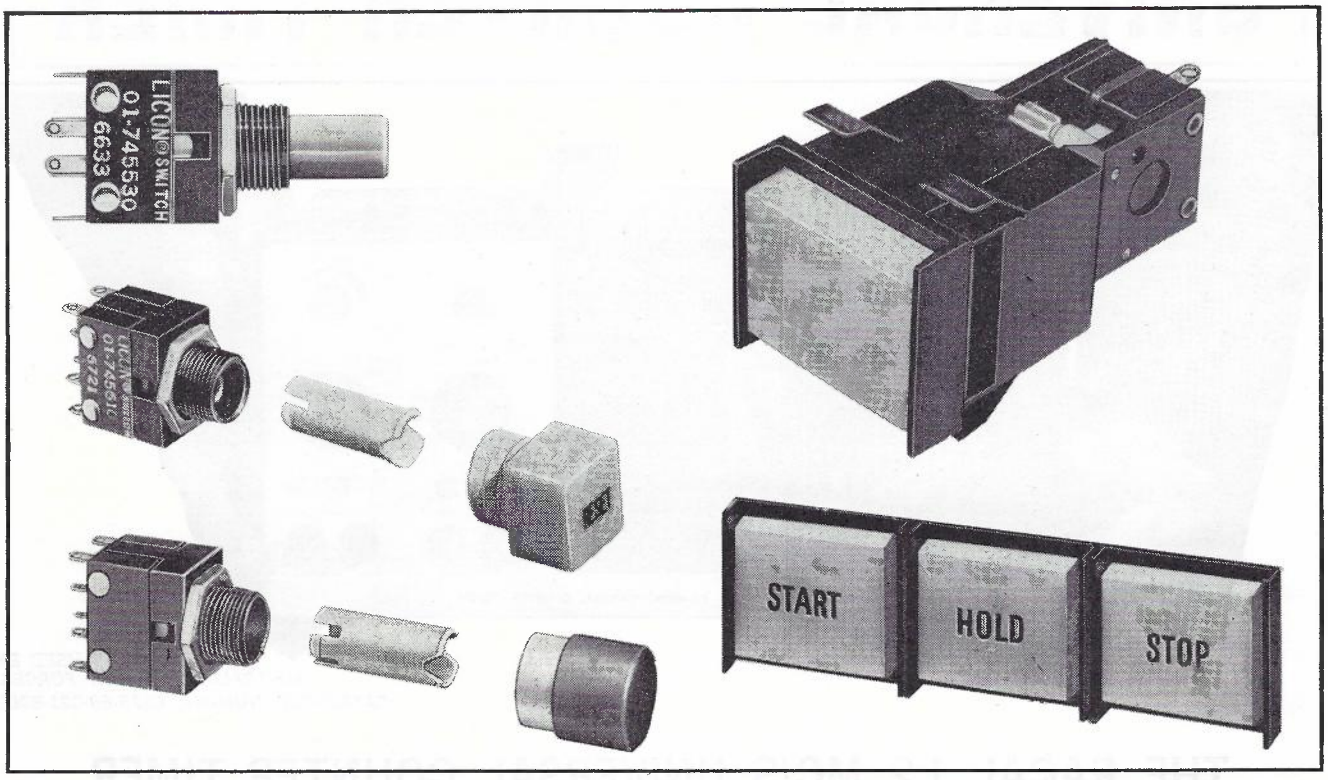

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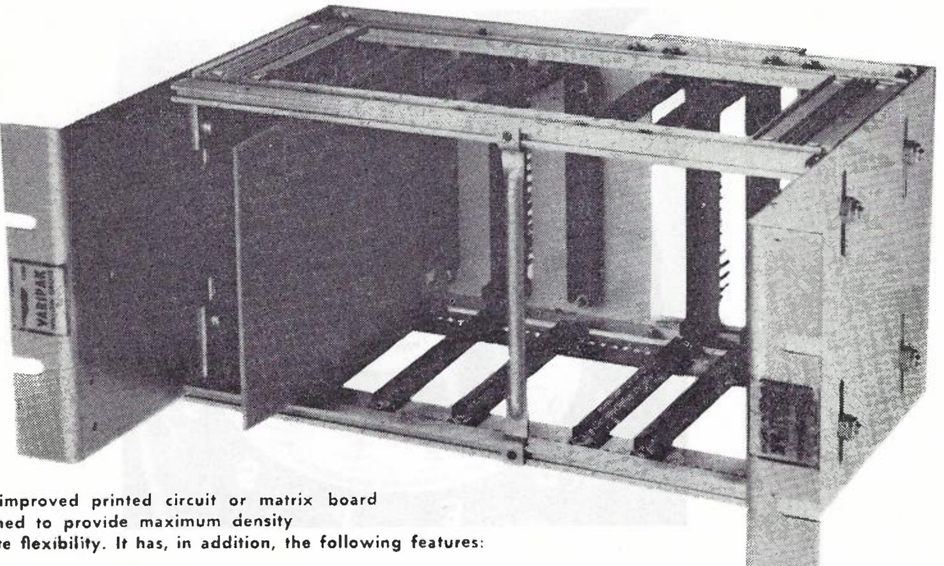

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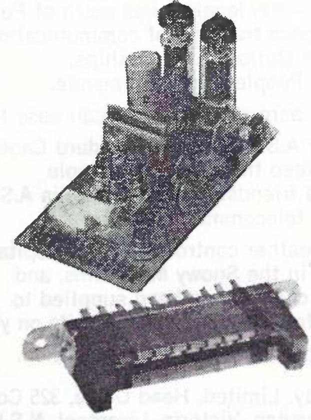

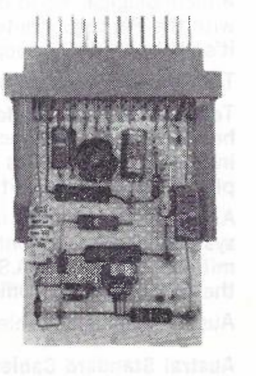

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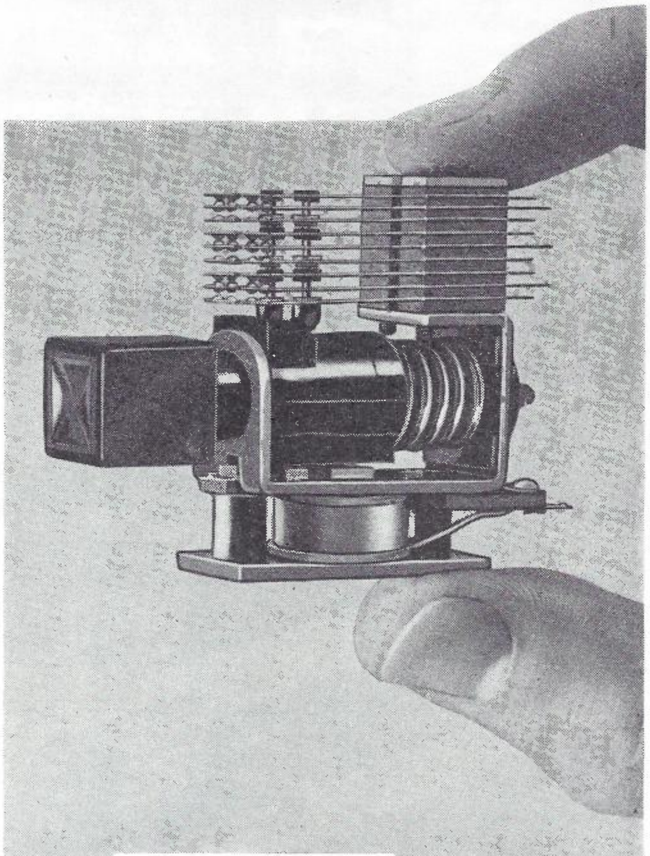

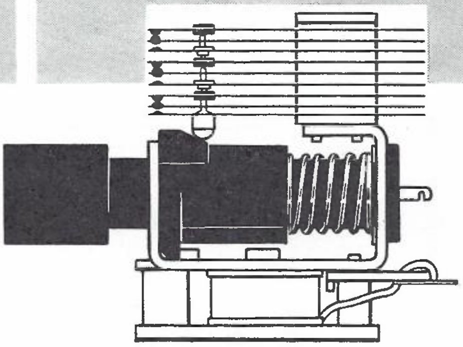

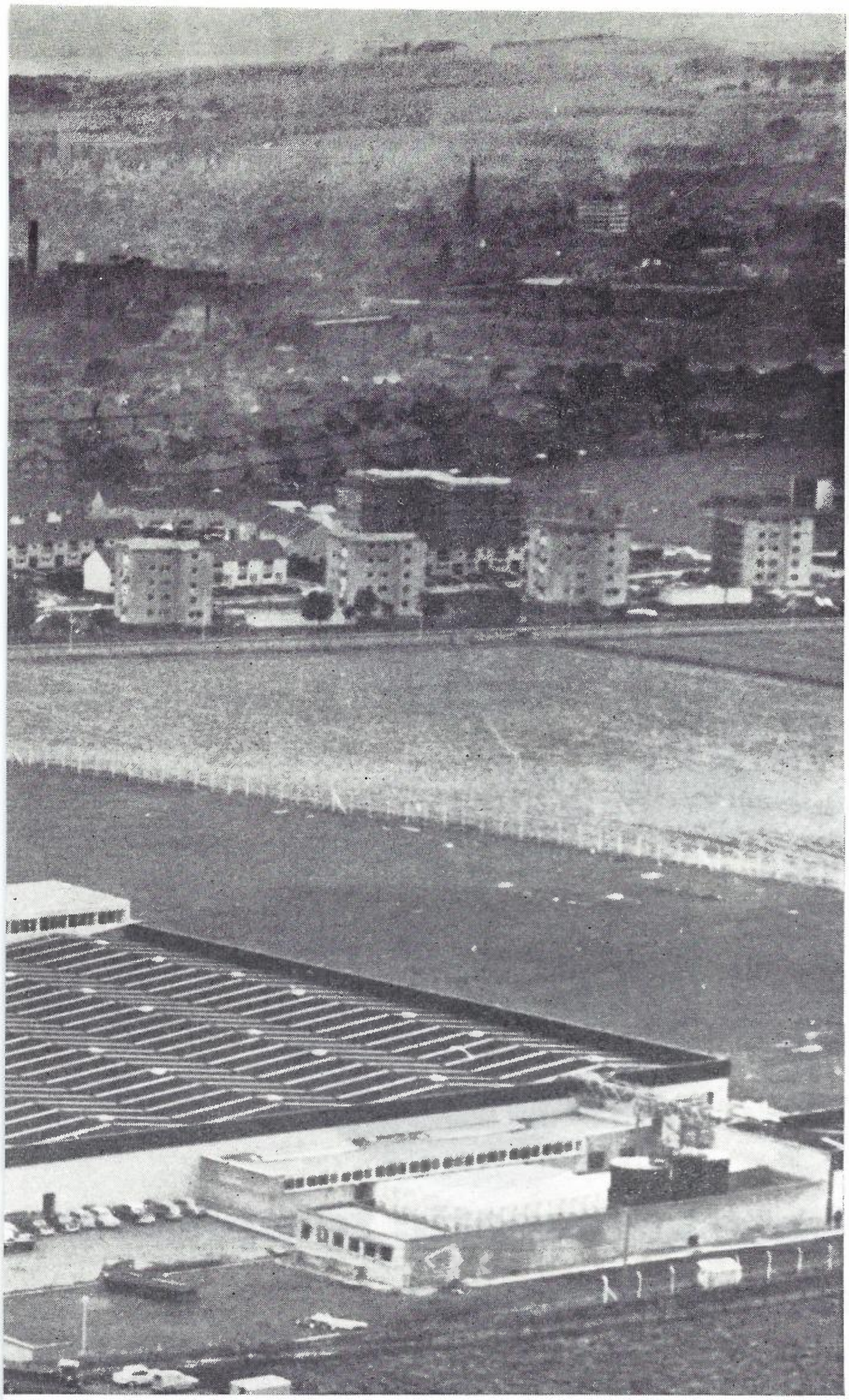

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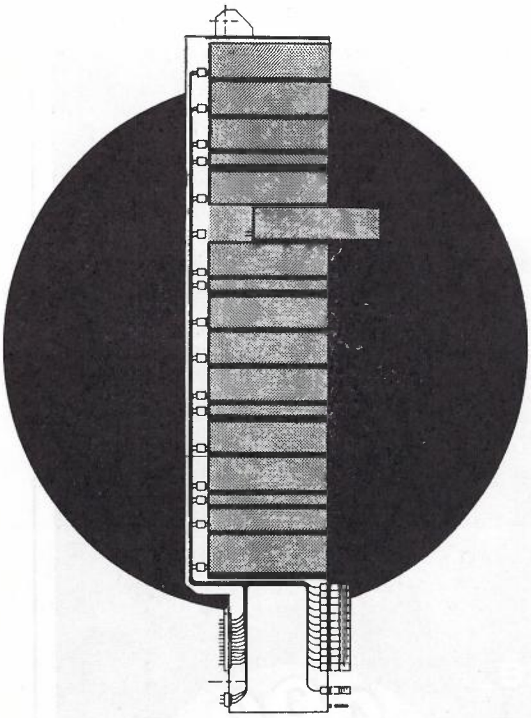
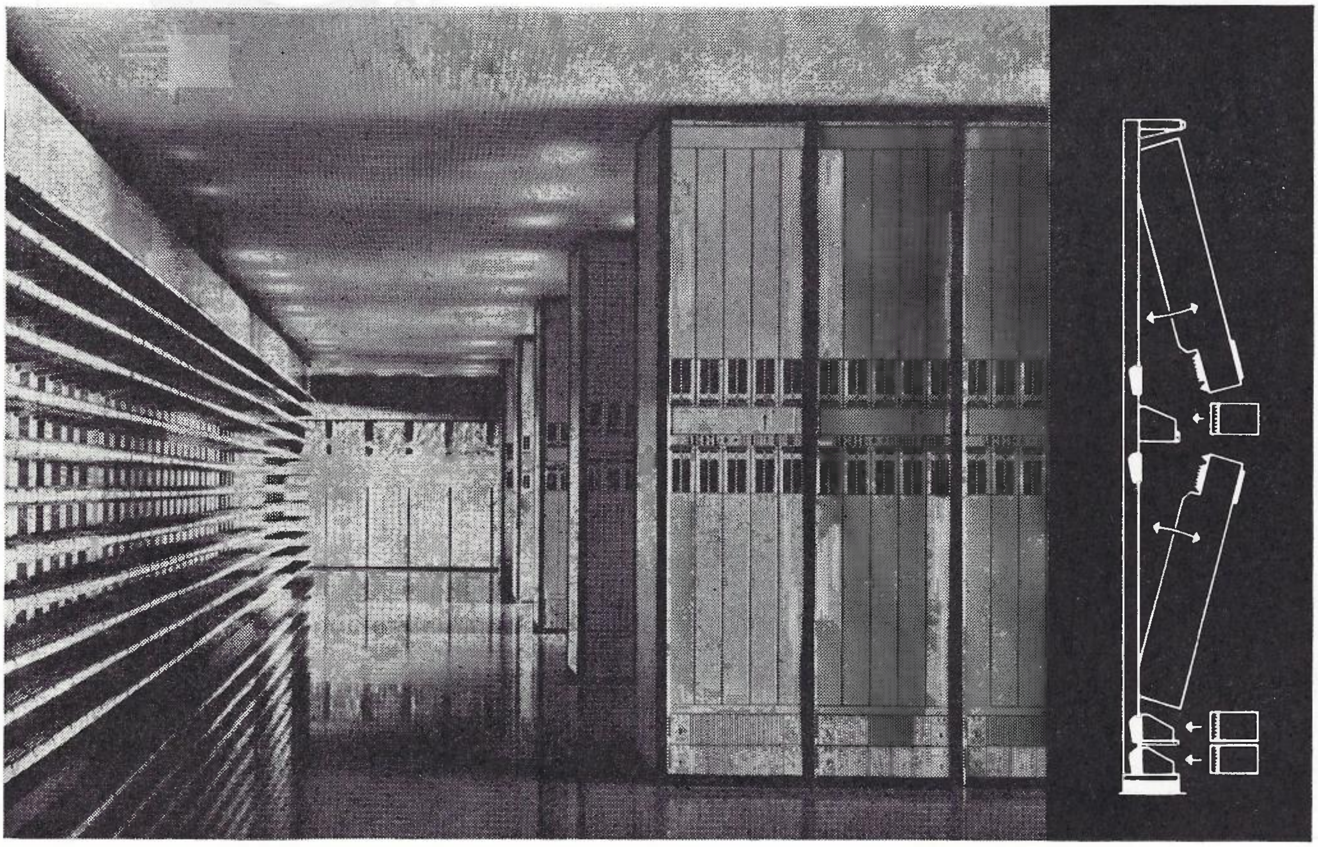
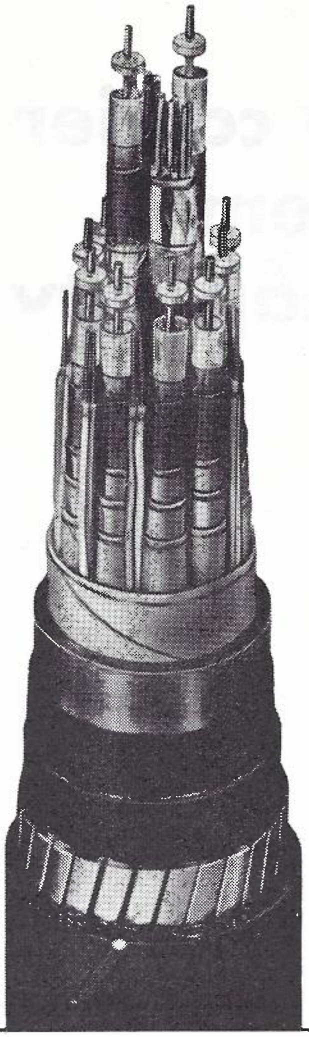






SIEMENS

Underground Repeater Stations for Coaxial Cables

facilitate planning and simplify operations

Telecommunications Cables

with coaxial tubes 1.2/4.4 and 2.6/9.5 mm — coaxial tubes and cable make-up to suit any application.

Improved reliability of the cable systems by monitoring with the Siemens gas pressure alarm system.

Underground Containers for these Cables

for direct underground installation — no buildings needed.

Easy installation. High immunity to damage.

Two types: for a maximum of three and a maximum of six repeater insets.

Repeater Insets

Standard design for carrier systems V300, V960 and V2700 — easy to exchange.

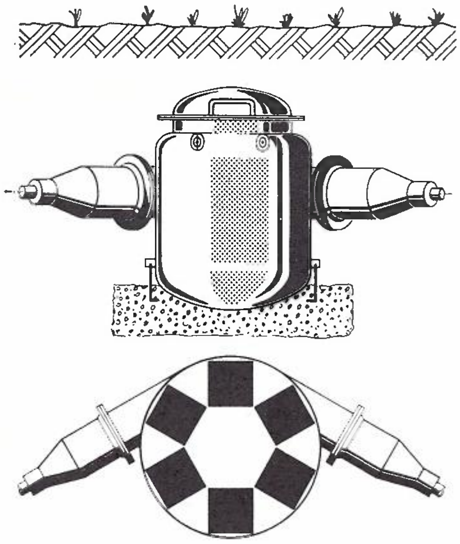
Power-feeding over the cable, and remote supervision.

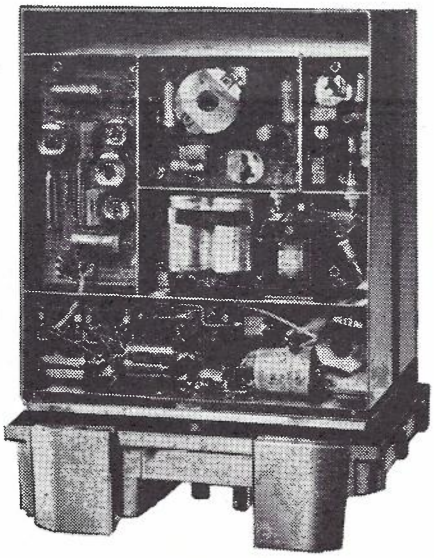
Level regulation by simple temperature control.

Tripling of the channel capacity with each halving of the repeater section lengths.

Applications in Australia

Siemens universal repeater insets not only fit into the Siemens containers illustrated, but also into the smaller containers designed by the APO for applications in Australia with locally made coaxial cable. Siemens coaxial transmission equipment is on order for a number of routes in Australia, amongst them the 600-mile Perth/Carnarvon link in Western Australia.





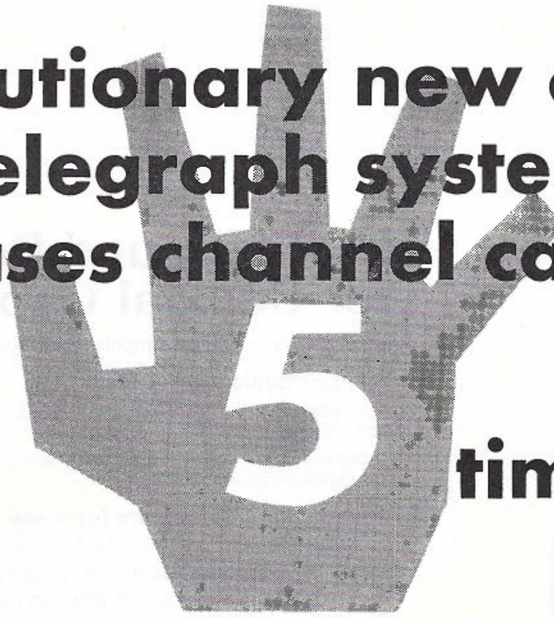
For additional information contact

Siemens Industries Limited

544 Church Street, Richmond, Victoria. 42 2371
Branches at Sydney, Brisbane, Newcastle

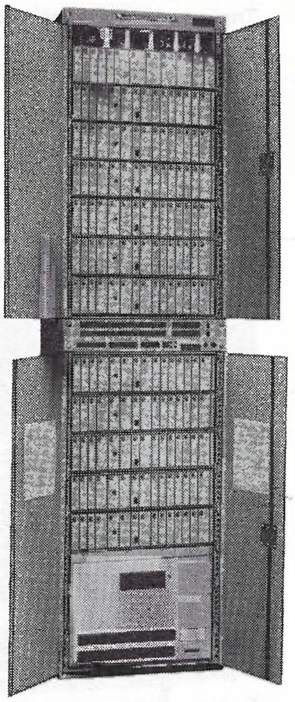
241-203-401

Revolutionary new carrier telegraph system increases channel capacity



times!

"RECTIPLEX" from FUJITSU



Where transmission costs are high or frequency band width limited, the demand for more communications channels becomes pressing.

FUJITSU's epoch-making RECTIPLEX multi-channel telegraph system, developed with the cooperation of KDD, Japan's overseas radio and cable system, was designed to meet this need. Transmission speed is 5,400 bits/sec on a single voice channel with nearly an ideal error rate. Capacity is 108 telegraph channels per voice channel. America's RCAC and ITT World Communications Inc. have already contracted to install FUJITSU RECTIPLEX systems in 1968 between Japan and the U.S.

To modulate three binary channels onto one carrier, the RECTIPLEX system shifts the phase of the carrier by some multiple of 45° depending on the state of the binary inputs. These binary inputs may have any one of eight possible combinations, corresponding to the eight possible 45° shifts. The phase for a particular signal combination is established relative to the phase of the preceding signal. The system therefore employs differential phase modulation which provides excellent performance with respect to noise and line interruption. The RECTIPLEX system uses no band-pass filter. The filtering function is performed by an integrator with a reset function, enabling efficient demodulation and utilizing the active channel bandwidth.

This system has transmission capacity five times that of conventional systems. It can transmit not only a 50-baud signal but also 75-baud and 1200-baud signals. Employment of differential phase modulation provides excellent performance with respect to noise and line interruption.

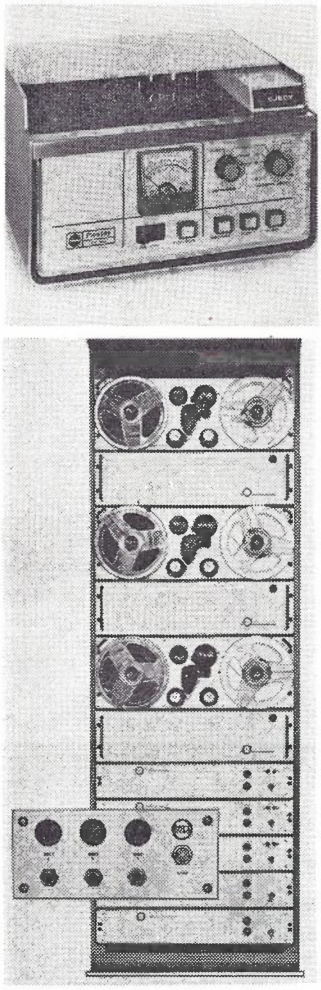
This is just one recent example of the many contributions FUJITSU has made to the field of modern communications.

FUJITSU LIMITED
Communications and Electronics
Marunouchi, Tokyo

MAIN PRODUCTS: ☐ Telephone Exchange Equipment ☐ Telephone Sets ☐ Carrier Transmission & Radio Communication Equipment ☐ Remote Control & Telemetering Equipment ☐ Telegraph & Data Communication Equipment ☐ Electronic Computers & Peripheral Equipment (FACOM) ☐ Automatic Control Equipment (FANUC) ☐ Electric Indicators ☐ Electronic Components & Semiconductor Devices

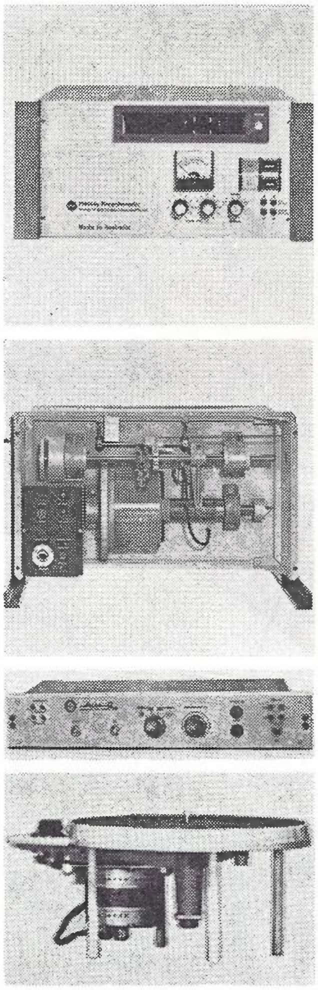
PLESSEY

A fully comprehensive range of broadcast and telecommunication equipment is available for professional and industrial applications. Many of the units described below have been developed as a result of the close collaboration established by Rola engineers with their major customers — the Broadcasting and TV industry, the Australian Post Office and the Services. The latest advances in transistorisation and modular construction are utilised, and continuous development ensures the addition to the Rola range of the newest and most up-to-date equipments.

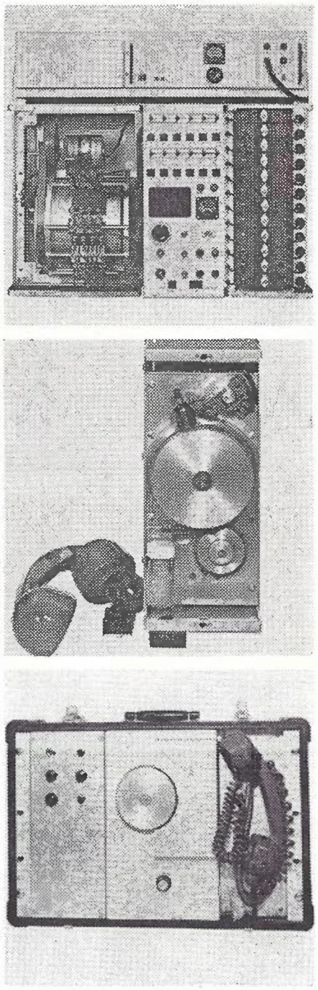


The desk-mounted **Record/Replay CT80 Cartridge Recorder** — for broadcast applications. The **Auto Station** — provides low-cost, automatic programming using multiple pre-recorded programme sources. The **Remote Control Panel** — for Auto Station operation.

The **Model 707 Solid State Studio Console** — superlative facilities include high fidelity sound reproduction. The **Model 66 Mk.II Portable Tape Recorder** — for general purpose, high quality recording. The transportable **Model 77 Mk.III Professional Studio Tape Recorder** — a high grade unit with every facility.



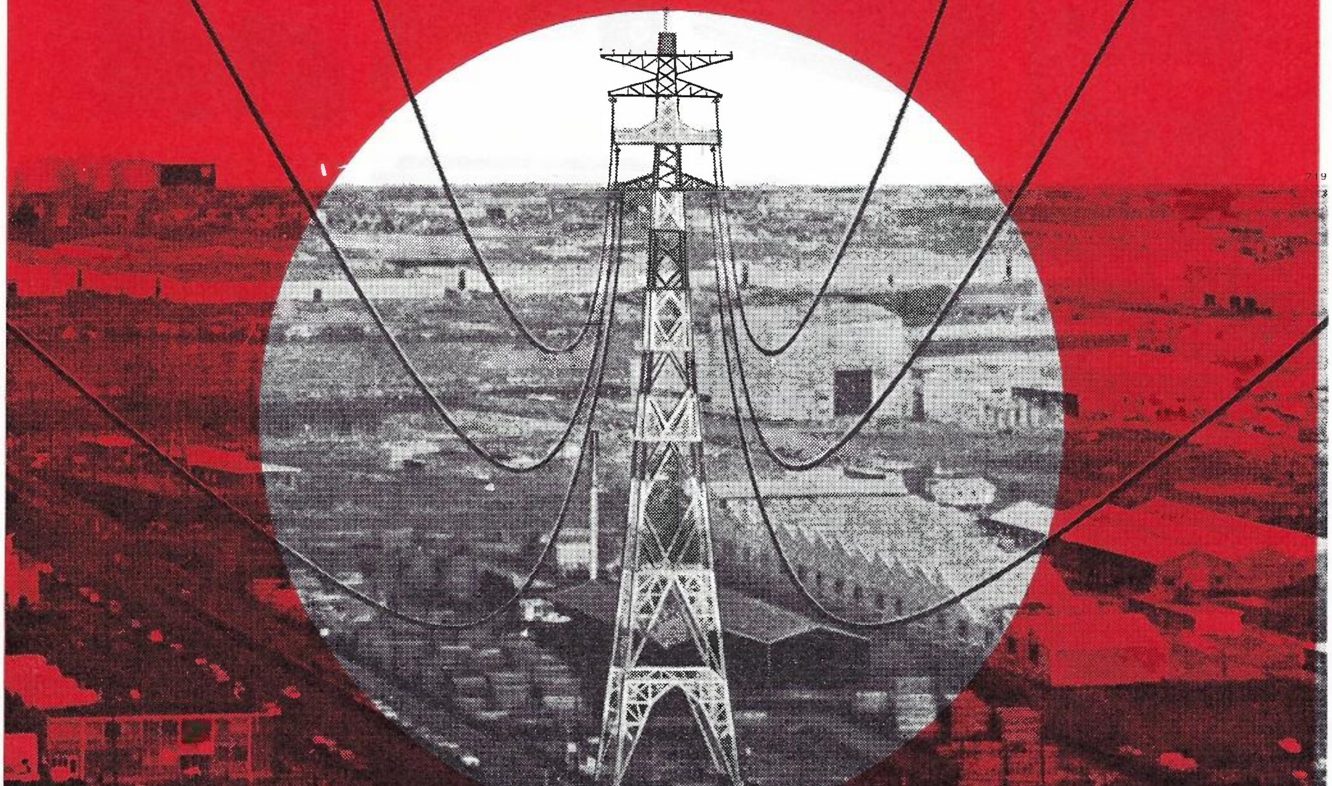
The rack-mounted, **Record/Replay CT80 Cartridge Recorder.** The **Variable Message Repeater** — a heavy-duty drum announcement unit for telephone information services. The **Rola Auto-Q** — for low cost automatic tape cueing facilities. The professional, heavy-duty 4 speed **Studio Turntable.**

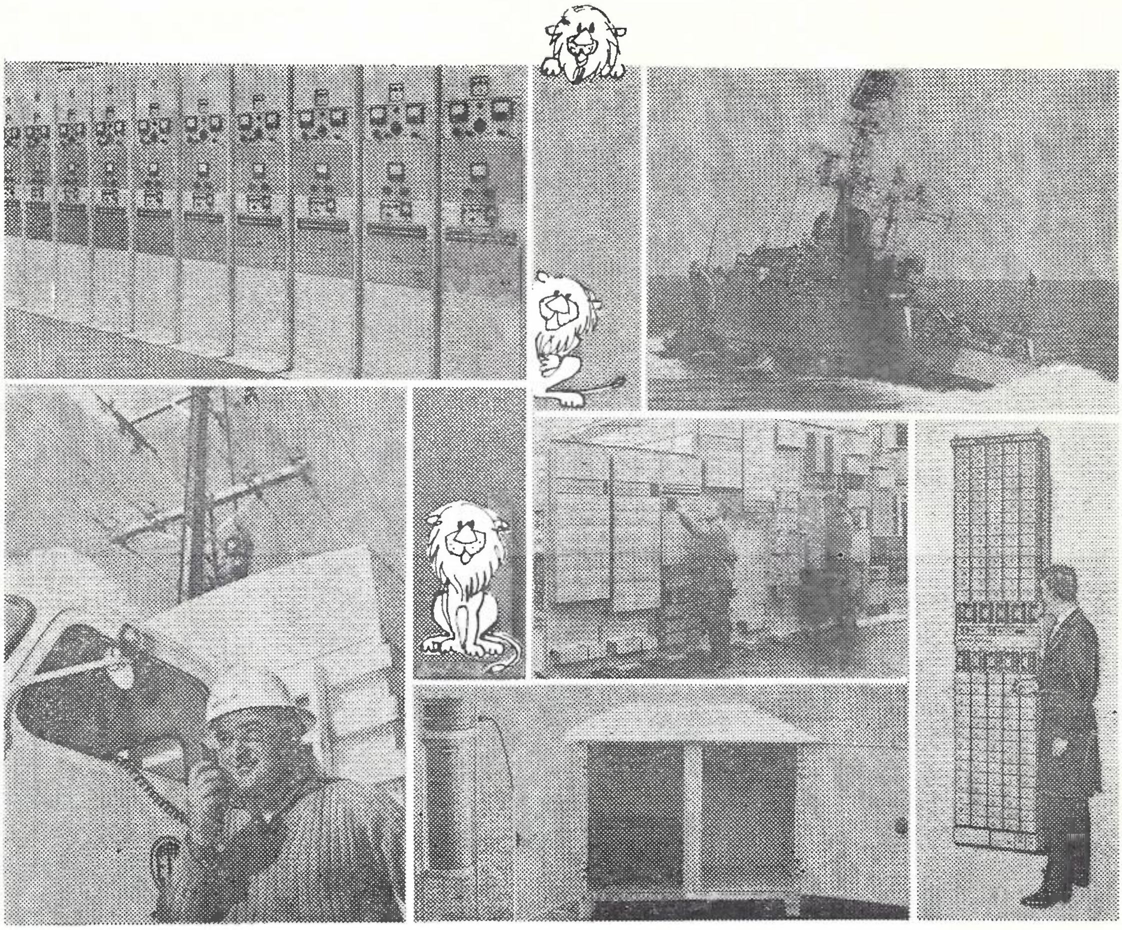


The **Automatic Verbal Telephone Announcing Equipment** — a drum announcing unit with up to 24 track capacity for 15 second messages. The **Auto Announcer Mk.II Play and Record Units** — suitable for short duration messages over a telephone system. Extremely economical and flexible.

Complete details of units currently available as well as advance information concerning new products may be obtained from:

Plessey Components Group
Rola Division The Boulevard
Richmond Victoria Telephone 42 3921
NSW Plessey Components Group Rola Division Box 2 PO Villawood Telephone 72 0133





Complete Earth-station by Collins

The Overseas Telecommunications Commission (Australia) selected Collins to provide a satellite communications ground station at Moree.

Collins' total systems approach, including specially designed modular building construction, offers the most efficient solution available for earth station needs — whether the station requires limited movement antennas for use with synchronous satellites, or a horizon-to-horizon capability for tracking medium altitude satellites.

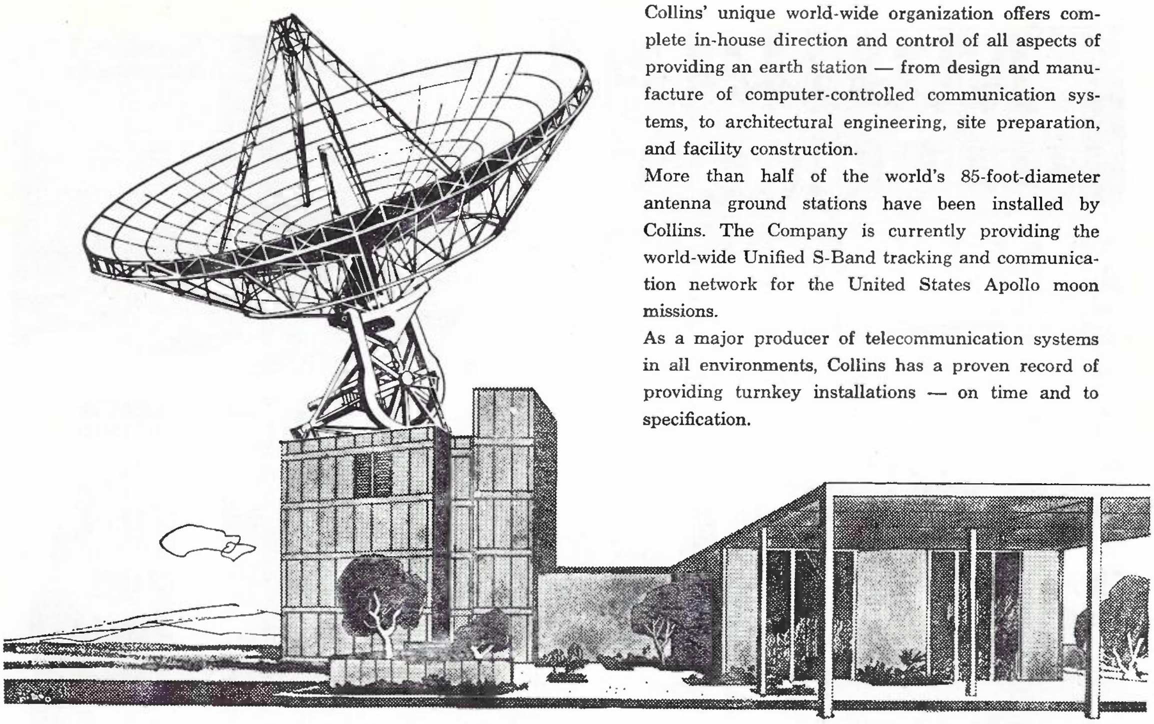
In microwave — the basic mode for satellite communications — Collins offers superior capability based on long experience as the largest independent microwave manufacturer in the United States.

Collins' approach to earth station design includes implementation of advanced communication/computation techniques that provide automatic control of a station's entire system.

Collins' unique world-wide organization offers complete in-house direction and control of all aspects of providing an earth station — from design and manufacture of computer-controlled communication systems, to architectural engineering, site preparation, and facility construction.

More than half of the world's 85-foot-diameter antenna ground stations have been installed by Collins. The Company is currently providing the world-wide Unified S-Band tracking and communication network for the United States Apollo moon missions.

As a major producer of telecommunication systems in all environments, Collins has a proven record of providing turnkey installations — on time and to specification.



COLLINS RADIO CO. (A/Asia) PTY. LTD.
327 Collins Street, Melbourne—Tel.: 61.2626.

COMMUNICATION/COMPUTATION/CONTROL

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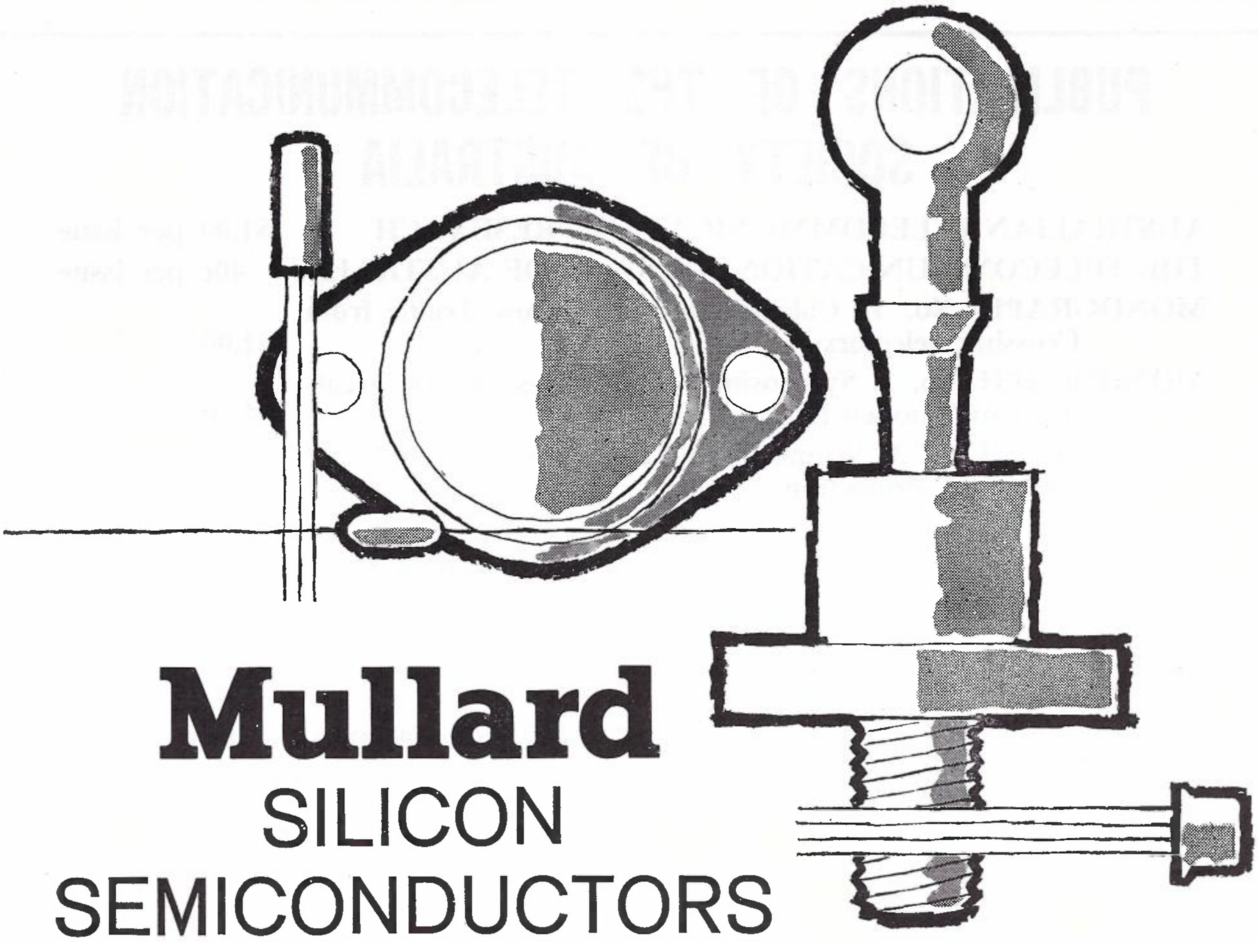

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Enquiries to State Secretary, General Secretary or European Agent at following addresses:—

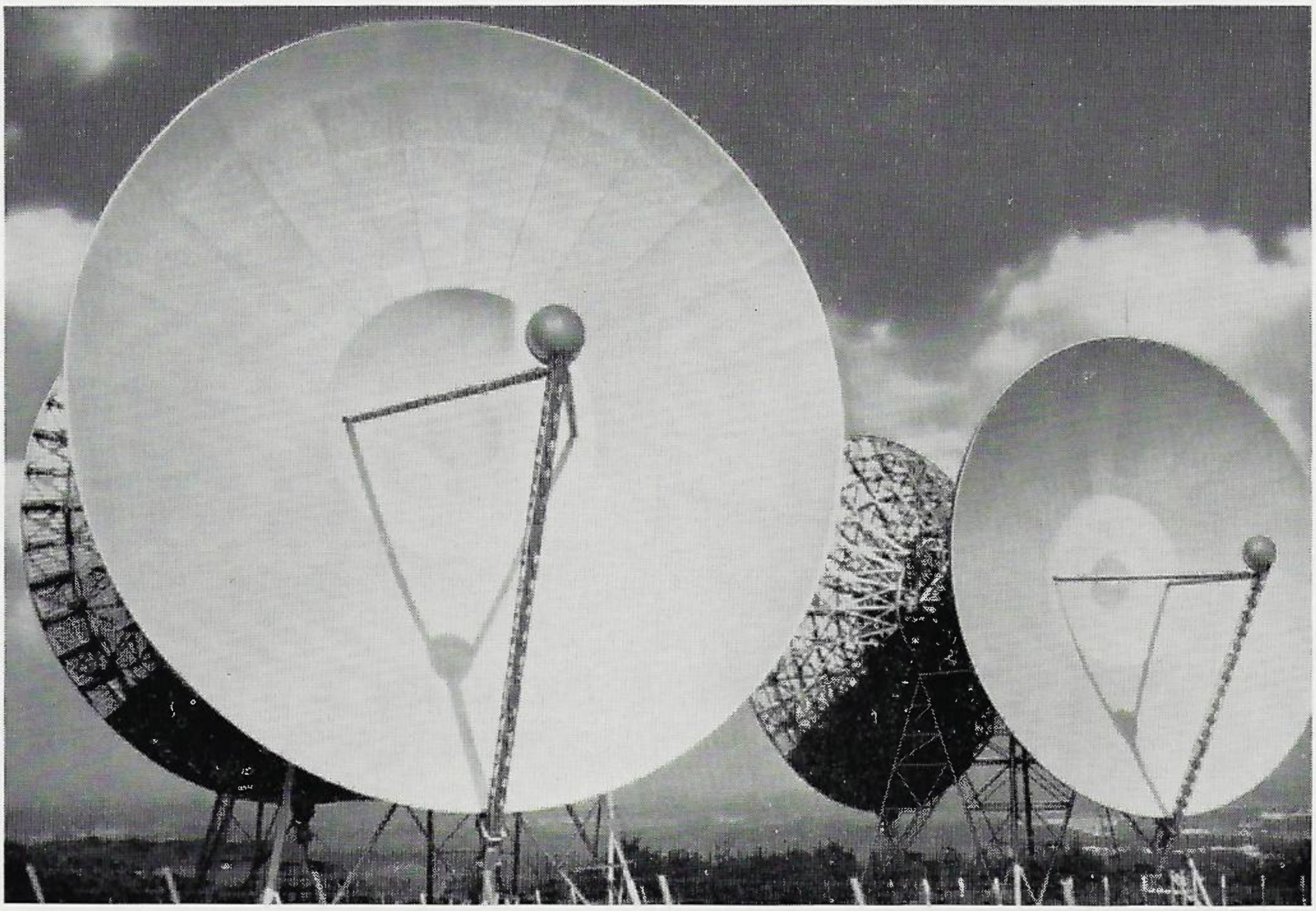
The State Secretary, Telecommunication Society of Australia,

Box 6026, G.P.O., Sydney, N.S.W., 2001. Box 1802Q, G.P.O., Melbourne, Vic., 3001. Box 1489V, G.P.O., Brisbane, Qld., 4001. Box 1069J, G.P.O., Adelaide, S.A., 5001. Box T1804, G.P.O., Perth, W.A., 6001. Box 1522, G.P.O., Hobart, Tas., 7001.

The General Secretary, Telecommunication Society of Australia, Box 4050, G.P.O., Melbourne, Victoria, Australia, 3001.

Agent for Europe, R. C. M. Melgaard, Canberra House, 10-16 Maltravers St., Strand, London, W.C.2., England.

NEC and Over-the-Horizon Microwave Communication



NEC's unique Over-the-Horizon (OH) Microwave system has ushered in a new era in the field of radio communication. The OH-2000 system affords a reliable non-optical radio link (capacity up to 120 ch.) in the 2000 MHz band over extremely long-hop distances where large propagation losses are involved. Transmitter output is reduced to less than one tenth of the conventional systems through NEC's development of a high sensitivity receiving system, a negative feedback, phase detection demodulator, a baseband ratio square combiner and a low noise parametric amplifier. Already, 382,869 channel-miles are in operation.

NEC's OH technology has further proved its value in the satellite communications field. NEC has designed and built complete earth stations in India and Japan and supplied satellite communications equipment to Australia and the U.S.

The never ending research and development work carried out by NEC has already born fruit in other fields of telecommunications and electronics as evidenced by the company's successes with: electronic switching equipment, 24-channel PCM carrier system, 2700-channel coaxial cable carrier system, automated TV studio equipment and electronic data processing and communication systems.

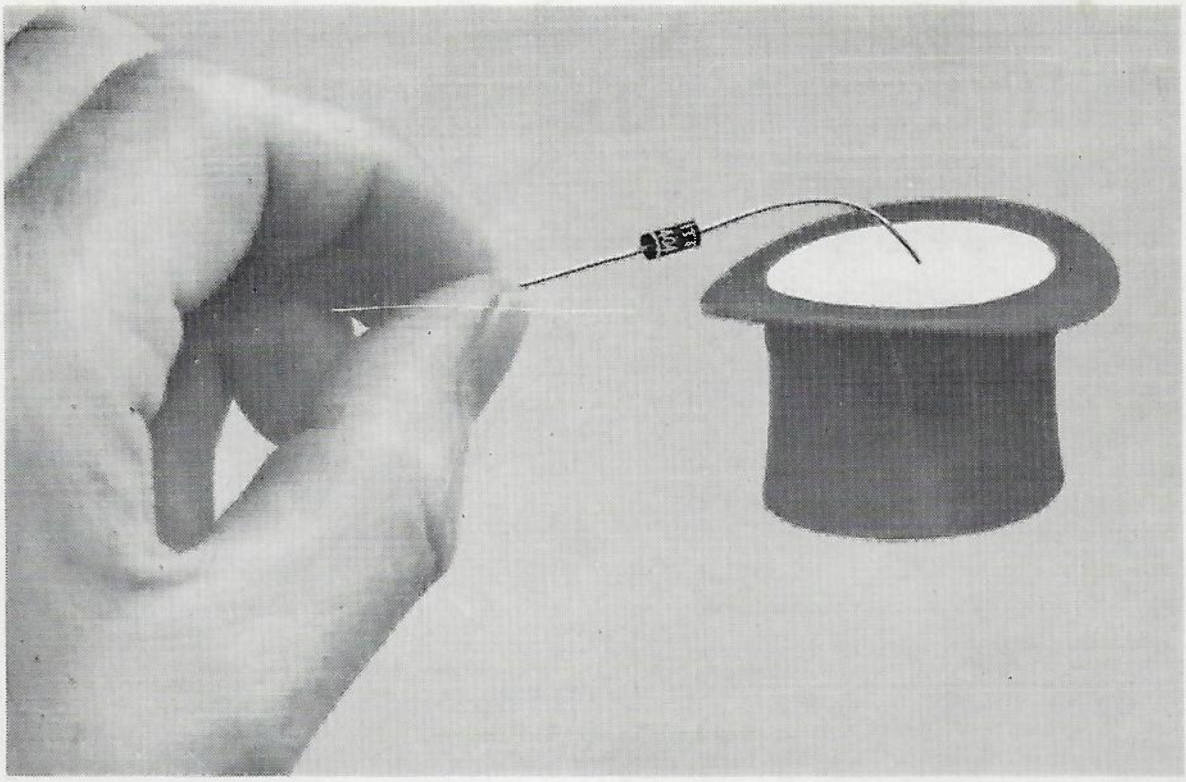
With many breakthroughs behind them NEC will continue to serve mankind with innovating technology and newer, advanced products.

Products for today— Innovations for tomorrow

NEC

P.O.Box 1,Takanawa,Tokyo,Japan *Nippon Electric Company, Limited*

2nd Floor, A.C.1. House 550 Bourke Street, Melbourne C.1, Victoria Tel.: 67-5321, 5322 Melbourne Representative



Makes "top hat" diodes "old hat"... the STC EM404 Silicon Power Rectifier

You save space — and you save money — when you install EM400's in new equipments.

EM400 series are epoxy-cased miniature rectifiers that pack a real punch, with up to 1000 PIV if required.

The STC EM404 goes up to 800mA, but the price goes down to 35 cents each in 1000 lots (quantity discounts on application).

Runs cool and keeps going. Do away with those old obsolete shapes and fit the new EM404 by STC. Made in Australia ... ex stock delivery.

For details, contact Standard Telephones and Cables Pty. Limited, Moorebank Avenue, Liverpool, N.S.W. 2170. Phone Sydney 602.0333. Melbourne 480.1255. Canberra 49.8667. Brisbane 47.4311. Adelaide 51.3731. Perth 21.6461.

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