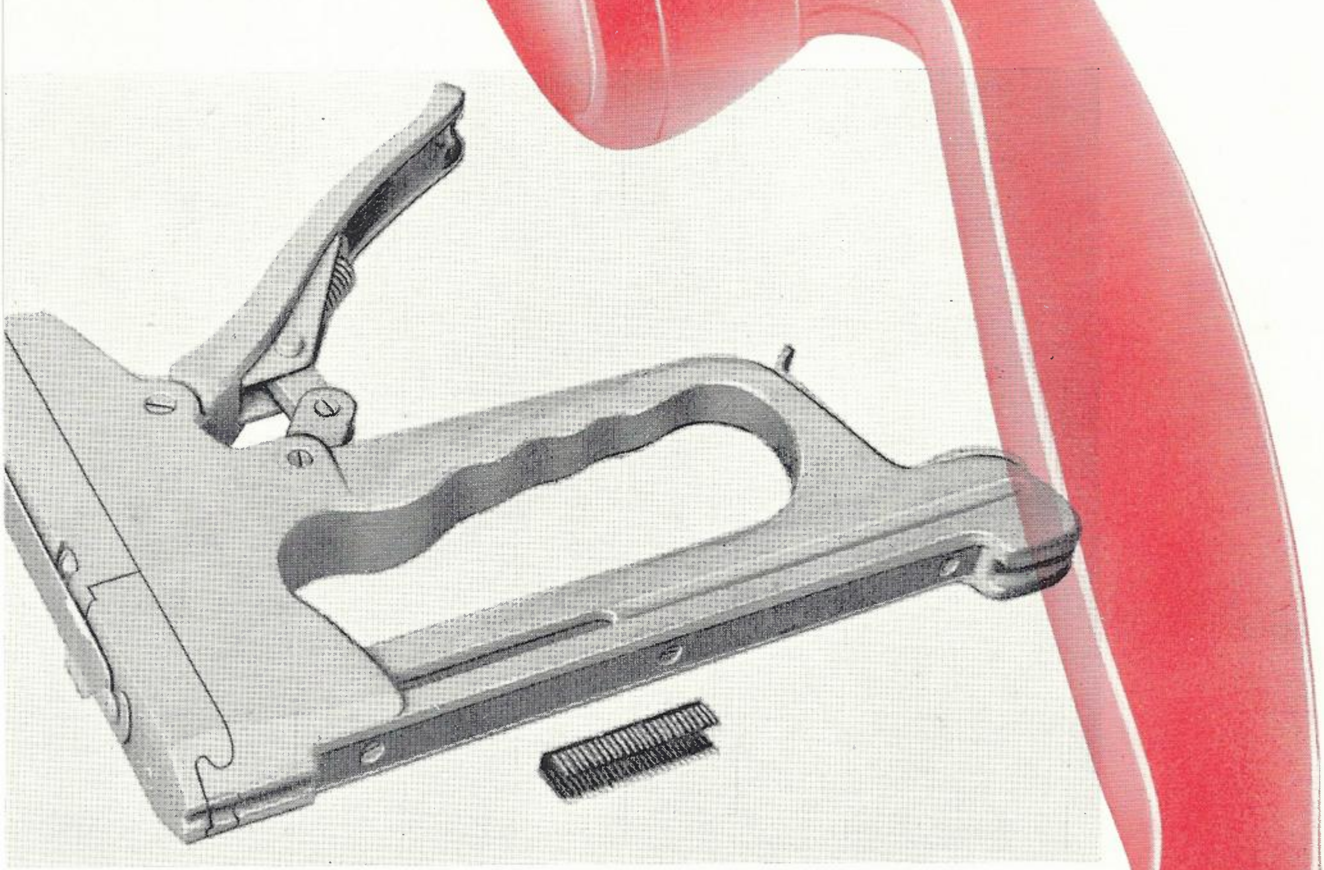
THE
Telecommunication Journal OF AUSTRALIA



IN THIS ISSUE

VOL. 12, No. 2. Registered at the General Post Office, Melbourne, for transmission by post as a periodical. OCTOBER, 1959

TELECOMMUNICATION SOCIETY OF AUSTRALIA

In the closing years of the 16th century, William Shakespeare caused his balconied Juliet to exclaim:

"What's in a name! that which we call a rose
By any other name would smell as sweet,"

The Bard has our utmost respect, and in many fields his wisdom is as apt today as when he penned those lines. But not all of us share Juliet's brisk and almost contemptuous rejection of the idea that a name has some importance. For instance, some have felt that our POSTAL ELECTRICAL SOCIETY OF VICTORIA could be more aptly named in the light of present conditions.

Our activities, while admittedly centred on the Australian Postmaster-General's Department, are perhaps not best described as "postal", which, to some, brings visions of postage stamps and letters. "Electrical", we agree, is apt. But it is surely too restrictive, and not truly descriptive of the range of our interests, which includes every aspect of telecommunications, broadcasting and television, including the associated civil and mechanical engineering fields. Finally, since authors from all States contribute to this publication, which is already known as the "Telecommunication Journal of Australia", and since two-thirds of our subscribers live outside the State of Victoria, the retention of the word "Victoria" can no longer be defended.

Having demolished, how to reconstruct? At a General Meeting of members of the Postal Electrical Society of Victoria, on October 19, 1959, the Committee of the Society presented a proposed new Constitution in which our name would be changed to THE TELECOMMUNICATION SOCIETY OF AUSTRALIA. The Constitution was adopted and we now have that title, which we are sure will be favourably received by our subscribers.

What's in a name? Much more than this. The new Constitution provides for the election of a State Committee in each Capital City, for lectures, visits and Journal subscriptions to be organized by these Committees, and generally for a more efficient service to be rendered to our members and subscribers. The formation of State Committees is being examined at present, and judging by the response to our preliminary enquiries, it should be possible to have them fully effective by the time the 1960-61 subscription renewals are due. Our next issue of the Journal will contain important information for our subscribers and prospective members in each State.

The sweetness of Juliet's hypothetical rose was independent of its name; we regard our change of name as more meaningful: it is a fitting acknowledgement of the greater part the society and the Journal will play in the vast changes which are already under way in Australian telecommunications.

The

TELECOMMUNICATION JOURNAL

of Australia

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Editors of other publications are welcome to use not more than one-third of any article provided credit is given at the beginning or end, thus:"The Telecommunication Journal of Australia".

STAFF CHANGES

Mr. C. J. Griffiths, M.E.E., A.M.I.E.E., A.M.I.E.Aust. has been appointed to the position of Deputy Engineer-in-Chief and Mr. I. M. Gunn, M.B.E., has been appointed to succeed him as Assistant Engineer-in-Chief (Services). Reference was made to Mr. Griffiths' career in our last issue and the Board of Editors take this opportunity to extend to him on behalf of the Society our congratulations on his new appointment.

Mr. Gunn joined the Department in Victoria, as a Cadet Engineer in 1928. Before his training was complete he was involved in the general recession of the depression years and worked as a clerk in Research Laboratories and in Transmission Section, Central Office. He was appointed as Engineer, Bendigo Division in 1935 and went to the newly created Benalla Division in 1937. He commenced acting as a Divisional Engineer in 1940 and his first job was the installation of the Melbourne-Seymour trunk cable.

Early in 1942, at the request of the Army Authorities, Mr. Gunn was released for active military service in the Corps of Signals. He commenced in the Army as a Lieutenant and rose to the rank of Major. During four years' service he was in charge of many large line and submarine cable projects in Australia and the South-West Pacific area.

In 1946 Mr. Gunn was discharged from the Army and after a brief period as acting Divisional Engineer, Transmission Measurements, Victoria, he was appointed Divisional Engineer, Ararat, Victoria. He was promoted to the position of Supervising Engineer, Country District Works, in 1950, and he occupied this position until March, 1956, when he was promoted as Deputy Superintending Engineer, Metropolitan Branch. In July, 1957, after periods of acting Superintending Engineer in the Metropolitan and Services Branch, he took up duty as acting Supervising Engineer, Lines Section, Central Office, and was promoted to this position in April, 1959.

Mr. Gunn figured prominently on several Central Office Committees during the period 1953-1955, and as a result played a major part in several important policy decisions. These included the introduction of the Divisional Store System to External Plant Divisions and the introduction of pressure preservative treatment for wood poles and crossarms. Whilst Supervising Engineer Country District Works, he was awarded the Coronation Medal.

Mr. I. M. GUNN

One of the highlights of Mr. Gunn's career came in 1956 when, as Chairman of the Victorian Olympic Games Branch Committee and Engineering Controller for the Engineering Division, he organised the communications required for the 1956 Melbourne Olympic Games. (This work was referred to in an article by Mr. Gunn in the Vol. 10, No. 6 issue of this Journal.) For the successful completion of this work he was awarded the M.B.E. in the 1957 Birthday Honours List.

In spite of the demands of his official career, Mr. Gunn has developed wide interests and activities outside the Department. Until very recently he held an active appointment as O.C. of a Citizen Military Forces Signals Unit and whilst at Ararat he was prominent in both Legacy and Rotary Clubs. He was President of the Victorian Branch of the Professional Officers' Association for two years and President of the Engineers' Group for one year. He plays a good game of golf and is actively interested in a local Youth Gymnasium Club.

Mr. Gunn's likeable personality and easy social manner have quickly won the whole-hearted support of his colleagues and staff wherever he has been, and these qualities should stand him in good stead in his new position.

The Board of Editors and the Society have pleasure in congratulating Mr. Gunn on his promotion, and on behalf of all our readers we offer him best wishes and full support in his new position.

AUSTRALIAN POST OFFICE ADOPTS L. M. ERICSSON'S CROSSBAR AUTOMATIC SYSTEM

*F. P. O'GRADY, M.I.E.Aust., S.M.I.R.E.Aust.**

In a previous article (The Telecommunication Journal of Australia Vol. 12, No. 1) reference was made to the fact that the Department had decided to adopt the crossbar type of automatic switching system as the standard method for the future. It has recently been decided to adopt the type of crossbar system supplied by L. M. Ericsson of Stockholm, Sweden. This firm has been one of the pioneers in the study and development of the crossbar principle. The firm manufactures a wide range of equipment suitable for use from the very smallest rural exchanges up to the largest city exchange. It also provides trunk terminal and transit switching equipment using the same crossbar techniques. It includes also multi-frequency high speed signalling systems for the rapid transmission of register information from one exchange to another. In addition to the main switching mechanisms the available designs include modern fault detecting and recording devices as well as artificial traffic machines, all of which are of considerable assistance in maintaining the switching equipment in good order.

The Department has made arrangements for two existing Australian firms—Standard Telephones & Cables Pty. Ltd. and Telephone & Electrical Industries Pty. Ltd., both of Sydney, to obtain the necessary licensing arrangements to enable them to manufacture the L.M.E. crossbar systems in Australia.

Detailed planning is now proceeding on the smooth introduction of this new system into these existing factories. It is anticipated that a progressive changeover from bi-motional switching equipment to crossbar switching will take place during the next two or three years.

*Mr. O'Grady is Deputy Director-General.

DEVELOPMENTS LEADING TO SUBSCRIBER TRUNK DIALLING IN AUSTRALIA

F. P. O'GRADY, M.I.E.Aust., S.M.I.R.E.Aust.

This article is substantially a reprint of a paper published in the June 1959 issue of the Journal of the Institution of Engineers, Australia, and is reprinted with the kind permission of the Editor of that Journal. It gives an excellent overall picture of developments leading up to the recently announced plan to provide for nationwide subscriber trunk dialling and extended local service areas. The article also illustrates the close similarity between automatic telephony and automation. Ed.

PART I

Automation

The use of automation in the Post Office goes back to the year 1912. In that year the first automatic telephone exchange was placed in service in Australia at Geelong, Victoria. In those days the term "automation" was not used, but nevertheless the basic principles of the automatic telephone exchange were in line with the generalised conception of automation as understood at the present time. This conception is of a machine or a combination of machines which are capable of performing desired functions in an automatic fashion, provided that sufficient information in the form of instructions is supplied to the machine at the required intervals. In some processes the information need be supplied only once at the beginning, but in other processes, the same information must be repeated at subsequent stages or different instructions furnished throughout the complete cycle of events. The degree of truly automatic functioning which is provided by modern devices varies between wide limits.

In all cases, the essential elements are an assembly of devices capable of doing work within the prescribed limits and not subject to any further intervention by a human being once the necessary instructions are fed to the assembly and a signal given to commence. The automatic telephone exchange similarly varies between wide limits. The early exchanges were of a rather simple character and were, generally speaking, rather small. Nevertheless, they inherently possessed the foregoing features of automation. They comprised an assembly of electromagnetic devices which were capable of carrying out what were regarded in those days as very involved operations, and they received instructions only at the beginning of a cycle of operation. This instruction or programming was fed into the device by the telephone subscriber lifting his receiver from the switch hook and then twisting the well-known telephone dial in a prescribed manner. This dial transmitted information to the exchange in the form of pulses of direct current and these pulses were sufficient to enable the exchange equipment then to proceed to switch the calling party's telephone to the wanted party's line without further intervention. In the process of connecting the two telephones together, the exchange equipment was required to exercise a number of functions which are found in some of the most modern examples of automation.

The type of automatic switching equipment varied as did also the range of internal functions which the equipment was capable of performing. In many of the early automatic exchanges can be found the counterpart of the basic items used, for example, in modern mathematical computing devices. It is interesting to note in passing that one of the American mathematical computers produced in the early years of the 1939-1945 War was constructed of telephone-type relays. This machine not only used the telephone relays as items of equipment, but made use of some of the features of a telephone exchange.

Strowger Step-by-Step Equipment

The earliest automatic telephone exchanges were of the Strowger type. This type is distinguished by the use of a very simple decimal coding control system in which the mechanical movement of the selecting device is directly related to the trains of impulses fed in from the calling subscriber's line. The dial is numbered from 1 to 0 and the selecting switches are all multiples of 10. The subscriber's numbering system is also on a decimal basis. The simplicity of the basic conception of this system has made it a popular system in many parts of the world, and in one or more forms it exists on a very large scale at the present time. In this system, the selecting devices which are required to search for a suitable connecting path between the two telephones concerned move directly and in synchronism with the movement of the subscriber's dial. Because of this synchronous action, the Strowger system is frequently described as a "step-by-step" system.

Register Type Equipment

There are several other types of automatic telephone exchanges. Some are of the step-by-step type but they use selecting devices different from the Strowger bimotional switch. There are others again which are not step-by-step in principle but make use of storage of information in some form or another. In these exchanges, the information furnished by the subscriber in the form of a series of trains of impulses from the dial of the telephone is received in a device usually caller a "register". This register stores the information in some mechanical, electrical or other form. Having noted the complete instructions from the subscriber, the register then proceeds to control the setting up of the connection to the wanted telephone. In some cases, a register waits until the last digit has been received from the subscriber, but in other cases it is possible for it to begin the selection of the connecting path while the subscriber is still dialling the successive trains of impulses.

Storage-Memory-Intelligence of Registers

The register takes several forms. It is similar to some of the components in a modern mathematical computing device. It must comprise, for example, some form of memory since it must remember for a certain period the instructions transmitted by the subscriber. It must also contain control facilities or intelligence, since it must be able to scan the memory and then decide what instructions it must send forward to the other parts of the system to enable the necessary connection to be established. In some cases, the information stored in the memory can be directly utilised to control the remaining functions, but in other cases it is necessary for a form of translation to be incorporated. In this sense the register may be said to have superior intelligence to that in the case of the simple register without translation. The register translator is able to store the information in the memory section, then read it and determine what changes are necessary in the information as stored to enable the selection to be made in the most appropriate manner. A simple example of this is where the subscriber dials the full number as printed in the telephone directory into the register. The register scans this information and notes that the number required is, for example, in the same exchange as the calling party. In such a case, some of the digits are redundant and the register therefore drops out the redundant digits and sends the controlling signals forward to enable the connection to be effected locally with a minimum amount of equipment in circuit. On the other hand, if the wanted party is in the most distant part of the network, then all of the digits are required to control the successive selecting stages and, in that case, the register will note this and will make use of the whole series of digits.

Another example of the intelligence of the register translator is where the normal junction route to the desired exchange is congested with traffic but it is possible to reach the desired exchange by taking an alternative route through a third exchange. To do this, it may be necessary to add artificially one or more digits to control the selecting device at this intermediate exchange. Naturally, a subscriber has no means of doing this, but the register translator can scan the information from the subscriber, determine that the direct route is busy, scan the one or more possible alternative routes, determine the additional digits necessary to make use of the alternative routes and generate them at the right stage in the sequence of events to control the switching device in the intermediate exchange.

Remote Control or Automation

The foregoing examples are illustrative of the fact that a simple step-by-step telephone exchange of the automatic variety only barely qualifies for inclusion under the term "automation". It is true that the selecting device at each of the step-by-step stages may be relatively complex electro-mechanical or even electronic devices in themselves, but they are controlled throughout directly by the subscriber's manipulation of the dial. A more correct description of such an exchange system therefore would probably be to call it a "remotely controlled" system. On the other hand, a telephone exchange which incorporates a register and particularly the one which incorporates register translators, qualifies more fully for inclusion under the title "automation". This is because the assembly of devices begins to incorporate many of the features of automation as now understood. It is capable of exercising a high degree of intelligence in performing its functions quite automatically without further intervention on the part of any operator or even on the part of the subscriber once the initial instructions are given.

Existing Equipment

The metropolitan cities of Australia have been arranged to use the simple Strowger step-by-step principle because to date it has not been necessary to incorporate the special features which register translators can provide. However, with increasing size, it is apparent that the networks in Sydney and, to a slightly lesser extent in Melbourne city and suburban areas, are now becoming so complex that some of the basic features of register translators become important enough to warrant their incorporation on economical grounds.

It is not proposed to discuss further in this paper the advantages and disadvantages of register translation methods in metropolitan networks, since these features are adequately covered in existing literature.

Proposed Automation

It is proposed instead to take as an example of automation in the telephone service the proposed full mechanisation of the trunk line service throughout Australia.

Definition of Existing Plant

It may be as well to define here some of the terms in common use in Australia. The line, whether overhead open wire conductor or part of an underground cable, which connects the telephone instrument itself to the relevant exchange is called a "subscriber's" line. When the initial system grows beyond the stage of a single exchange it is necessary to determine the economic sites for two or more separate exchange buildings, each with its own plant. Different blocks of subscribers are connected to the nearest suitable exchange. It is then necessary to add special lines to connect one exchange with another to allow for the case when a subscriber on one exchange wishes to talk to a subscriber connected to another exchange. These tie lines are called, in Australia, "junction" lines. In other countries they are given various other names.

When the number of separate telephone exchanges increases to the stage where rather long junction lines are required, then it is usual to impose a special tariff for calls passing over these long lines. These lines are called "trunk" lines in Australia. (In America, by contrast, they are called "toll" lines or "long distance" lines.) In Australia, therefore, there are three distinct groups of lines:

(a) subscribers' lines,
(b) junction lines,
(c) trunk lines.

Differential Tariffs

It should be emphasised that the distinction between a junction line and a trunk line is largely arbitrary and is determined by a rather complex series of factors. It should be borne in mind that, even after a great number of years of development, there is no country except possibly Switzerland which has a completely automatic telephone service at the present time. The change-over from manual methods to automatic methods has been retarded by many factors, a number of which are not of an engineering character. It has been necessary therefore, in the past, to make allowance for a mixed system of manual and automatic exchanges throughout the country. This has been an important factor in fixing the distinction between subscribers' lines, junction lines and trunk lines from time to time. The tendency has been to set up zones of traffic around certain centres and to regard these as units in determining the various charges to be applied for telephone service. Naturally, the telephone was first introduced in the already populated centres (which are now the capital cities of each State). The first telephone exchange was in the General Post Office or nearby and was thus approximately at the business centre of the then existing capital city. For a number of years all telephones were connected to the single manual central exchange. When the use of the telephone increased to the stage where it became economical to establish suburban exchanges and, later, additional city exchanges, junction lines were provided between the various exchanges along a series of patterns which varied somewhat from city to city depending, for example, on such conditions as geographical layout, the presence of rivers or harbours, etc. In some overseas countries, notably in very large cities such as New York and London, a special tariff was applied for the use of long junction lines between certain parts of the metropolitan city zone. With a completely manual exchange system this required merely slight additional work on the part of operators who had to prepare special accounting dockets for calls beyond their own exchange to certain exchanges in the more distant parts of the metropolitan area but not to others relatively close. This additional toll charge, as it is called there, is still applied in many of the large American cities.

In the case of Australia, however, it was decided many years ago to average the charges and allow a uniform charge to be levied for a call between any two subscribers in what was then defined as the metropolitan area. This area was arbitrarily defined, allowing for a number of important factors current at the time. In the case of Sydney and Melbourne, it is a circle of 15 miles radius from the G.P.O. In the case of the other capital cities, it is a circle with a radius of 10 miles. Within these zones calls between any two subscribers are known as "unit fee" calls. At the present time the charge is 4d. for a unit call and the charge is independent of the time of conversation. It is obvious that it must cost more money to connect two subscribers together at diametrically opposite points of the circle than it does to connect two subscribers on the one exchange, but it is important to note that the principle of a flat rate between all subscribers in this arbitrarily defined area has been accepted for many years. In this respect, of course, the principle is quite like that accepted for the cost of conveying letters throughout the whole of Australia for a fixed average fee. Similar principles have also been accepted in the case of telegraph tariffs where, for example, at the present time only two rates apply, that is:

(a) for telegrams within 15 miles of the office of origin, or
(b) beyond 15 miles.

Flat Rate versus Measured Rate

It is quite important to note the principles of flat rate charging at this stage because much of the subsequent discussion on the mechanisation of the Australia-wide telephone network depends upon acceptance of this principle within wide limits. It may be relevant to mention here that many overseas public transport systems nowadays use a flat rate irrespective of distance of travel on trams and buses, apparently because it has been found cheaper to dispense with the conductor and the issuing of complicated tickets for varying distances. Undoubtedly, the flat rate principle does penalise the person travelling or telephoning over a very short distance by comparison with the one travelling or telephoning over a long distance. The point to bring out here is that in order to provide an accurate differential method of charging which is truly related to the cost of providing the service, it is necessary to install and maintain a great deal more special plant than is otherwise necessary. In itself this must add considerably to the total cost of providing the service. The apparatus required for making an accurate determination of the appropriate rate, for example, for varying lengths of junction line, is relatively complex and therefore costly in annual charges. When the cost of this equipment is added to the remaining charges, it is found that all subscribers, including the ones making short distance calls, are penalised by the inclusion of this additional charge to such an extent that the attractions of a differential rate soon disappear, even for the short distance user. In any given area it is possible to evaluate these various factors. In the past, it has been found economic to dispense with differential rate determining methods, either manual or automatic, for all telephone calls within the arbitrarily defined metropolitan areas. It need hardly be emphasised that changes in technological developments may easily change the point at which it becomes economic to pass from a flat rate to a differential rate system. It is interesting to note in this connection that recent trends in some overseas countries, notably in England have tended towards the extension of the flat rate system rather than the reverse. Appendix I illustrates the trend of trunk line charges in England.

Existing Accounting Methods

In the past in Australia, having fixed the metropolitan unit fee zones and the smaller provincial zones, it has been possible to use very simple call accounting methods for calls within these zones. In the case of manual exchanges, the operator merely presses a meter key to record one local call on the subscriber's ratchet-driven cyclometer dial meter or, where meters are not provided, makes a note of the calling party's number on a simple card. It should be noted that the charge is the same whether the connection is a purely local one within the exchange or involves the use of one or more junction lines in tandem, so long as the two telephones concerned are within the unit fee area.

For calls extending from within the unit fee area to telephones outside that area, it has hitherto been the practice to treat this class of traffic in a special manner. It is classified as trunk line traffic and usually special operators, special operating positions and special methods have been used in distinction from those for purely local calls. For example, for many years a subscriber making a trunk line call had to give details of his call to an operator at a recording position who merely wrote out on a trunk docket the necessary information. She then passed this docket to the operator on a line operating position who called back to the calling party and then connected him through to the trunk line and to the distant wanted party. This method of "reverting" each call was the normal method for practically all trunk line calls until recent years. The additional labour involved on the part of the two telephonists compared with the setting up of the local call was justified by two factors:

(a) the cost of operators' labour was relatively low,

(b) the cost of trunk line channels was relatively high.

Efficient use of the trunk line channel by the orderly stacking of call dockets in proper sequence and connecting the subscribers one after the other with a minimum amount of idle time on the line was obviously a desirable objective.

Important Changes in Cost Structure

Two fundamental changes occurred, however, in recent years:—

(a) The cost of operators' labour, especially by the imposition of penalty rates for shift work, etc., and of much more extensive provision of amenities, has increased very considerably.

(b) The cost of trunk line channels has been reduced very considerably.

Economic Point for Automation

The point at which it becomes economic to consider semi-automatic or automatic methods rather than continue the use of manual methods has moved sharply downwards into quite small sizes of exchanges. In a normal R.A.X., (Rural Automatic Exchange) some of the traffic is purely local and can be dialled on a fully automatic basis by the subscribers. However, much of the traffic and, in many cases, the bulk of the traffic, is from a subscriber on a R.A.X. to other exchanges. Generally speaking, from a tariff viewpoint, two R.A.X.'s are not close enough together to permit fully automatic methods to be used and, consequently, it has been necessary to retain manually operated exchanges at certain key centres. These manual exchanges function as parent exchanges for the one or more R.A.X.'s in the vicinity. The manual operators make the connections between subscribers on one R.A.X. and those anywhere else in the network. The change in emphasis on the various components of an economic study has high-lighted the fact that to retain these manual parent exchanges would mean continuing a method which shows every indication of steadily rising costs even where labour is freely available.

Current Problems

While it has been technically possible to convert a number of parent manual exchanges to automatic working in past years, it has not been possible to solve all of the concurrent problems. Some of these problems are the accounting of the appropriate charge to be made against the individual subscriber for a call which extends beyond his own local R.A.X. to another subscriber in the unit fee area, and especially to one beyond that area. Another problem has been the provision of a sufficient number of trunk lines to enable the subscriber to make his own calls automatically. With the manual method at the parent exchange it is possible for a great deal of traffic smoothing to be effected. The operator is able to connect the calling subscriber immediately in the slack hours, but in the busy hours she has insufficient trunk lines to give everyone demand service. She is, however, able to stack the trunk line dockets in order of booking and, by revertive methods, is able to give everyone a fair share of the available trunk lines. When a change over to automatic is proposed for trunk line operating, however, it is obvious that the individual subscribers, while receiving satisfactory service in the slack hours, will encounter frequent and annoying conditions of all trunks busy in the busier periods of the day (or in the evenings, in certain localities). The subscriber would merely receive a busy signal and would have to make repeated attempts to get through. In the past, trunk lines have been relatively expensive and it has been necessary therefore to take full advantage of the traffic smoothing features of manual working in order to keep the overall costs of the nation-wide system at a minimum.

Decrease in Cost of Trunk Channels

As mentioned above, however, there has been a rather spectacular change in conditions in recent years. The invention of carrier methods of working by which large numbers of telephone channels are derived from a single pair of conductors has made it possible to reduce the cost per channel mile substantially. The early applications of carrier systems were limited to rather long distances and to the provision of a relatively small number of channels per pair (for example, three), because the terminal costs of the carrier systems made it difficult to justify their use on short lines. With the gradual introduction of mass production methods into the carrier field, however, and following the introduction of a number of new inventions, notably transistors, it has become obvious that the whole concept of provision of trunk channels has now changed. Concurrently with the cheapening of the cost of terminal equipment of carrier systems of the 1-channel, 3-channel and 12-channel types on open wire conductors, it has become possible by improvements in many separate items of plant to extend the use of carrier techniques to underground or aerial cables so that the provision of large blocks of channels between towns has now become quite a sound economic proposition. For the long, and very long distances, the development of the specialised cable known as concentric or coaxial cable has made it possible, with suitable carrier terminal and repeater techniques, to produce an economic solution to the provision of many hundreds of telephone channels between towns many miles apart.

A simultaneous development in the use of V.H.F. and U.H.F. radio systems using optical path microwave techniques has made it possible also to superimpose hundreds of telephone channels on a single radio frequency carrier wave. This use of broad band microwave systems has been an extremely useful addition to the Department's network and also has made it possible to provide very large numbers of channels at an attractive price.

Increasing Cost of Subscribers' Plant

An incidental matter which has a bearing on the form of the future nation-wide telephone service is the mounting cost of provision of telephone services in the perimeter areas of large cities. The early development of the telephone service was naturally limited to the more closely built-up areas, especially in the business sections of cities, where the telephone density has been high. The investment in cable plant for such densely populated areas has been relatively small per telephone. The distances between the exchange and the various subscribers have been relatively short and it has been possible to use cables made up of very large numbers of conductors in a single sheath and the corresponding ductways under city streets have been able to accommodate very large numbers of subscribers' wires. In spite of the obviously costly work involved in civil engineering work in city and densely populated suburban streets, it has been possible to plan well ahead and to lay a sufficiently large number of ducts in the early days to obviate extensive rearrangements in later years. So far as these areas are concerned, therefore, the cost per unit of telephone service can be said to be at a minimum.

Because of general congestion in the heart of cities and the concurrent problems in public transport and particularly in parking problems of motor vehicles, there has been a marked tendency for a rather straggling development to take place in outer suburban areas. Some of this has been unplanned, but much of it is nowadays planned deliberately by town planning authorities in an attempt to solve some of the problems of the inner city areas. In providing telephone service to these outer suburban areas it is naturally found that the cost per unit is becoming very high. It is necessary to lay new duct-ways whose size is well in advance of initial requirements in order to avoid future costly additions or, alternatively, it is necessary to lay a relatively small number of individual cables in pipe or of the steel or wire armoured variety, laid directly in the ground, and run the concurrent risk of having to add additional cables at relatively early dates, as soon as the development really gets under way.

The task of adding additional cables where a proper duct system is not provided in the original manner is quite a difficult one and sometimes involves very costly work. One of the typical problems is that the Department is called on to provide telephone service to newly established outer suburban areas before roads and footpaths are built or even planned. This makes the determining of levels and runs for cable-ways extremely difficult, and frequently very expensive alterations are involved when the suburban area finally takes on a more settled air with properly formed roads, sewerage services, etc. The cost per unit of new telephone service in outer areas is now very high and all indications are that it will continue to rise.

Need to Encourage Greater Number of Calls per Subscriber

The importance of this factor in the nation-wide system is that where the capital cost of providing a telephone is high it is essential that the telephone be put to the maximum possible use in order that the Department can recover its capital cost by revenue derived from the individual calls made by the subscriber. In the planning of the system, therefore, it is essential that the final system should be one which will encourage people to make the best possible use of their telephones.

Salient Traffic Features

There are some important factors in this regard:—

(a) The number of calls made by a subscriber each day—called the daily calling rate.
(b) The time occupied in conversation on each call—known as the holding time.
(c) The distribution of calls throughout the 24 hours.
(d) The distance involved in each call.

In regard to (a), the calling rate per telephone varies widely between one class of telephone service and another, and also between telephones in different localities. A telephone in business premises, in general, will originate many times the number of daily calls that is originated by the telephone in a small private home occupied by an aged couple who retain the telephone almost entirely for medical emergencies and very limited social reasons.

The length of time occupied on each conversation also varies between very wide limits. Many telephone conversations last only a few seconds, there being many examples where the nature of a person's business is such that he must talk to the other party at certain regular intervals, but is required only to deliver short messages on each occasion. There are also well-known examples of telephone calls of a domestic social character which last for half an hour, or even longer, especially in the evenings.

The distribution of calls throughout the day also varies widely from one day to another and from one part of the country to another. On ordinary weekdays, Mondays to Fridays, however, there is a very consistent pattern in which a great percentage of the daily calls is originated in rather limited periods in the morning and in the evening. There tends to be a concentration of traffic between 10 a.m. and noon, and between 3 p.m. and 5 p.m., which is much denser than for any other corresponding number of hours in the day. In every exchange there is detectable a consistent "busy hour". This is the hour of the day during which the greatest percentage of the daily traffic is originated. It may be between 10.30 a.m. and 11.30 a.m. at one exchange and perhaps between 9 a.m. and 10 a.m. at another. In a few odd cases or on a few days of the year it may be in the afternoon rather than the morning, although the morning traffic load is generally the heaviest. The evening hours also exhibit a particular peak, which is approximately from 7.30 p.m. to 8.30 p.m., but again, it varies between exchanges.

The distance over which calls are made also varies widely but consistent patterns are observable in the traffic from any particular exchange. In very general terms, for example, it can be said that the great majority of the traffic is between exchanges quite close together, and certainly lying within the nominal unit fee area. Among the traffic going beyond the unit fee area there is a consistent pattern in that the great majority of trunk traffic goes to stations within 50 or 60 miles of the point of origin. Naturally, the geographical conditions surrounding the particular group of exchanges will have a considerable influence on the average distance involved in trunk line calls.

Reverting to (b), the average holding time is important to planners. It is found that on local calls, for example, the average holding time is well below three minutes.

Cost Structure of Telephone Service

With the foregoing knowledge, it is possible to evaluate the cost factors which determine the final tariff to be paid by the subscriber. We have accurate information available on the following factors:—

(a) The capital cost of providing the subscriber's service, including the telephone instrument and the line or cable conductors connecting this telephone to the exchange. We also have the annual charges involved in maintaining this section of the plant.
(b) We have the capital cost of the telephone exchange site, building and plant, which are required to enable a satisfactory telephone service to be given; again, we have the necessary information on the annual charges involved in maintaining this section of the plant.
(c) We have similar information on the junction line plant.
(d) We have similar information on the trunk line plant.

Tariff Structure

From this point there are obviously many ways in which a tariff system can be built up. We could, for example, install the telephone service free of charge and make no annual rental charge but, on the contrary, fix the cost per call at a rate sufficient to make the necessary revenue available to the Department. This method might be satisfactory for certain classes of subscriber but, for the telephone with a low calling rate, it is obvious that the Department would lose heavily, and this loss could be recouped only by overcharging the subscribers who have high calling rates. Another method would be the opposite and make no charge for installation, levy an annual fixed sum for rental and make no charge for individual calls. Such a method is sometimes referred to as a "flat rate" system and is used extensively in America and New Zealand, for example, except that the free calls are limited to local calls within some defined area. (Trunk line or long distance calls are charged for quite separately and related to each individual call.)

Another method is to make no charge for installation, to levy an annual charge as a rental and to charge a fee per local call in addition. (In this system trunk line calls would also be separately charged.)

The remaining method is to make a fixed charge for installation, levy an annual rental, make a charge for each local call and make a charge for each trunk line call. This method is the one at present in use in Australia.

The merits of each of these systems can be argued at great length. The weight to be given to the various factors must vary widely between extreme limits even within groups of telephone subscribers relatively close together. The present Australian method represents probably the fairest method available. It means that the total annual amount paid by a subscriber more nearly approaches the actual cost incurred on his behalf than would be the case with some of the other methods.

Developmental Tariffs in Country Areas

In all countries there are factors other than engineering economics involved. It is not always possible to fix the tariff structure on an accurately calculated cost basis. One of the important factors, of course, is the deliberate policy of endeavouring to develop unused parts of the country in order to help the better growth of the country as a whole. For this reason, it is not unusual to deliberately provide telephone services in country areas at annual rentals and at call tariffs for local calls which are well below the annual cost to the Administration. Naturally, the loss on these country services must then be made up by charging city or provincial town subscribers more than the cost of providing service. In addition to the deliberate policy of subsidising country telephone costs as an aid to national development, there are other important factors present in this tariff problem. In the past, for example, a telephone in a small country locality was of only limited use because the subscriber could call only a relatively small number of people. It would not therefore be fair to charge the same amounts as paid by a city subscriber who has access for 24 hours a day and seven days a week to many thousands of subscribers. The country service, in addition to being limited in access, was often limited in hours of operation because of the difficulty in obtaining suitable staff prepared to work the night shifts and weekend shifts, coupled with the high cost of their salaries and overhead charges.

There have been marked changes, however, in this picture. The introduction of rural automatic exchanges, and particularly the invention of carrier current systems, have made it possible to extend considerably the range of communication of all subscribers in Australia and to extend the hours of operation, until many country folk now enjoy a 24-hour service.

Design of Future System

The foregoing discussion on some of the broad features of tariff structures has been included rather fully in order to give a clearer picture of the problems facing a Design Engineer who is planning a nation-wide telephone service. As mentioned earlier, it is now technically possible to enable any one telephone to dial any other without the intervention of any operator. It is clear, however, that before such a plan could be implemented it would be necessary to replace a very large number of existing manual exchanges by automatic exchanges, and it would be necessary to accept some new principles in telephone tariff structures.

Mechanical Call Accounting Methods

If means could be found to account for the trunk line call charges automatically, it is obvious that the operators could be dispensed with completely and much more effective use made of the automatic switching equipment already provided. To this end, for some years a great deal of inventive ingenuity has been expended in solving this problem. In America the situation was that the great majority of local exchange service was provided on the so-called flat rate system in which the subscriber paid an annual fee and his local calls were free. There were some variants of this in which, for example, the first 500 calls would be free, but calls above that number would be charged for. Long distance or trunk line calls, as we know them, were handled by operators and a purely manual docket writing process was used to make note of the appropriate charges to be levied against the subscriber for each trunk line call. The first attempt to solve the problem of automatic trunk line operation was the introduction of automatic toll ticketing machines. The first use of these was in Belgium some years ago. It has been taken up in more recent years in the U.S.A. and has now reached a high state of development. In this type of service, the subscriber dials a distant subscriber over a trunk line by first dialling a special code of digits which indicate to the switching equipment that the call is to pass beyond the local area and is to be routed in a particular direction to some distant city. The subscriber, having dialled the first steering digits, then dials the ordinary number of the distant subscriber and the call is completed without any operator intervening. In this method the automatic toll ticketing machine must be capable of performing a number of functions. In the first place, it must reliably identify the calling subscriber's number and print this on some card or tape or record it on a magnetic drum, or by some other similar process. It must also identify and record the number called at the distant end. It must determine the trunk line channel which has been chosen and identify from that the appropriate trunk line charge to be made, which will naturally vary with distance and, possibly, other special factors. It must identify the time of commencement of conversation and the time of completion. It must have also recorded the date, and it must print or otherwise record all of these details in some reliable manner. The automatic toll ticking method has undergone many developmental changes and naturally these are still continuing. However, the device in one form or another has been applied on a very large scale indeed in the U.S.A. In those areas where the conversion is made, the subscribers can now dial any number in the United States or Canada, which are regarded as a single telephone unit. This numbering area unit has recently been extended to include Mexico and the Hawaiian Islands. In European countries automatic trunk line services have been provided for some years, notably in the case of Switzerland, and also in Belgium, Holland and large parts of Germany. In some of these countries, automatic toll ticketing methods have been used. The tariff structure naturally varies widely between countries and where the structure is similar to that in the United States, toll ticketing methods have been adopted.

Multi-Metering Methods

In Great Britain, however, local calls have been charged for and have been registered on a meter individual to each subscriber, for many years. Instead of making a fixed annual charge and giving free local calls as is done in most parts of the U.S.A., the British Post Office has preferred a method in which the subscriber pays an annual rental, pays a fixed fee for each local call as registered on his meter in the exchange, and pays for each trunk line call as recorded on a manually written docket by an operator. Because of the existence of this subscriber's meter for local calls, the B.P.O. has endeavoured to avoid the rather complex and therefore costly mechanism inherent in an automatic toll ticketing device and has developed a method known as "multi-metering" for trunk line calls. This multi-metering method has also been used extensively in Germany and Sweden, where similar conditions existed.

In this multi-metering method, the subscriber is enabled to dial trunk line calls himself and his meter, instead of operating once only for each call as it does with a local call, operates periodically throughout the trunk line conversation at a rate which means that he is being debited with the appropriate trunk line charge. For example, if the trunk line charge to the distant town is 6d., which corresponds with twice the local fee of 3d., then the subscriber's meter would operate twice instead of once. If the charge to the distant town, however, is 2s. 0d., then the meter would operate eight times. This multi-metering technique can be applied in many forms. For example, the mechanism in the exchange can make note of the appropriate information required to determine the charge and then operate the meter rapidly, say eight times, at the end of the conversation. On the other hand, it can be arranged that the meter operates at regular intervals during the conversation, but the rate of repetition will depend upon the appropriate trunk charge. On a very long distance call, for example, it might operate every twelve seconds. It should be noted here, of course, that on a local call at present the meter operates once only for each effective call, irrespective of the length of the conversation. On a trunk call, however, the number of operations of the meter is proportional not only to the length of the trunk line, but also to the holding time.

In Australia, the present call charging method is similar to that in Great Britain and it is natural, therefore, that multi-metering should be an attractive proposition.

Toll Ticketing versus Multi-Metering for Australian System

In the current planning for the Australian network, consideration is being given to the introduction of an ultimate subscriber dialled telephone network in which all charges will be recorded on the existing subscriber's meter. At this stage of development it would not be safe to assume that the economics of multi-metering will necessarily always favour that method as compared with automatic toll ticketing methods. At the present time, however, there is a large economic saving in favour of the use of multi-metering methods against toll ticketing methods.

At this point it might be mentioned that with the traditional method of manual trunk line operating, it is possible to furnish the subscriber with a detailed account of his trunk line calls as distinct from his local calls. When he makes a local call on an automatic exchange there is no recording device which notes the number which he calls, the route which he follows, or the length of conversation. It is not possible therefore to settle successfully any dispute between the subscriber and the Administration on the number of local calls, so far as establishing the fact that he did call a particular number at a particular time. All that can be established is that the meter and associated system is kept in reliable condition and the registration of the meter must be accepted as evidence that a certain number of local calls has, in fact, been made. Subscribers, in general, have accepted this principle for many years and, in fact, disputes are few. With the trunk line bill, normally the subscriber is not given details of the individual calls but is asked to pay a lump sum as shown on the telephone account. If, however, he wishes to examine the matter in detail, he can, on payment of a small fee, be given full and accurate details of each trunk line call made from his telephone. With the American method of toll ticketing machines it is possible, of course, to furnish a subscriber with the same information. Traditionally, therefore, it might be argued that subscribers would insist on retaining this feature. However, experience has shown that the number of requests for details is relatively small. If, in order to retain this facility, it is necessary to use complex and expensive toll ticketing devices, it is obvious that the cost of these devices must be recovered in some manner in the total tariff structure. It becomes a question, therefore, of how far the Administration is justified in installing and maintaining expensive equipment the sole function of which would be to give accurate details of each trunk line call to a very small percentage of the subscribers who request them.

Probably the main reason for the American Administrations adhering to the toll ticketing machines is the fact that the very large amount of automatic local plant already installed does not have facilities for registering local calls and in their case it is quite probably true that the cost of altering existing exchanges to incorporate meters for local calls would be much greater than the cost of installing toll ticketing machines. Where meters already exist, however, and where it is possible to incorporate them in a relatively simple multi-metering scheme, it is obvious that this technique becomes very attractive. It does, however, mean that the subscriber will no longer be able to obtain details of trunk line calls, since the meter will merely exhibit so many units of registration with no means of distinguishing between local and trunk calls. In this connection, it is interesting to notice that in other countries where multi-metering has been used, notably in Germany, subscribers have accepted this principle without difficulty. In the early stages of its introduction arrangements were made that subscribers who did not like this idea could make their trunk calls by dialling an operator and having her establish the call manually for them. In this case, the operator could retain the ordinary trunk line docket which would record full details as was customary with a purely manual service. In this connection, it was not necessary to retain the operator specially. Even with a fully automatic network some operators are required for information, complaints, and other miscellaneous services, and it was possible to use these operators for the very small percentage of subscribers who wished to retain this manual operating, either because of their desire for details of the trunk line calls or because, for some other reason, they could not establish the trunk line calls themselves. Examples of the latter would be persons with poor eyesight, persons distressed through some emergency situation and, of course, persons not knowing the number of the distant subscriber but knowing only his name and address. It is important to note here, however, that experience soon showed that the number of persons who made use of this alternative manual service soon became negligible.

Facilities for Hotels

There is one exception, of course, to the foregoing general acceptance, and that is in the case of hotels, etc., in which guests make trunk line calls and have to pay the hotel before leaving. With the manual methods, the custom was for the operator at the hotel to call the trunk exchange after a call was completed, when she could be quickly told from examination of the trunk docket the amount of money involved. With a multi-metering system such a facility disappears. This problem can be tackled in two ways. In the first place, it is possible, on request of the hotel management, to arrange that the telephones in that hotel are barred from direct access to the automatic trunk line network and can make calls only by going through one of these operators referred to above. This has the disadvantage that it slows down the rate of setting up the calls and, in addition, in the case of a large city, means the retention of an undesirably large number of operators. The alternative and better method is to fit a meter on the subscriber's premises. This could be fitted, for example, on the face of the P.B.X. switchboard in the hotel. Its registration would indicate to that operator the appropriate fee to be charged to the guest. It is noteworthy that provision for this meter on the subscriber's premises is made in all recent overseas multi-metering installations.

Multi-Metering Method for Australia

In the light of the foregoing remarks on the tariff structure and on the relative costs of multi-metering versus toll ticketing, current Australian plans will be based upon multi-metering as an integral part of an ultimate subscriber trunk dialling network.

Present Manual Tariff Structure

One approach to the engineering problem in Australia would be to assume that the present trunk tariff structure should be retained. At the present time, the trunk line charges in Australia are determined on a co-ordinate grid system. The map of Australia is divided by parallel vertical and horizontal lines so that any exchange can be described by its vertical and horizontal ordinates from an arbitrary zero point. The exchange is considered to be at the intersection of the vertical and horizontal lines which is nearest to the arbitrary zero point. The distance between two exchanges for trunk purposes therefore can easily be determined by the difference between the vertical and horizontal ordinates of these respective points of intersection. A relatively simple table enables the operator to determine the appropriate money value of the call from this ordinate difference distance. Naturally, the accuracy of the nominal distance between the two exchanges concerned is greater for a larger number of vertical and horizontal lines. On the other hand, the complexity of the table is increased and therefore the practical system used is a compromise. It follows from this system that some anomalies must exist. For example, within the square represented by the intersection of the appropriate vertical and horizontal lines there can be two exchanges one of which is right on the intersection of lines nearest to the distant exchange concerned, while the other is diagonally opposite and therefore some miles further away. In these cases, the trunk line charge is the same for each exchange although obviously the amount of plant must be greater for the latter case. Some years ago when all trunk lines comprised actual physical conductors, it was a reasonable assumption that the cost of providing the trunk service would be proportional to the distance. However, with the introduction of carrier methods, broadband microwave systems and particularly with the introduction of coaxial cable systems, it is no longer true. The actual cost of provision per channel mile is determined by many factors and the distance between terminals has lost a great deal of its significance.

Possible Changes in Tariff Structure

Another solution to the automatic trunk line problem would be to decide that no distinction would be made between local and trunk line calls. The meter would register once only on each call, quite irrespective of distance. To adopt this method it would be necessary to recover the total costs by substantially increasing the annual rental charge (and possibly the installation charge) and/or by substantially increasing the charge per registration of the meter. This would mean, of course, that the subscriber who rarely makes a trunk line call would be penalised by comparison with the one who makes frequent use of the trunk line service. At first sight, such a flat rate system would result in the minimum amount of plant and therefore in the minimum actual cost of providing service. However, one important qualification should be stated here, and that is the fact that such a method might result in subscribers making such an extensive use of the trunk line facility that the cost of providing the necessary additional trunk channels would rise very sharply. This is an interesting point for speculation. Undoubtedly, during the novelty stage of the new service on such a basis people would make trunk line calls which perhaps they would otherwise not make. It is difficult, however, to believe that they would continue to make these unnecessary trunk line calls any more than they write letters to distant parts of Australia merely because they can do so for the same price as a local letter. It is difficult to believe also that people send unnecessary telegrams to distant parts of Australia merely because they are transmitted for the same price as to points quite close by.

This is a problem, however, in which there is room for a great deal of difference of opinion and it is extremely difficult to fix the constants in the equation which no doubt could be evolved to describe the case. Tradition plays a big part in a problem of this character and it is also quite impossible to disregard the political and general developmental aspects of the tariff structure, which are referred to above. While, therefore, it is true that a single charge for any telephone call irrespective of distance and irrespective of holding time would mean the simplest type of switching plant, it is perhaps too bold a step at this stage, because of the risk of increased cost in other directions.

Looking at the problem at the other extreme, there are at present 22 different rates of charge for trunk line calls, which, as mentioned earlier, are based on the distances between points on the gridded map. On the assumption that the plant investment and maintenance factors favour multi-metering rather than toll ticketing, it would be possible to consider an ultimate plan in which the multi-metering equipment would provide for 22 different rates of trunk charge in addition, of course, to the unit fee for local calls. Appendix II shows the 22 rates.

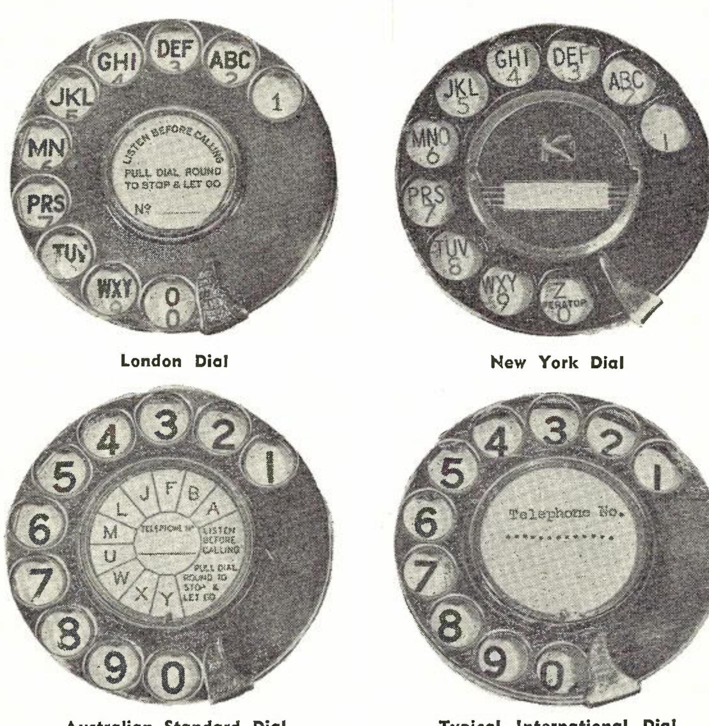
Effect of Numbering Scheme

In considering a nation-wide subscriber trunk dialling system, it is necessary, however, to consider also the numbering plan. If, in the ultimate, a subscriber is to be allowed to dial any other subscriber without an operator, then it is clear that every telephone in Australia must be given a distinctive number which is different from the number of any other subscriber. At present this is not so. For example, in Melbourne a number such as MA2000 is used by some individual subscriber in one of the local areas of Melbourne, but there is also an MA2000 number subscriber in Sydney, and quite likely also in Brisbane, Adelaide, etc. With the present mixture of automatic service for local calls and manual service for trunk line calls, this does not matter, since a subscriber on booking a trunk line call prefaces his description of the wanted number by saying first Sydney, Adelaide, etc., and then giving the local number appropriate to the subscriber in that city. With a completely automatic system it is necessary for the subscriber to dial some additional digits which will carry the same significance to the automatic plant as the voicing of the word "Sydney" indicates to the present manual operator. The first point, therefore, is that the nation-wide numbering system must involve additional digits over and above those necessary on a purely local service basis.

In this connection, the number of digits required at present using the existing dial and the existing Strowger step-by-step system is related to the number of subscribers in the area concerned and to their distribution over a particular number of exchanges. Ideally, six digits should suffice for one million subscribers. However, this would be true only if all the subscribers were connected to a single exchange in the centre of the total area and there were no other extraneous problems such as trunk line service, information, complaints, time of day, weather announcements, etc. In practice, with the subscribers divided up into blocks connected to exchanges separated by some miles in typical suburban areas and allowing for the foregoing miscellaneous services, it is found that six digits will not suffice for anything like one million subscribers. One obvious reason for this is that each exchange must be left with spare numbers for growth, and because it is impossible to accurately forecast growth month by month in each separate exchange and to install plant exactly as required by the growth, there are always large blocks of numbers unallotted at any particular time. In brief, with a city of the present size of Sydney and growing at its present rate, it is necessary to pass beyond six digits into seven digit working. Plans for such a move are now current and, in fact, one exchange has already begun service on this basis, thus involving a mixture of six and seven digit working in that particular area. The city of Melbourne will follow closely on Sydney in using seven digit working. On present indications, the remaining States can be encompassed within the limits of a six digit system for some years to come.

Type of Dial and Directory Presentation

Investigations have been made in recent years into the best method of identifying individual subscribers in a telephone directory. With small exchanges particularly, bearing in mind the decimal basis of the Strowger step-by-step system, it is natural that up to four or five digits in a plain decimal arrangement is the best method. This, of course, presupposes that the subscriber will have a dial with ten finger holes numbered from 1 to 0. When the size of the area increases and five digits are not sufficient, then first six and then seven digits become necessary. At this stage in past years much thought has gone into the use of combinations of letters and figures instead of all figures. In many American cities and in several United Kingdom cities, the practice was adopted many years ago of placing sufficient letters on the dial to enable the old manual exchange names to be retained when they were converted to automatic working. Fig. 1 shows various dials. In this system it was considered that subscribers were accustomed to thinking of exchanges by name and it would help them if the same name could be retained and printed in the directory. Thus, for example, a typical number would be printed as CENtral 1234. The subscriber was instructed to dial the first three letters of the name of the exchange—CEN, and then the four figures—1234. In this system the subscriber obviously was encouraged to think in terms of geographical locations. Originally, the Central exchange was the first one in the heart



London Dial

New York Dial

Australian Standard Dial

Typical International Dial (All figures)

Fig. 1.—Typical Automatic Telephone Dials.

of the city and the other exchanges were more or less named after the suburbs in which they were located. It might be stated here that the original decision was dictated largely by the fact that the introduction of automatic working was necessarily a very gradual process and it was known that there would be a mixed system of manual and automatic exchanges for many years. Whatever the original justification for the retention of the name of the exchange, it was soon found that with the growth of cities and subsequent rearrangement of exchange boundaries it became extremely difficult to retain the original idea of dialling three letters. Some years ago, therefore, most of the American cities were changed so that only the first two letters were dialled and five figures were added instead of four. The subscriber would thus dial CE6-1234 (the figure 6 corresponding with the letter N on the American dial). The use of two letters naturally departed somewhat from the original idea but was necessary because of complications encountered in finding a sufficient range of distinctive names for exchanges as the whole American network grew. There has been considerable controversy in America in recent years following the introduction of subscriber trunk dialling on the question of whether the letters should be dropped completely and all subscribers' numbers indicated entirely by figures.

In Great Britain the original conditions were much like those in America and a similar combination of letters and figures was used except that the actual location of the letters within the dial holes was different from the American. The matter of retaining letters in Great Britain has also received considerable attention.

Use of Letters on Dials

In the majority of countries letters have not been used at all, and all subscribers' numbers are shown simply as a combination of figures. Although there is room for difference of opinion, the consensus throughout the world seems to be that an all-figure system is probably the most satisfactory from all points of view. In this connection, it is relevant to point out that the present dial and the present numbering system in each country was evolved many years ago when long distance working was practically negligible and there was certainly no immediate prospect of international working on an automatic basis. The situation in recent years, however, has been transformed. The whole of the United States and Canada, for example, is now a single numbering scheme and a subscriber equipped with the necessary apparatus in his local exchange can dial any number in those two countries. He will shortly be able to include Mexico and the Hawaiian Islands (following the recent provision of a submarine repeatered telephone cable). In the European scene, automatic subscriber dialling between adjacent countries is extending and there seems little doubt that before very long subscribers in the United Kingdom will be able to dial numbers in Europe. It does not require much imagination, therefore, to see that consideration must be given to a world-wide numbering system. This immediately raises the difficulty of different languages and makes the use of letters much less attractive than when considered from a purely local point of view. Apart from the difficulty of printing letters of various foreign languages, it must always be borne in mind that even with the completely automatic telephone system it is sometimes necessary for subscribers to give their number to somebody over the telephone by word of mouth. In these cases it is clearly desirable to avoid phonetic and other language difficulties arising from the use of letters.

The present Australian dial was introduced a great number of years ago and it was not intended to be used with exchanges having a geographical name. The letters were chosen to be as unlike each other as possible in the phonetic sense. It is not possible to spell out exchange names even if such a method were deemed advisable. With the growth of the network, it has become obvious that the retention of letters would introduce very difficult problems, notable examples being numbers such as WUU-1234. When such a number is spoken it becomes indistinguishable from WW-1234 or UUUU-1234. There are many other similar combinations which would be impracticable. Taking cognisance of these difficulties and taking a very long range view, it has been decided therefore to omit letters gradually from Australian telephone numbers and use an all-figure basis.

It is considered that a subscriber would not be able to trust his memory when he has to dial more than six or seven digits but will have to become accustomed to the idea of having the number written in front of him while dialling. However, other things being equal, it is clear that the less number of digits he has to dial, the less likely he is to make mistakes and the faster will be the setting up of the connection. With expensive lines and equipment, even a few seconds saved on each call can be an important point.

It is considered after detailed investigation, particularly taking into account similar work done in other countries, that a maximum of ten digits should be aimed at in planning a nation-wide dialling system.

Number of Trunk Charging Rates.

There is a relationship between the numbering scheme and the arrangement of the multi-metering equipment which determines the charge to be applied to any particular trunk line call. Although the relationship is not simple it can be said that, in general, the number of separate trunk line rates has a bearing on the complexity of the multi-metering charge determining equipment. Without going into a detailed analysis it can be stated that the number of trunk line tariffs should be reduced below ten in order to simplify the design of the multi-metering equipment and thus reduce its cost to a minimum. At the same time, such a figure simplifies the relationship between the multi-metering equipment and the numbering scheme.

It has been decided, therefore, that a maximum of eight trunk line rates should be allowed for in the future Australian network planning. In this regard, it is interesting to note that the B.P.O. in similar planning has recently reduced the number of subdivision of trunk tariffs from their original large number to a maximum of three. With the unit fee for local calls, this means that the switching equipment is required to discriminate only between four possible charges on any call in the United Kingdom. Because of the much greater distances in Australia, it is not practicable to reduce the number of trunk charge rates as low as three, but the adoption of eight sub-divisions plus the unit fee for local calls, means that the switching equipment in the future network will have to discriminate only between nine possible charges for any one call. This is a substantial reduction on the present number of 22 subdivisions of trunk tariffs which are in use in Australia on a manual basis. It would not be practicable to retain such a large number with automatic devices associated with multi-metering.

PART II

In Part I some of the features which justify the planning of the future nation-wide telephone system of Australia on a purely automatic basis have been discussed. Brief reference has been made to the developments which have already taken place and particularly to the factors which now justify a further expansion in the amount of automatic plant. Consideration was given to the various tariffs which might be used and to the changes in tariff structure which might be necessary to enable the further adoption of automatic methods.

Proposed Future System—Full Subscriber Dialling.

There is now no doubt that technical facilities are available to enable the ultimate form of telephone network operation to be achieved, that is, one in which the subscriber merely lifts the receiver and dials the number of any other subscriber in Australia without the intervention of any manual operator anywhere at all. It is clear also that the changing economic factors justify much more rapid adoption of this system than would have been the case a few years ago. The system of the future which, of course, must be planned a long way ahead, must therefore at least have this method of full subscriber dialling as its ultimate objective. The stage at which sections of the country are converted to this system will depend upon the availability of the necessary equipment and labour and also of course, on the relative urgency of providing relief from congestion as it occurs in various parts of the network. The really desirable point in planning is that no equipment should be installed which is not capable of being used economically in the ultimate scheme. This, of course, is an idealistic approach and therefore some plant must be installed which will ultimately require replacement or modification. It is most important, however, to reduce the amount of this plant to a minimum.

The Philosophy of Telephone Switching.

On the assumption that the ultimate objective is full subscriber dialling with recording of calls made by the multi-metering technique, it is as well to review the general philosophy of the art of telephone switching. It is worthwhile reviewing briefly the history of telephone switching so that the influence of the past in this regard can be given due weight in assessing the main technical features of the desirable system of the future. With this object in mind, the following section of the paper is devoted to a consideration of the philosophical and technical bases on which the art of the telephone switching system is founded and the progressive modifications necessary to achieve the ultimate aim of fully automatic local and national networks.

Telephone Switching a Statistical Problem

The primary function of a telephone authority is to provide a means whereby any telephone subscriber can be provided with a speech connection of the necessary quality to any other subscriber whom he may specify. It is immediately obvious that this problem is essentially a statistical one, and, in fact, some of the earliest practical applications of mathematical statistics were in the telephone field.

The Danish statistician and engineer, Erlang, established that subscribers in groups of as few as 200 originate calls in a purely random manner, the probability of a given number of calls arising at any time being described by the Poisson distribution curve. Further, it is clear that these calls occurring randomly in time will require to be connected to subscribers distributed at random throughout the network. Erlang's work and the extensions by such workers as O'Dell, Crommelin, Jacobaeus and Jensen form the basis from which the required quantities of telephone circuits and switching equipment are derived. From a measurement of the number of calls initiated by each subscriber it is possible to assess the average number of calls requiring connection at any point in time, and the expected variation in this number about the mean. For example, in a network the size of Melbourne or Sydney, about 1,000,000 new calls require connection every hour.

Amount of Switching Equipment

The simplest solution to the network problem would be to provide lines to link every subscriber with every other subscriber in the network; however, this is obviously both uneconomic and impracticable. Since any one subscriber initiates relatively few calls the connecting circuits can be pooled at a central point and just sufficient provided to connect the number of calls simultaneously in progress at the peak periods.

The original answer to this problem was the single manual exchange to which all the subscribers were connected. A sufficient number of operators was provided to handle the demands for connection. Once this concentration was provided each subscriber needed a designation or number by which his or her line could be identified. Sufficient cord circuits were provided to connect the number of calls simultaneously in progress. This switching concept is basic, and the old manual exchange with the operator to establish the connection and record the charge was an efficient method of solving the philosophical problem. However, it suffered from two serious limitations, the high cost of manual operating and the decreasing efficiency as the number of subscribers grew.

The Strowger Step-by-Step System

The original Strowger switch had 100 outlets, although Strowger's patent foresaw capacities of 1,000 outlets on one switch. Each subscriber was connected to such a switch and through it could gain access to the other 99 subscribers.

It was now necessary to dial pulses, to designate the subscriber required, and the logical development was a stepping switch responding to impulses from the caller's dial. In these switches the positioning control is associated with the switch. The original automatic system was limited in size by the switch used and it became necessary to provide tandem switching stages to allow access to more subscribers. Where, in the manual exchange case, the operator could take in the whole subscriber's number and then find the required outlet, the original automatic switch was only capable of examining two digits one after the other. Therefore the step-by-step exchange evolved which found the subscriber by a process of grouping, division and regrouping until the calls were sorted into the correct 100 line parcels and a final selector could determine from the last two digits the required subscriber. This process is shown in Fig. 2.

Growth in Network Complexity

This concept was extended to cover several exchanges, the junction routes merely being outdoor links between switch ranks.

With time the number of subscribers in the networks increased. The geographical boundaries extended in the case of Sydney and Melbourne first to 10 miles and then to 15 miles radial distance from the G.P.O. These factors threw into relief several technical and economic limitations in the straightforward step-by-step system. The number of impulse repetitions and the long junctions between exchanges caused excessive impulse distortion and false signalling. The junction links became increasingly costly to provide with rigid transmission and signalling resistance requirements and, in particular, the step-by-step blind searching method of establishing a connection resulted in provision of junction circuits and switching equipment in accordance with a rigid pattern.

Problems of Increased Size of Networks

With the increase in network size the statistical variation with time of the traffic flow became more apparent. For example, during the working day heavy telephone traffic flows into and out of the main city exchanges, whilst in the evenings and at weekends these exchanges and the junctions between them are practically unused, whilst the bulk of the traffic flows on the junction routes between main and branch exchanges in the residential areas. Thus, the rigid step-by-step nature of the network implies that the city junction plant lies idle in the weekend and is not available to connect calls between residential exchanges. Slight improvements are possible and have been made within the framework of this system, to utilise spare junction plant for peak loads, but basically the system is limited by its fundamental step-by-step concept.

Nation-wide Network Equivalent to One Single Exchange.

A study of this problem revealed clearly that the automatic network must be considered as an entity, as one big equivalent of the original manual exchange in which exchanges and junction plant are so designed and oriented that they can be utilised at any time in the most efficient and economic manner to carry the traffic.

It is also evident that as subscriber dialling (or, in other words, automatic control) is extended into the trunk network, this network also becomes an automatic equivalent of the basic manual exchange model. In fact, the present method of single operator trunk dialling in use on all main routes and many minor ones is a close approach to full automatisation. All that remains is to replace the trunk operator with an automatic intelligence, and discriminating device, and build into the system further routing flexibility, required for such an intelligence to use.

Route Selection.

The problem of providing the path is basically the problem of providing in the network sufficient combinational possibilities to enable the traffic to be carried. It is possible to define an operating function which must be satisfied, to ensure that sufficient paths are available at all times. The addition of available cost coefficients yields an overall cost function as an objective relationship which must be minimised for optimum operation of the network.

The problem formulated this way is obviously very large and, in fact, because of the non-linear and irrational co-efficients, impracticable to process or solve. An example of the magnitude of the pro-

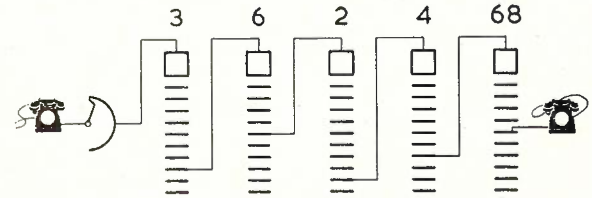


Fig. 2.—Step-by-Step Grouping System.

blem is that great difficulty was experienced in using SILLIAC (the University of Sydney computer) to process the data for a few of the basic coefficients, because of limited storage capacity.

This type of fundamental impasse is well known in engineering, and the telecommunications engineer resorts to the usual iterative techniques to obtain initial network planning solutions. The initial network decisions add additional constraints to the problem such as exchange positions, junction routes and so on, and the developing network must be modified by a series of progressive adjustments to optimise the investment in plant at each stage.

General Features of the Problem

Let us now examine the general requirements to be met by the switching and junction plant in order to provide optimum conditions. First, the old step-by-step method of destination determination must be abandoned. The manual telephonist examined the complete subscriber's number before making a decision and then made the best possible decision at her disposal. This is the fundamentally sound approach since the more information that is available before a decision is made, the more intelligent can be that decision. Thus in the ideal network, automatic common control must be resorted to, to replace the manual operator. In fact, with the growth of large telephone networks the decisions to be made by the operator have become far more complex than those confronting a manual telephonist with a small magneto switchboard. The present-day operating demands go far beyond the capacity of a manual telephonist if full advantage is taken of efficient traffic disposal techniques.

Common Control versus Step-by-Step Method

The common control units receive and process the information and set the switch paths, in the best way available. This process of searching can be represented topologically as in Fig. 3. If ABC designates the required destination, the step-by-step system explores the path from A to B and then to C. In the automatic control system the full ABC designation is examined and the best available path is chosen. This path may be direct A to C or via B and so on, the path chosen depending on the traffic flowing at that time in the various sections of the network. In this system the routing of a call is independent of the called subscriber's number, whereas in the step-by-step system the number of switching stages is tied to the subscriber's number and the investment in plant becomes uneconomic.

Importance of Full or Large Availability on Switch Outlets

There are two essential strategies that must be adopted to ensure the efficient routing of the calls through the network as required above. Each circuit when provided must be used with maximum efficiency and, between any two points, the shortest and cheapest available possible route should be taken. A group of circuits to be used most efficiently must be equally available to all possible users, or in other words, the circuits must be provided in full availability groups. Any form of partitioning of the circuits so that only a proportion of the circuits are available to a proportion of the offered traffic will lower the traffic capacity of the group as a whole. A good analogy is the consideration of two groups of ticket offices, one at each end of a railway platform. Congestion at the main entrance end windows cannot be relieved readily by the other windows whereas if the windows were in one group this combined group would be available to to handle all requests. This principle is important in telephony where peaks in traffic occur in different directions and parts of the network at different times during the day. In practice, for normal traffics, availabilities of 60-70 circuits in one group provide the highest economic efficiencies. The switching equipment used often limits the availability possible on junction routes to the detriment of system efficiency. In the present bimotional system availability is limited to 20 unless special measures involving extra time, delay and cost are adopted. However, MUS and crossbar systems do provide for higher availabilities and are consequently more efficient in this respect.

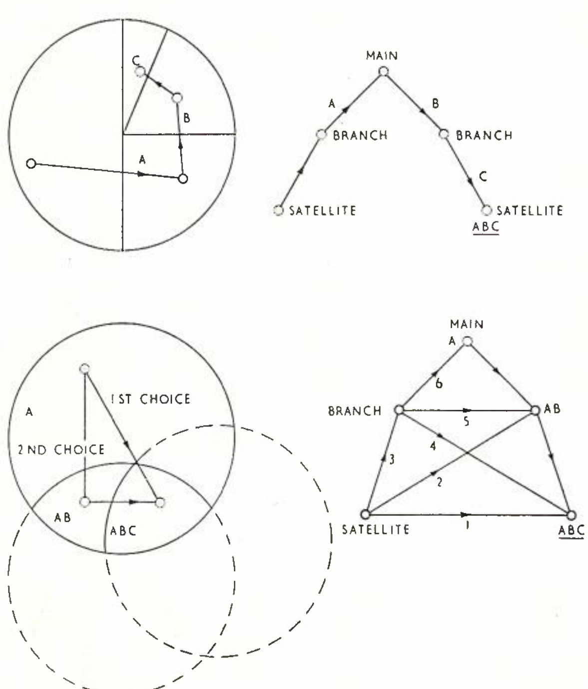


Fig. 3.—Step-by-Step versus Common Control Searching.

Importance of Overflow or Alternative Routing Method.

The use of the shortest and cheapest route available follows logically from a desire to carry the traffic across the network at a minimum cost. With common controls a process of direct and overflow routing is possible so that the base load of traffic between two points is carried on direct circuits whilst the sporadic peak traffic loads are combined with other such peaks and grouped on overflow routes via traffic grouping centres or tandem switching points. The basic principle is to provide circuits on the direct route until a point is reached where it is cheaper to carry the traffic via the overflow or main route. The main route efficiency is high since this route carries traffic comprising a large number of small traffic peaks which, when combined, themselves form a fairly constant traffic load.

Importance of Speed of Switching

With a system meeting the above conditions, it is necessary to have a relatively high speed of decision and connection to allow for effective examination of the routing possibilities available, and still provide the caller with a rapid connection.

It can be seen from the above discussion that effective automation of either local or trunk networks is best achieved by endeavouring to produce a high speed equivalent of the simple manual exchange. In such a network there will be three main components, the connection between the caller and the automatic operator, the operator, and the cord circuits or switching and junction plant.

The core of the system, however, is the operator or the register translator. This is in effect a specialised computer into which route designation information is fed and which is charged with establishing the connection, supervising it and charging for the call. The system as a whole is therefore an automatic mechanism controlled by a central computer which must rationalise and direct the outcome of a large number of statistically independent call attempts.

The diagram, Fig. 4, of a Bell No. 5 link trunked crossbar exchange shows clearly the similarity between the modern common control exchange and the original manual switchboard.

Early Use of Common Control Methods

The need for common control units in large networks was realised as early as 1910 or thereabouts and a number of electro-mechanical units were devised which, despite the severe technical limitations present at that time, were fairly successful. As mentioned earlier, the most notable shortcoming of all these early control systems was their relatively slow operating speed and the consequent appreciable or even severe delays between the end of dialling and the location of the required subscriber. These delays could not be overcome despite extensive curtailment of the logical functions associated with such automatic controls because of the slow operating speeds of the electro-mechanical components which comprised the units. Many readers will no doubt be acquainted with the delay encountered between the end of dialling and the transmission of ringing tone in the Director system used in large cities in the United Kingdom.

Electronic Common Control Methods

In this field, therefore, intense effort has been devoted to increasing the speed of operation of the common control unit. Success has been achieved in recent years due to several developments in different fields of the switching art. The most notable is the application of electronic components to common control units. Considerable attention has been devoted to applying electronic components, hot cathode valves, cold cathode valves, transistors and diodes to most phases of telephone switching. As yet, economically suitable applications have been found only in equipment which is required to operate at high speed, is relatively complex and need only be retained on a particular call for a short period of time. This last factor compensates for the relatively costly nature of electronic circuitry up to date.

Wholly Electronic Exchanges.

In sections of the network, such as the speech path where mechanical equipment can be provided relatively cheaply and with a more satisfactory technical performance, electronic elements have so far found very little economic application. In fact, it would appear that a fully electronic exchange will not be a commercial proposition for some years. Several fully electronic exchanges have been built, two of note being the "ECASS" system built by the Bell Laboratories and "Andrew" at present under construction by the B.P.O. in co-operation with the five British telephone manufacturers. So far the main value derived from these fully electronic models has been that they provide pointers to sections of the network where economic savings could be made immediately by the use of electronic circuitry and techniques. A notable example will be referred to later, namely, signalling over subscribers' lines.

Common Control Crossbar Type Exchanges

The desire to increase speed of operation of common control systems also caused fundamental changes in trunking philosophy and led to the abandonment of the bimotional and unimotional mechanisms with their excessive setting times in favour of crossbar switching mechanisms. Associated with this development was the introduction of high quality pressure contacts in the speech path, in place of the base metal sliding contacts widely used on bimotional and unimotional selectors, giving rise to a considerable and, as it happened, essential improvement in the psophometric noise performance of the speech path.

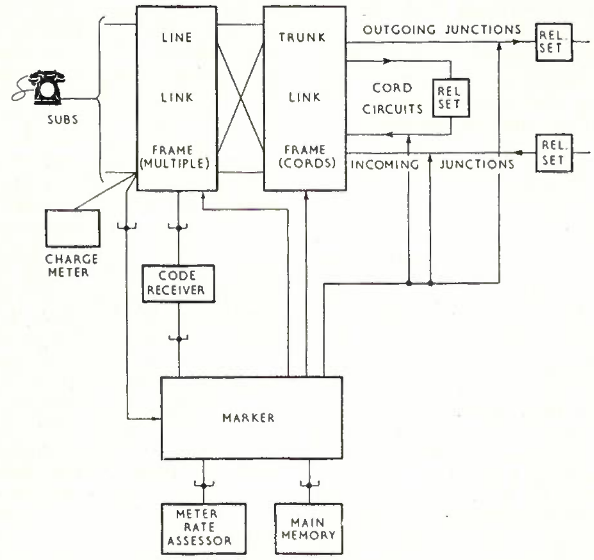


Fig. 4.—Crossbar Exchange—American No. 5 Bell System.

Link Trunking

Associated with the development of the crossbar switch and these high quality contacts the need arose to adopt a new trunking principle. This principle is link trunking which, in contra-distinction to the direct trunking principle used with bimotional and unimotional selectors, will provide an availability from a given selecting stage which is independent of the size of the switch. This consideration has increased in importance with the realisation that overall network performance must be optimised as mentioned earlier, by the use of full availability junction routes. An example of the difference between direct and link trunking is given (see Fig. 5) in the solution to the problem of switching 100 incoming circuits to 100 outgoing circuits with no blockage in the switching stage. It can be seen from the figure that the link trunked system requires only 57 per cent of the crosspoints or speech path connections used for the direct trunked example. This saving was important since the higher quality contacts in the link trunked crossbar system cost more to produce than their equivalents in the base metal direct trunked case.

Because of the larger number of smaller switches associated with the link trunked selecting stage, slightly more complex control circuitry needs to be provided to steer the calls through the system. However, the additional cost of these control elements does not outweigh the net advantage gained by adopting high quality cross points and a more compact and economical trunking configuration. One reason for this economic advantage is that the hunting time of the 100-outlet selector is long relative to the setting time of the crossbar switch and therefore the link trunked system requires one or two relatively complex high-speed control elements, whilst the direct trunked system requires 100 fairly simple low-speed control units and, in fact, require considerably more material in both the speech path and the controlling circuitry.

Link Trunking with Electro-Mechanical versus Electronic Control

Today, with high speed signalling techniques and electro-mechanical control elements link trunked systems are sufficiently fast for efficient network operation and more economical than their direct trunked equivalents. Nevertheless, the recent development and production of reliable high-speed computer elements at economic prices has induced the telephone switching engineers to design and use very elaborate controlling intelligence units which take full advantage of these electronic developments.

Computer Technique in Telephone Switching.

Let us now examine the way in which computer techniques and philosophy have been applied to this common control element of the telephone network. The register translator or telephone switching computer, whilst using the same techniques and circuitry as conventional digital computers, is a solution to a basically different computational problem, which is in some respects more sophisticated. Each section of the computer logic has three main functions:

(1) The unit determines when and where it is required and proceeds to associate itself with the source demanding service.

(2) The unit then receives and at times checks the correctness of information transmitted to it and, as required, requests extra information.

(3) The unit then processes the information by a series of successive logical functions, the outcome of the preceding function determining the nature of the subsequent operation, in order to route the call through a series of exchanges and junction routes as efficiently as possible.

Circuit Operation using Computer Technique

Let us now examine the way in which this register translator or computer will operate during the progress of a call. Reference will be made to the block diagram, Fig 4. The first function is to identify the calling subscriber and to associate him with the code receiving element in order that he may transmit his route information into the system. As mentioned earlier, at this switching stage in an automatic exchange, there is a considerable degree of concentration of the subscribers' lines on to relatively few storage devices or code receivers. The subscriber initiates a demand for service by lifting his receiver and the computer must recognise this caller. This may be achieved by means of an identifying field which may take several forms, two of which are mentioned below.

(1) *Relays.*—These are the traditional and still the cheapest storage elements. The subscriber operates his own line relay and places a potential on a signal wire which is scanned periodically by the access control circuitry.

(2) *Electronic Identification.*—With fully electronic operation the line relay is replaced by an assembly of diodes and resistors and the change of potential for a particular subscriber's line may be identified by a time scanning device as above, or, if the subscriber generates a pulse associated with his line having a unique time identification, time division gating may be used to identify the request for service and the position of the subscriber in the multiple.

The computer must, having recognised the demand for service, associate the subscriber via a suitable free path with a free code receiver. There are normally a number of suitable paths over which association may be achieved and the computer must, in the interests of overall statistical efficiency, prescribe only a free path or a group of paths on which there are several vacancies. This requirement is necessary in order to minimise the states of disorder imposed on the system and thus the demands on its combinational capacity in order to achieve optimum statistical efficiency. Unfortunately, such an operating specification requires relatively complex path switching circuitry. The choice of the best free circuit is a requirement common throughout the telephone network and perhaps relatively unknown elsewhere.

Having specified the selection preferences available, a random choice is made within the most desirable group and the speech path selectors are set connecting the calling line to the code receiver. This register is a simple volatile store designed to permit subsequent operations to take place at high speeds. The subscriber is now fed dial tone and invited to transmit the routing information into the system. The speed of the above operations will be readily appreciated when it is realised that they take place in the time it takes to lift the receiver and prepare to dial. The three fundamental functions of the intelligence unit have been used in this initial association operation. The computer recognised the calling line, it examined the position of the caller and the available paths and it effected an efficient connection in the interests of the subscriber and the exchange as a whole.

The second main function, that of reception of the destination information, is now ready to begin. Simple decimal D.C. pulse transmission has been used up to date to convey digital information in the telephone system and this is necessary with a step-by-step direct control of the switches. However, complete centralisation of the intelligence renders it desirable to convey the information into the register as quickly as practicable. Increases in the speed of signalling have been achieved experimentally using multi-frequency V.F. pulsing, multiple line potentials, and a system of pulse position modulation.

Fast signalling systems of these types necessitate the use of press buttons on the caller's telephone and it is interesting to note here that the average human being can only signal on a row of press-buttons at between 50 and 200 milliseconds per digit. This is really too slow to take full advantage of the speed of the storage device at the exchange and the American ECASS electronic exchange requires the caller to preset the required number before lifting the receiver. The digits are then transferred to the exchange at high speed using a pulse position modulation code. Fig. 6 shows examples of the two types of press-button telephone discussed.

The destination digits are received into the code receiver and stored. There are several methods of storage available and to date the cheapest electronic form of storage is the magnetic drum. Fig. 7 shows the magnetic drum in a typical register translator. The information received is stored on the periphery of the drum in decimal binary form, for example, digit 6 would be 0110.

Referring to the block diagram, Fig. 4, there are three main components of the route selecting computer (register translator), the code receiver, which is a form of volatile store, the marker, which incorporates static stores and is the unit which explores and acts on instructions from the third unit, the memory. Code receivers are provided on the basis of the traffic flowing whilst there are one or two markers provided for each group of code receivers. The main central memory is provided on the basis of one, or at the most two, per exchange and it is this unit which contains the inbuilt pattern of reaction for all the possible events liable to be encountered in the experience of the exchange controls.

The code receiver, having received sufficient digits for the route determination to be initiated, passes these routing digits to the marker. The marker, which is subsequently to establish the connection through the exchange, must pass the code digits to the central memory where they are processed in one of a number of ways.

The received code may be converted directly into a destination specification and this specification may define a particular route which should be tried by the marker. This code to route designation field is designed for easy modification in the event of network alterations. The route marking information is fed to the short term store in the marker and used to establish the connection. The route marking information would also notify the marker of the type of switching plant at the far end of the route in question, the number of digits to be sent forward and the speed at which they must be transmitted. This procedure is necessary because it is not economically feasible to control the complete routing throughout a multi-exchange network from one originating point. Such a function would be technically practicable but only at the expense of extreme complexity and the requirement for a very complex high speed signalling system to correct errors in the wide range of route marking information it would be necessary to transmit between exchanges. The digits transmitted forward to the next exchange may either be the original codes or some suitably processed information. For several reasons, it would appear at the present time that transmission forward of the original codes is the most desirable solution.

A modification of the method of route selection mentioned above has been

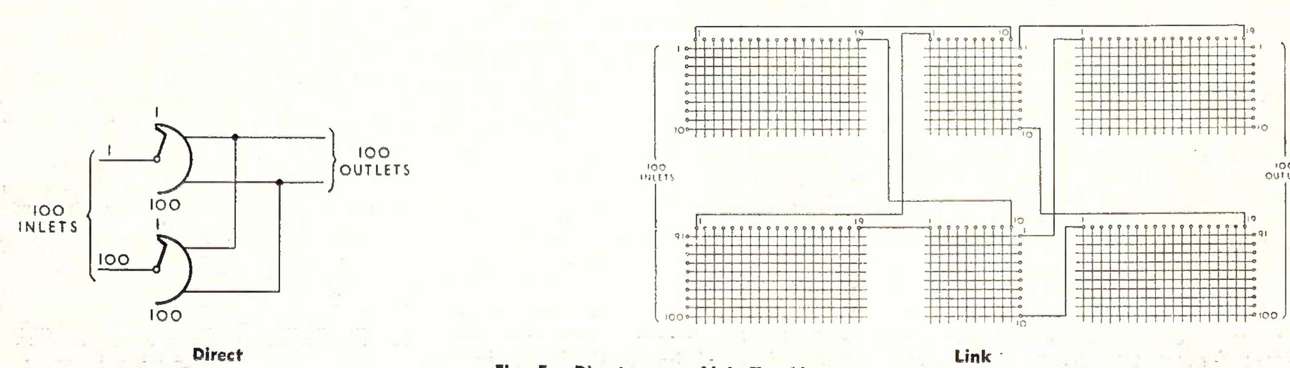


Fig. 5.—Direct versus Link Trunking.

evolved whereby the memory is pre-informed of the condition of the first, second and subsequent choice routes available to a particular code. Under these conditions the marker is automatically informed of the first available route for the code in question and time is saved in route selection. However, increased complexity is required in the memory which must not only have the pattern of reaction built in but must have a motivating logic attached to the intelligence in such a way that the outcome of a particular question may be varied depending on the conditions of the outgoing routes prevailing at the time the question is asked. If no pathway is found on a particular route or a no-progress signal is returned from a subsequent exchange, another portion of the same route or even another route may be tried. Thus the marker must be equipped to conduct successive trials until such time as it is arbitrarily decided in the interests of economic operation that the call should be abandoned and busy tone returned to the subscriber.

Whilst route selection is in progress the marker, in association with the charge determination equipment, will be informed of the required meter rate for the particular connection. This information is conveyed to the relay set associated with the line and when the call is connected meter pulses at the required frequency will be transmitted to the subscriber's meter.

Another possible application of automation here is the development of an automatic metering and counting system to replace the present traditional cyclometer type 4- or 5-wheel subscriber's charge meter. In this case, the magnetic drum is being proposed as a convenient storage device. Each subscriber has a section on the magnetic drum on which the meter pulses are recorded in binary form. Separate sections of the drum can be used for recording local and trunk charges for a given subscriber and a particular meter reading may be displayed whilst the unit is in operation. The meter registrations are read out of the drum on to whatever medium is best suited for subsequent processing, magnetic tape, punched tape for a page teleprinter, or punched tape for feeding into a charging computer for the automatic production of subscribers' accounts. Previously, the meters were read either singly or in bulk by photographic methods and the information had to be manually transcribed and subtracted from the previous readings. This automatic development with capacity for 9,000 subscribers on one 9-in. drum is already competitive when compared with the cost of the old mechanical meters and the manual reading effort required.

Having found a suitable route outgoing from the exchange, the marker is then charged with examining the switching possibilities between the subscriber requiring service and the outgoing route, and of selecting and connecting a suitable part. In this context the full advantages of crossbar in link trunked configurations can be realised, especially when these elements are associated with high-speed electronic common marker and memory controls.

Thus the extremely efficient automatic operator or marker has used the information in the code receiver to examine every possibility for connecting the route through the network and through the exchange and will only abandon the call if all attempts fail. Such successive trials lead to highly efficient use of switching plant and junctions but, at the same time, necessitate very high speeds of operation to ensure that the delay between dialling and ringing is a minimum. The speaking path having been established, the marker and code receiver disconnect themselves, clear their stores, and wait for another call.

The modern fully automatic operator not only replaces the manual telephonist but also solves network connection problems far more complicated than those of the early manual days and provides a rapid service which could not be equalled by any human.

Transmission Aspects of Nation-Wide Dialling

Very great progress has been made since the trunk lines depended upon heavy gauge wires and loading coil methods up to the present standards where practically all medium and long distance working is carried on by carrier telephone systems. These modern carrier telephone systems, used on either open wire or on various types of cables, have really transformed the situation. In the usual course of evolution, however, the standards of performance of the systems which were suitable for their initial use have required successive review from time to time. The early carrier installations were for point-to-point working and variations in system stability were not the cause of serious degradation of service. For example, a variation of 2 or 3 db from the nominal line-up figures would scarcely be noticeable by users in the case of a link connecting two towns together and not forming part of a multi-link circuit. As the use of carrier systems expanded, however, it soon became obvious that many calls would be established by placing a number of carrier links in tandem. This immediately raised problems due to variations from the normal performance on the part of each of the links in the complete chain.

When it became technically possible for operators to dial directly into distant cities it became necessary to pay still more strict attention to the performance of the individual carrier links. The performance of the signalling equipment of the carrier channels suddenly began to assume even greater importance than the performance from a talking point of view. It need hardly be stressed that subscribers can accommodate themselves to quite wide variations of working conditions of the telephone trunk line, whereas the signalling equipment in some cases has nothing like the same margin of adaptability. In recent years, therefore, with the widespread adoption of the single operator trunk dialling method, it has been necessary to tighten up pro-

Direct Acting

Pre-set Pulse-Position-Dialling Telephone Set.

Fig. 6.—Types of Push Button Telephones.

gressively the maintenance requirements of all carrier telephone and related transmission equipment.

The proposed adoption of full subscriber dialling in which there will be practically no operators at all introduces another problem. With an operator in charge of the setting up of the call, she can make note of gross degradation of service on individual trunk channels and can make use of alternative choices and can at least take steps to see that technicians take the faulty circuit out of service until it is restored to normal. With full subscriber dialling, obviously it will be much more difficult to deal with this situation. Subscribers will have no means of avoiding a faulty circuit in a group and will be much less favourably placed than the operator in reporting faulty working to the appropriate technician.

Fortunately, the progress in the art of carrier working is such that it is possible to tighten up the performance of the circuits. The introduction of more trunk cables, and particularly the introduction of coaxial-type cables, will go a long way towards providing more stable circuits. The circuits provided by these means also will inherently be less subject to fleeting interruptions and noise troubles. It is clear, however, that considerable attention will be required to many aspects of performance of transmission equipment to ensure the success of full subscriber dialling. Among the new features will be the much greater use of alternative routing which necessarily increases the possible number of links in tandem as compared with the present method where alternative routing is used only in a very restricted manner.

As part of the improvement in performance of individual links it will, of course, be necessary to pay additional attention to the part played by terminal equipment, including existing exchanges and junction line plant. With a nationwide subscriber dialling service necessarily employing a much greater number of links in tandem, even with full 4-wire switching at intermediate points, the performance overall will be very greatly influenced by such factors as return loss of terminal exchanges and junction and subscribers' lines. Another important point will be the noise contribution made by various items of plant and, again, it will be necessary to tighten up the performance requirements in this regard.

Date of Introduction of New Service

The introduction of full subscriber dialling will necessarily be a very gradual process. The first step was the introduction of a new scale of trunk tariffs in October 1959. The simplified trunk tariff structure will go a long way towards reducing the cost of operation even on the present part-manual and part-automatic basis, since it will reduce the amount of clerical and related matters associated with preparation of trunk line dockets by telephonists, etc. Once the date for the introduction of the new scale of tariffs is fixed, active planning for the use of subscriber dialling equipment using these new tariffs can be pushed on.

In the case of fringe areas notable progress can be expected, since it will be possible for much of the existing equipment to be used over a wider area of country without any technical changes at all. In other cases again, it will be possible by relatively simple modifications of existing equipment to extend the range of subscriber dialling so that over a period of a few years it is reasonable to expect quite a percentage of traffic will be carried by subscriber dialling even although the subscribers will not necessarily be able to dial over other than a limited area of country. As full advantage of the new methods such as registers, translators and multi-metering equipment is taken by incorporating them into new plants being installed, it can be expected that the number of subscribers being given automatic access to larger and larger areas of country will be substantially increased in the next few years.

Acknowledgments

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APPENDIX I.

BRITISH POST OFFICE.

TRUNK CALL CHARGES.

Distances	1915	1925	1936	1945	1957	1958
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
35— 50 miles	0 8	1 6	1 3	1 10	1 10	1 9
50— 75 miles	1 0	2 0	1 6	2 3	2 3	2 3
100—125 miles	2 0	3 0	2 0	3 0	3 0	3 0
200—250 miles	3 4	5 6	2 6	3 9	3 9	3 6

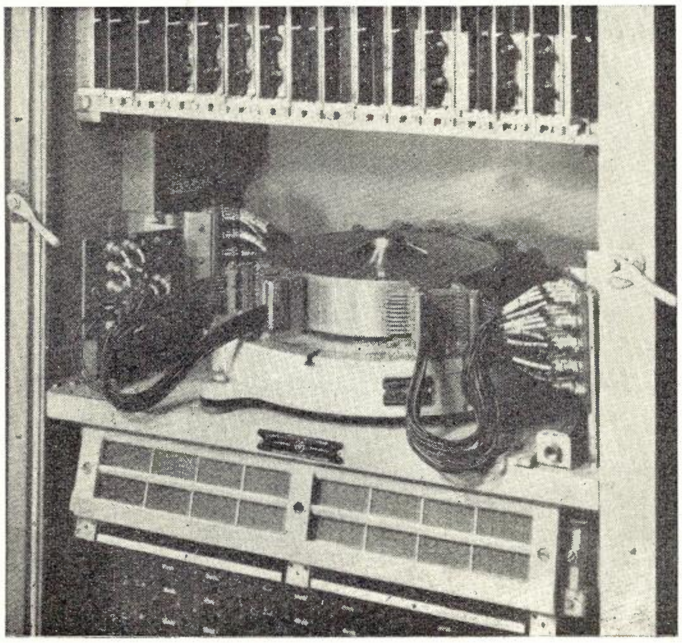

Fig. 7.—Magnetic Drum Translator.

APPENDIX II.

TELEPHONE TRUNK LINE TARIFF SCHEDULE

(Day Rates, 9 a.m. to 6 p.m., only).

Scale prior to October 1959

Miles	Rate per 3 mins.	Miles	Rate per 3 mins.
	s. d.		s. d.
5— 10	0 3	100—150	5 3
10— 15	0 6	150—200	6 6
15— 20	0 9	200—250	7 9
20— 25	1 0	250—300	9 0
25— 30	1 3	300—350	10 3
30— 35	1 6	350—400	11 6
35— 40	1 9	400—500	13 3
40— 50	2 3	500—600	15 0
50— 60	2 9	600—700	16 9
60— 80	3 6	700—800	18 6
80—100	4 0	Over 800	20 0

SOME DEVELOPMENTS IN QUALITATIVE MAINTENANCE

*G. MOOT**

INTRODUCTION

The principles of qualitative maintenance are now being examined and applied by most Telephone Administrations throughout the world. Its introduction in the Australian Post Office was described in a recent article by Mr. H. T. Wright in this Journal (1) and the present article is one of a series which will inevitably appear over the years as we gain experience and knowledge in this important phase of our work.

THE NEED FOR IMPROVED METHODS

This need is twofold. Throughout the world today authorities responsible for the servicing of automatic switching equipment are becoming increasingly conscious of the cost of maintenance. This has lead to some detailed studies as to the precise maintenance requirements of switching equipment and there has emerged a trend towards proper "engineering" of maintenance effort in preference to following the purely routine practices and procedures that have developed over the years. In short, the aim of modern-day maintenance methods is to extract the utmost economical life from plant and to endeavour to justify every maintenance effort expended on the plant on the basis of the real improvement to overall service it will provide.

Apart from the economic aspects the current world wide trend to provide subscriber trunk dialling facilities will, in its own wake, call for improvement and refinement in maintenance techniques. As our local networks expand and we think in terms of a national network the number of sources of faults which can affect a single call becomes astronomical. The need for better methods for reducing the number of faults and locating the more troublesome ones is obvious.

This article sets out some possible lines of development of Qualitative Maintenance embodied in current field trials being conducted in the A.P.O. Because maintenance is largely concerned with correcting and combating faults, the first section of the article gives a brief discussion of their causes and effects.

CAUSES AND EFFECTS OF FAULTS

Faults due to Mechanical Wear: Mechanical wear generally causes faults in switching systems, but whereas fear of the consequences of this wear once drove us to the regular checking and, where necessary, correcting of all mechanical adjustments, a more realistic outlook prevails today. The current outlook may be summarised as follows:—

Once mechanism adjustments have become stabilised after an initial period of service the maximum fault-free service is obtained if those adjustments are left undisturbed. This is based on the concept of bearing and mating surfaces becoming burnished or "work hardened" over the area of contact and their rate of wear being reduced as they become more firmly "bedded down". This is, of course, contingent upon proper mechanical design and choice of materials. As alterations to mechanical adjustments will disturb this relation between contacting surfaces and start off further wear, we should ensure that only the really essential readjustments are performed.

This raises the question as to what are "essential readjustments". In attempting to answer this we must keep in mind that many of the adjustment tolerances set down for the individual components of a switch have no absolute value but are mainly empirical and are laid down as being mean points suitable for application to a large number of mass-produced parts. Skilled adjusters may differ in their interpretation of a certain adjustment, particularly if it is critical in method of measurement.

This brings us to face one of the important fundamentals of qualitative maintenance, i.e., the need to devise better methods of checking an item of equipment (without recourse to checking each individual adjustment) in such a way as to ensure that its overall performance is now, and will continue for some time, to be reliable. Severe marginal testing is one commonly-used method; other possible aproaches include artificial mechanical vibration of switches to highlight poor contacts on relays and mechanical springs and tone transmission tests applied to speech paths. Most types of equipment have well-known weaknesses and the aim is to direct attention to these, rather than engage in meticulous checking of all individual adjustments.

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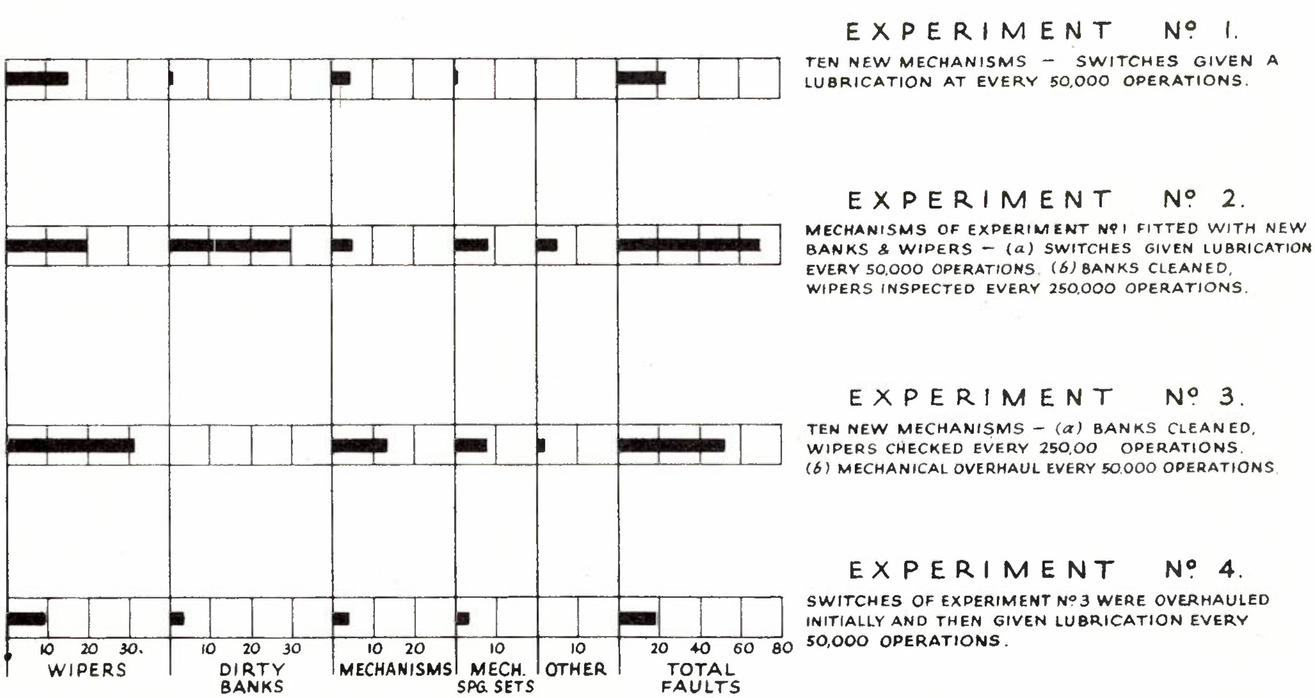


Fig. 1.—Summary of Selector Faults in A. T. & E. Co. Trials.

The effect of unnecessary readjustment work on mechanical switches was demonstrated in a series of experiments conducted some time ago by the A. T. & E. Co. of England (2). The results of these experiments are briefly summarised in the graphs of Fig. 1. They speak for themselves, even after due allowance is made for the difference between artificial life tests and actual field conditions.

Faults due to Human Error: The most highly skilled technician makes mistakes, or near mistakes, in the course of an intensive week of checking and adjusting switches. A source of potential trouble is the tightening of screws and lock nuts; it is quite easy for a technician to either overtighten and strain a screw thread or leave it loose. Add to this the work of inexperienced staff and we have a case for curtailing the activity of staff on equipment. The spate of bimotional switch wiper faults following a wiper inspection and bank-cleaning routine is witness to the seriousness of this problem.

Faults due to Dust and Tarnish: Dust and tarnish on relay contacts and wipers are both well-known as common sources of trouble. Actually it is not always clear to the faultman whether the fault is due to dust or contact tarnishing but the cure is the same, i.e., clean the contacts.

The appearance of tarnish or discolouring on a contact surface is not always a reliable guide of its functional efficiency. A Bell Laboratories investigation revealed that the thin sulphide layer caused by sulphurated hydrogen from industrial processes is not considered to be detrimental to contacts. One overseas administration has indicated recently that several of its exchanges have bimotional switch banks which are very much discoloured or tarnished but there is no evidence to suggest that they cause either switching trouble or noise. On the other hand, they have banks of reasonably good appearance which do cause noise troubles, all of which means that we must devise ways and means of objectively proving that what appears defective to the eye is actually so in service.

Dust and fibres derived from clothing, cabling and even the skin are a continuous source of trouble in telephone exchange equipment. This dust and fibre originates from both inside and outside the equipment room. There is a general trend toward the provision of dust-free switching equipment rooms and the use of dust-proof covers to enclose the whole of an equipment rack. All the evidence points to the need to reduce the movement of staff in the switching room to a bare minimum and this has led to such features as segregation of test desk and other activities from the switchroom and the attempt to make it a "closed room" as far as practicable. Such measures cannot, of course, be fully effective if the normal maintenance programme provides for frequent removal of switch covers and continuous staff activity amongst the equipment. In Japanese telephone exchanges the staff is provided with special lint free coats to help reduce contact troubles.

Effects of Humidity Changes: These effects have been summarised by L. M. Ericssons of Stockholm as follows:—

"It can be proved that the concentration of dust is effected by increased humidity owing to increased sedimentary separation. The light dust particles are, of course, weighed down by the higher specific gravity of the water particles. It has furthermore been pointed out in the literature that dust particles become less statically charged in wet air than in dry air. At low humidities the generation of dust from, for example, cotton insulated wires, clothing of maintenance personnel, and beeswaxed floors, also increases.

The humidity must not be too high in view of the risk of corrosion and poor insulation in bundles of cables and multiples. It must not be too low in view of the increased dust concentration and drying of the oxide layer on the contacts, leading to variation in contact resistance (noise).

Moreover, the humidity must not vary too much in view of changes that may occur in certain materials employed in the equipment (hydroscopic effect). Investigations that have been made, and especially experience from plants that have been in service for a long time, show that a constant level of humidity within the range of 55 to 70 per cent. relative humidity is the most desirable. The variations of temperature that occur within the temperate zones have no provable influence on the functions of the equipment if the relative humidity is kept constant."

Initial Installation Faults: No matter how much testing and checking is conducted before a new installation is placed in service it takes some 18 months at least of service to reveal the majority of faults due to defective manufacture or installation. Defective mechanical adjustments, poor soldering, faulty wiring, defective coils are typical of the defects which must be expected during the first year or so of service.

FAULT LIABILITY OF A SWITCHING SYSTEM

Switching systems are designed and manufactured with an eye to economics and it follows that they will have inherent weaknesses. The designers of modern switching systems have aimed at two major objectives:—

(1) The use of more flexible and economical methods of call routing.

(2) A substantial reduction in overall maintenance costs at the same time maintaining a high grade of service.

The second objective is achieved by:—

(a) The use of more reliable components.

(b) A reduction in the total volume of switching plant by the use of more efficient trunking schemes.

(c) The use of devices within the system which screen the public from the ill affects of those faults which do occur. Random choice of switching paths for successive calls to the same destination is an example of this.

The real purpose of exchange maintenance is not so much to keep equipment entirely fault-free but rather to ensure that faults cause a minimum of interference to service before they are detected. Therefore, faults should be classified according to their effect on the service. Because an open circuit trunk in a grading from homing type uniselectors will be passed over automatically, it obviously should not be regarded in the same light as a faulty early choice selector. Mr. Preist of the A. T. & E. Co. (England) has classified faults as right-sided and left-sided, whilst the Swedish P.T.T. refers to A and B faults. **The point is that faults in themselves are not significant, it is their effect on the grade of service that is important, and this should largely determine the amount of effort employed to locate them.**

A difficulty exists in distinguishing between faults and so-called unstandard conditions. In present Australian Post Office practice a fault is regarded as any condition discovered by routine testing or reported by the subscriber which in the opinion of the technician prevents an item of plant performing its proper function in service. Any other condition which, while not completely satisfactory, is still not preventing the item of plant performing its proper function in service is classified as an unstandard condition. It is characteristic of our present system of routine testing that many conditions found are classified as unstandard conditions. As qualitative maintenance is developed there may be less place for the concept of the unstandard condition. Faults seriously affecting service must be promptly cleared, all other conditions should not be the concern of staff engaged on day to day maintenance.

Faults can also be classified as predictable and unpredictable. Faults due to wear and tear are largely predictable as compared to accidental faults such as installation faults and those resulting directly or indirectly from maintenance activity. Faults caused by an exchange faultman in the course of a day's duty are particularly troublesome because they are unpredictable on two counts, namely when they will occur and where they will occur. One of the greatest foes to orderly and systematic maintenance is the occurrence of random unpredictable faults.

AIMS OF QUALITATIVE MAINTENANCE

The essential difference between qualitative maintenance and preventive maintenance is that where the latter places emphasis on regular attention to the individual components of an exchange and assumes that this attention must result in a satisfactory overall service, the former starts off by measuring the overall grade of service and directs attention to the individual components which appear to be adversely affecting this service.

Under qualitative maintenance use is made of indicators to determine the overall grade of service given by a telephone exchange and the condition of the individual selectors, relay sets, etc., in the

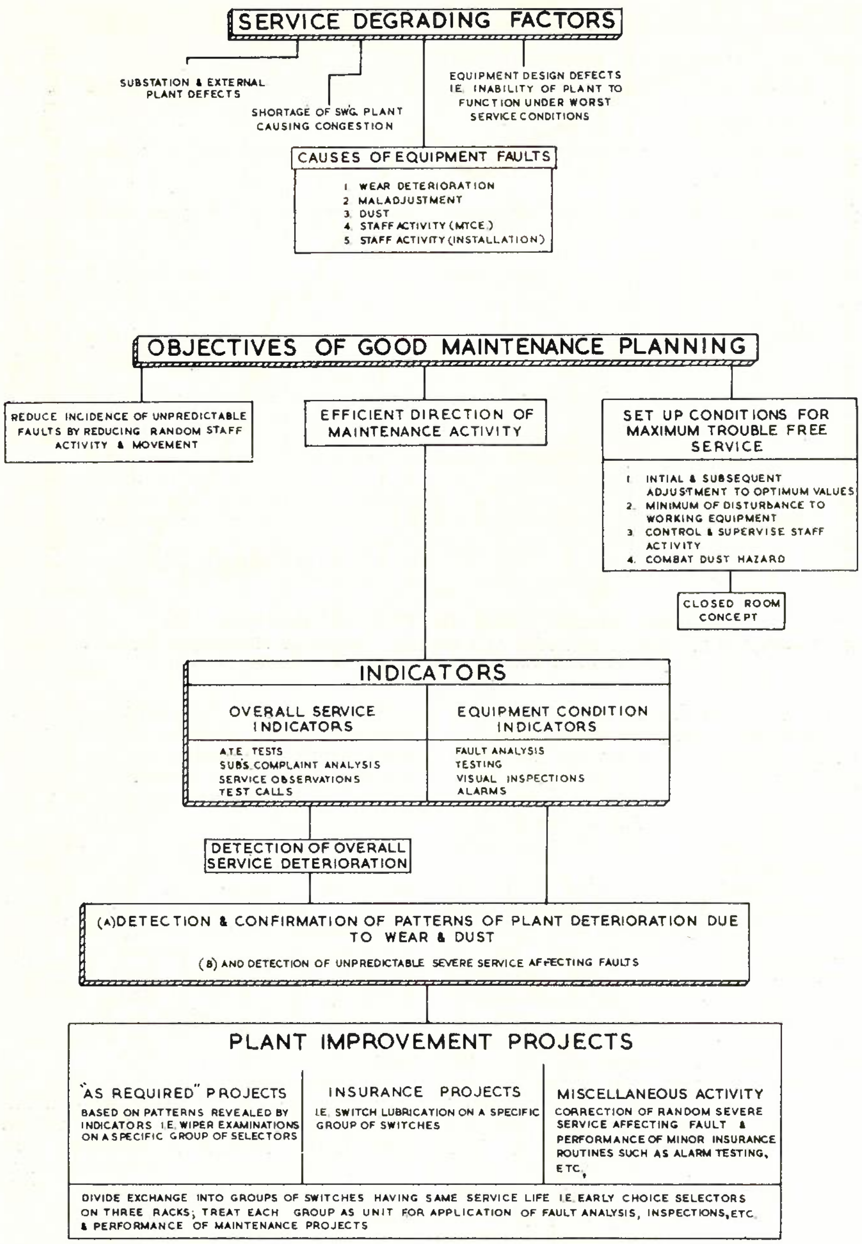


Fig. 2.—Plan of Total Qualitative Maintenance Principles.

exchange. Subscribers' complaint analysis, service observation results and test calls from artificial traffic equipment (A.T.E.) may be regarded as *Overall Service Indicators,* whilst equipment fault records, results of testing of individual sections of the plant and visual inspections of the plant can be regarded as **Equipment Condition Indicators.** The object is to perform major maintenance projects such as bank cleaning, wiper inspections and equipment overhauls or partial overhauls, according to the actual service needs of the equipment as revealed by the Overall Service Indicators and the Equipment Condition Indicators.

Faults in switching equipment are either the result of wear and deterioration of plant, and, as such, are largely predictable, or they are purely random failures and are unpredictable both with respect to when and where they will occur.

A fundamental objective of qualitative maintenance is the reduction of random faults to a minimum by planning maintenance activities so that disturbance of the equipment by the maintenance staff is avoided as far as practicable. With undisturbed equipment working in reasonably dust-free surroundings, the majority of faults are due to wear and deterioration of the plant.

The above-mentioned indicators are used to detect patterns of plant deterioration so that specific maintenance projects can be undertaken to combat the deterioration just prior to the stage when it would cause a severe degradation in overall service. Under ideal conditions the telephone exchange becomes a "closed room" and maintenance staff would only go into that room when the indicators suggest there is a real need to do so.

This approach calls for something more than the convention of doing things by the "calendar". It can well turn out that some work is best done on a calendar basis but at least we should justify it in each specific case.

A PLAN OF QUALITATIVE MAINTENANCE

A plan of qualitative maintenance applicable to a step by step exchange is illustrated in Fig. 2. The important features may be summarised as follows:—

(i) Every effort is made to establish conditions for maximum fault-free service on the individual items of equipment, viz:—

(a) Intitial or subsequent adjustments are performed to the closest practical tolerances.

(b) Once the equipment is working well it is left undisturbed until some essential maintenance activity is justified.

(c) The equipment must be kept as free as possible from dust.

(ii) The incidence of random faults is reduced to a minimum by the reduction of staff movement and activity in the switch-room. In short, we aim at "a closed room" principle.

(iii) The trend in grade of service as seen by the overall service indicators, such as subscribers' complaints, observation results, and A.T.E. tests, is watched to see if a pattern of plant deterioration is forming.

(iv) When the overall service indicators suggest that a pattern of deterioration is forming, the plant condition indicators such as fault analysis results, testing and visual inspections are applied to determine the actual equipment causing the deterioration, the nature of the defects and the corrective action required.

(v) Specific maintenance projects such as bank cleaning, wiper adjustments, relay examinations, mechanism adjustment and parts-changing are carried out on groups of switches as required, according to their real service needs as revealed by the indicators. It is desirable to establish approximately uniform conditions on groups of switches subject to the same service conditions. Projects are carried out on the group of switches according to its need from an overall service viewpoint. For this purpose the exchange is divided into groups of early middle and late choice switches so that the heavily worked switches receive separate attention to the comparatively lightly-worked later-choice switches. The justification for this division into early middle and late choice groups is seen by the graph of switch operations versus position in grading (see Fig. 3). It will be seen that the first 25% of the switches may operate 60,000 times per year whilst the last 25% may operate 1,000 times per year. The lightly worked switches at the end of the grading might well be considered as having different requirements by way of type and frequency of lubrication, bank cleaning, testing frequency, etc.

It will be seen that this approach to exchange maintenance places emphasis on the measurement or detection of trends in the overall grade of service given by the plant. Individual items or groups of plant are important only in so far as they affect this overall grade of service. At the present stage of development of qualitative maintenance in the A.P.O. we have to rely very much on the equipment condition indicators to judge the need or otherwise for maintenance projects. It is not unreasonable to expect that the development of overall service indicators, particularly in the form of artificial traffic equipment, will provide a more efficient means of maintenance control.

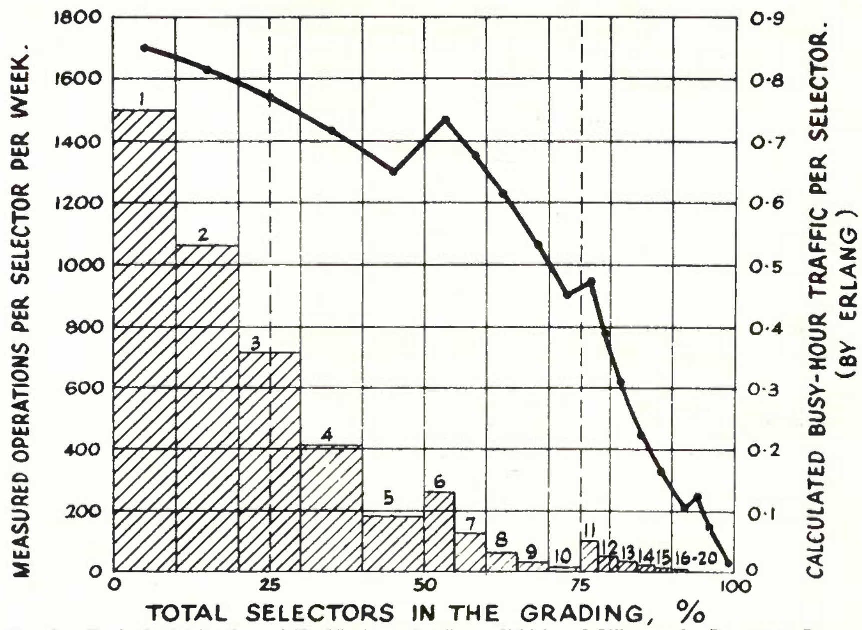


Fig. 3.—Typical Distribution of Traffic in a Grading. Widths of Pillargraphs Represent Proportions of 1st, 2nd Choices in a Typical 2nd Selector Grading.

OVERALL SERVICE INDICATORS

Artificial Traffic Equipment (A.T.E.): It is becoming increasingly apparent that, irrespective of the nature of tests conducted on individual items comprising a telephone network, i.e., selectors, junctions, trunk circuits, etc., there is a need to conduct overall or "end-to-end" tests to ensure that the intended overall result is actually achieved. This is becoming more important in an expanding network composed of old and new equipment.

Artificial traffic equipment provides for the automatic setting-up of test calls between a group of test numbers. In one such equipment 25 spare subscribers' numbers are connected to the test unit and test calls are set up from each number to the remaining 24 numbers in turn. By selecting test numbers in various 200 line groups, test calls are routed over a representative portion of the exchange switching equipment. Meters on the artificial traffic unit indicate number of test calls made, the number of calls encountering congestion and the number of faulty calls. When a fault is encountered, the fautly call can be held and information obtained as to the calling and called test number, and the nature of the fault encountered.

The prime purpose of A.T.E. is to measure the grade of service given by an exchange or part of a network. Under this method of use no effort is made to clear the fault conditions found; one is interested simply in determining the grade of service as it actually exists. In this regard it is hoped to develop the A.T.E. as the most effective direct indicator of overall service given by switching equipment and so use it to control our general maintenance activity. It may not be too much to hope that not only bank cleaning, wiper inspections, etc., but also fault clearance work can be reguated by A.T.E. results.

The second use of A.T.E. can be as a fault finder by holding and tracing faulty calls. Use of A.T.E. in this manner may be desirable during the initial stages of an investigation in order to determine precisely the nature of a trouble being encountered but thereafter a more direct and systematic approach in the form of individual switch tests or inspections should be considered.

Dr. Elldin and Mr. Lind of L. M. Ericsson have developed a method using artificial traffic equipment as a means of statistical quality control for use in crossbar exchanges. This particular method employs the principle of sequential analysis, in which tests calls are made and the number of faults recorded until it can be ascertained that the exchange is giving a grade of service better or worse than a predetermined standard. A typical example of this method is illustrated in Fig. 4. The number of faults observed for each 1,000 test connections is plotted on the graph. The testing continues until the test curve crosses one of the limit curves A or B. If the test curve crosses the limit curve B, the exchange fault incidence can be said to be less than one call failure in 2,000 calls. If the test curve crosses curve A, the exchange-fault incidence can be said to be greater than one call failure in 2,000. Whilst the test curve lies between the curves A and B, no firm conclusion can be reached and further tests must be conducted. The limit curves shown in the graph allow for a 5 per cent risk of error in reaching a wrong conclusion. The method assumes that the switching path for each test connection is chosen on a purely chance basis and that the fault incidence is constant and small. Random choice of outlets is a feature of crossbar switching. The method does not determine the absolute value of the grade of service; it enables a decision to be made as to whether the grade of service is above or below a certain predetermined figure.

The Australian Post Office is at present developing artificial traffic equipment which will enable test calls to be originated from any one part of an exchange or a telephone network to a test number located in any part of the network. This will be achieved by associating the A.T.E. facilities with the present automatic routiners, so that when a switch is seized by the routiner access equipment a test call is originated from the switch instead of performing a series of tests on the switch itself (3). It is hoped by this means to readily measure the grade of service given by any portion of the plant, and so decide when maintenance attention is required.

It seems logical to suggest that the correct procedure in designing a maintenance plan is to conduct overall tests in the network or exchange concerned and then design additional indicators in the form of test equipment, fault records, equipment inspections in the light of the results of these overall tests.

Subscribers' Complaints Analysis: The Bell System use analysis of subscribers' complaints quite extensively in their maintenance work. It does not follow that the average grade of service must be very poor for such an analysis to be useful.

Routine testing would have to be performed at a prohibitive frequency if every fault is to be detected before it gives rise to a complaint. The fact is that complaints due to faults are inevitable and the object is to use the complaint data as a service indicator where this is practical.

Complaints analysis will help detect faults in originating and terminating equipment; the problem is to set up a cheap yet efficient analysis system and this is not easy in our large networks of small and medium size exchanges. It may well be that a sampling technique, whereby a detailed analysis is made over a short period, of all "can't call out" complaints originating from a group of subscribers or "can't be called" complaints for calls to a particular group of subscribers is the best method of using this information.

Service Observation Results: Service observation are carried out by most telephone administrations as a means of measuring trends in overall grade of service. By such means a telephone administration is able to determine whether or not the subscribers are obtaining a service which is satisfactory and not subject to junction blockage, switch congestion or unsatisfactory equipment performance at a particular point in the network. Service observations are the only real indication of the overall grade of service, because switching equipment, external plant and substation equipment are all seen in action together to produce the service required. The limitation of this type of indicator is that the actual cause of call failure is not readily revealed due to the many variables present.

The introduction of 1st selector observations should facilitate taking larger and hence statistically more reliable samples for individual telephone exchanges. If it is known that the average grade of service given to the subscribers at an exchange is 2.0% calls lost due to equipment failure then even in a sample of 800 observed calls, we could expect a grade of service in the range 1.0% to 3.0% at 95 percent confidence limits.

When sufficient service observations are being taken as to be reliable statistically, they should at least serve the purpose of indicating:—

(a) Any individual exchange in which subscribers are experiencing a poor grade of service.

(b) General trends in the average grade of service for a network as a whole.

The development of artificial traffic equipment should enable the questions raised by service observation results to be more adequately followed up.

EQUIPMENT CONDITION INDICATORS

Routine Testing: The testing of all major switches and junctions in a telephone exchange once or twice per week has been a feature of telephone-exchange maintenance for years. The results of routine testing are a form of plant condition indicator as mentioned previously. As a plant condition indicator, routine testing has certain limitations and it is possible that its role in exchange maintenance may change when overall service indicators are more fully developed.

If equipment is placed in reasonable working order, is located in reasonably clean surroundings, has ample margin in design to meet service requirements and is not unduly interfered with, then most faults would be of a predictable nature, i.e., they are due to wear and tear of plant. The incidence of purely random unpredictable faults would be small. Under these conditions there would be no real justification for frequent testing of the equipment in the form of either functional or marginal tests.

Marginal tests help to measure the degree of deterioration of plant. For example, the loss of release lag on a relay can be measured by marginal relay timing tests. As such, these tests should not be applied frequently but only for purposes of equipment readjustment or as an aid to determining the degree of plant deterioration when other indicators have suggested trouble exists.

Functional tests will only detect the extent of plant deterioration when it has reached the stage of causing a service failure. This basic limitation of the "go" or "not go" test is not always fully appreciated, and it is sometimes assumed that because a switch passes a certain test it must be satisfactory, whereas it could fail on the next service call. For example, a 2000-type selector may be reaching the stage where it will fail to latch on release. Functional testing will not indicate this until it has actually failed.

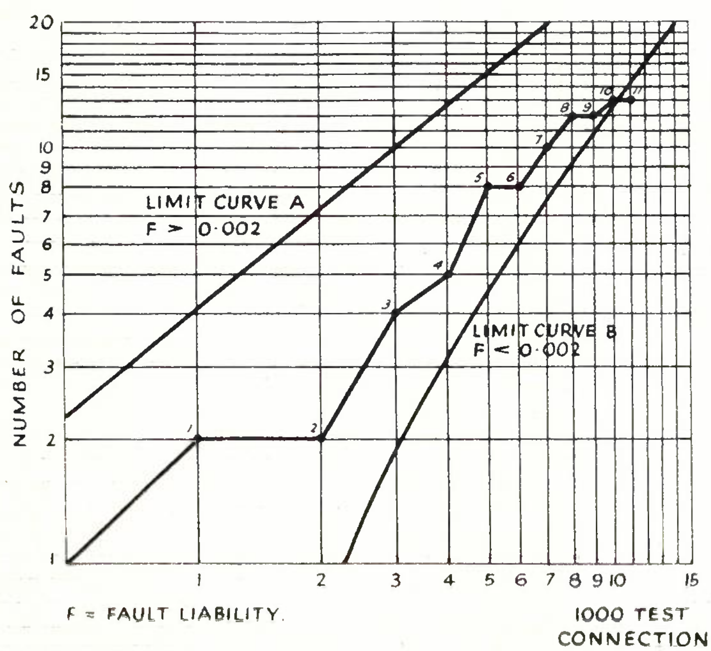
If we could readily measure the state of all mechanical adjustments, the maintenance problem would be simplified. Where we cannot do this readily, we have to rely on visual inspections and observation of switches in action if we want to know the real likelihood of failure in service. This emphasises the point made earlier as to the need for improved methods of checking equipment.

The Bell System regard testing as an aid to the detection of fault patterns, or patterns of deterioration. Marginal tests should be applied very infrequently and only on an "as required" basis. Functional testing should be performed objectively, i.e., the results should be examined to see if they are indicative of a general fault pattern.

Frequent functional testing would only be justified where the incidence of purely random faults is high. The aim of good maintenance planning is to reduce the incidence of purely random faults to a minimum so that the need for frequent testing can be reduced or eliminated. Sometimes short term conditions may impel frequent testing. In all cases the aim should be to remove the basic defects which give rise to the need for testing frequently.

The Bell System outlook is interesting; it may be summarised as follows:—

"The probability that service-affecting failures can be located by routine tests



DAY	SUM OF CONNECTIONS	EXPECTED Nº FAULTS AT 2%	Nº FAULTS OBSERVED EACH DAY	SUM OF FAULTS OBSERVED
1	1,000	2	2	2
2	2,000	4	0	2
3	3,000	6	2	4
4	4,000	8	1	5
5	5,000	10	3	8
6	6,000	12	0	8
7	7,000	14	2	10
8	8,000	16	2	12
9	9,000	18	0	12
10	10,000	20	1	13
11	11,000	22	0	13

Fig. 4.—Qualitative Service Control Graph.

before they affect service calls is in proportion to the ratio of test calls to service calls. Considering the frequency with which a particular circuit is used in regular service it would be necessary to make routine tests at a prohibitive frequency in order to minimise the chance of service reactions. Routine testing is not recommended as a method of securing service improvement in equipment conditions. Scheduled routine tests, used to find specific troubles and to provide information for analytical purposes, should be expanded or curtailed as they meet those needs."

As an example of the above, a first choice final selector may fail completely just after it has passed its weekly functional test; some subscriber reaction is certain and unavoidable in this case.

At least one large overseas maintenance organisation favours simple manual tests sets in preference to automatic routiners and this for the very reason that frequent testing should not always be required. Simple tests are devised to meet specific needs and applied when required. In the past we have tended to maintain our equipment to pass the automatic routiner standards rather than to meet actual service needs.

The ability of the automatic routiner to apply tests at a low labour cost is such as to justify its use when large quantities of complicated equipment are being maintained.

Provided the routiners are such that maintenance staff can select specific tests to be applied as required and are not forced to apply all tests, critical or non-critical, whenever the routiner is used, then such equipment can continue to play an important role in exchange maintenance. In particular, the routiners should be capable of applying a short non-critical test cycle to check the more important functions of the equipment.

The main thing required in a large telephone exchange having many individual switches or relay sets as in step-by-step systems is a flexible automatic access to the switches and relay sets; an access to which can be readily attached, by patching or keys, such facilities as observations, Artificial Traffic Equipment, and specific test cycles, either short non-critical cycles or a marginal test cycle. The facility to introduce new tests or modify existing tests is more important than the provision of a complicated routiner with a series of comprehensive tests which must be applied every time the routiner is used whether they are all required or not.

Visual Inspection of Plant: The visual inspection technique carefully applied on an "as required" basis can be an effective aid to determining the existence and extent of patterns of plant deterioration. The Bell System recommends the use of combined test-inspections in preference to frequent testing for the reasons mentioned above.

The inspection technique should be used after the overall service indicators have suggested that detailed investigation is required in a section of the plant.

Quick visual inspections should not degenerate into the very thing we are out to avoid, i.e., needless "tinkering" with plant. Any inspection of equipment is certain to reveal some unstandard conditions which we would prefer to see corrected. The inspection should have a

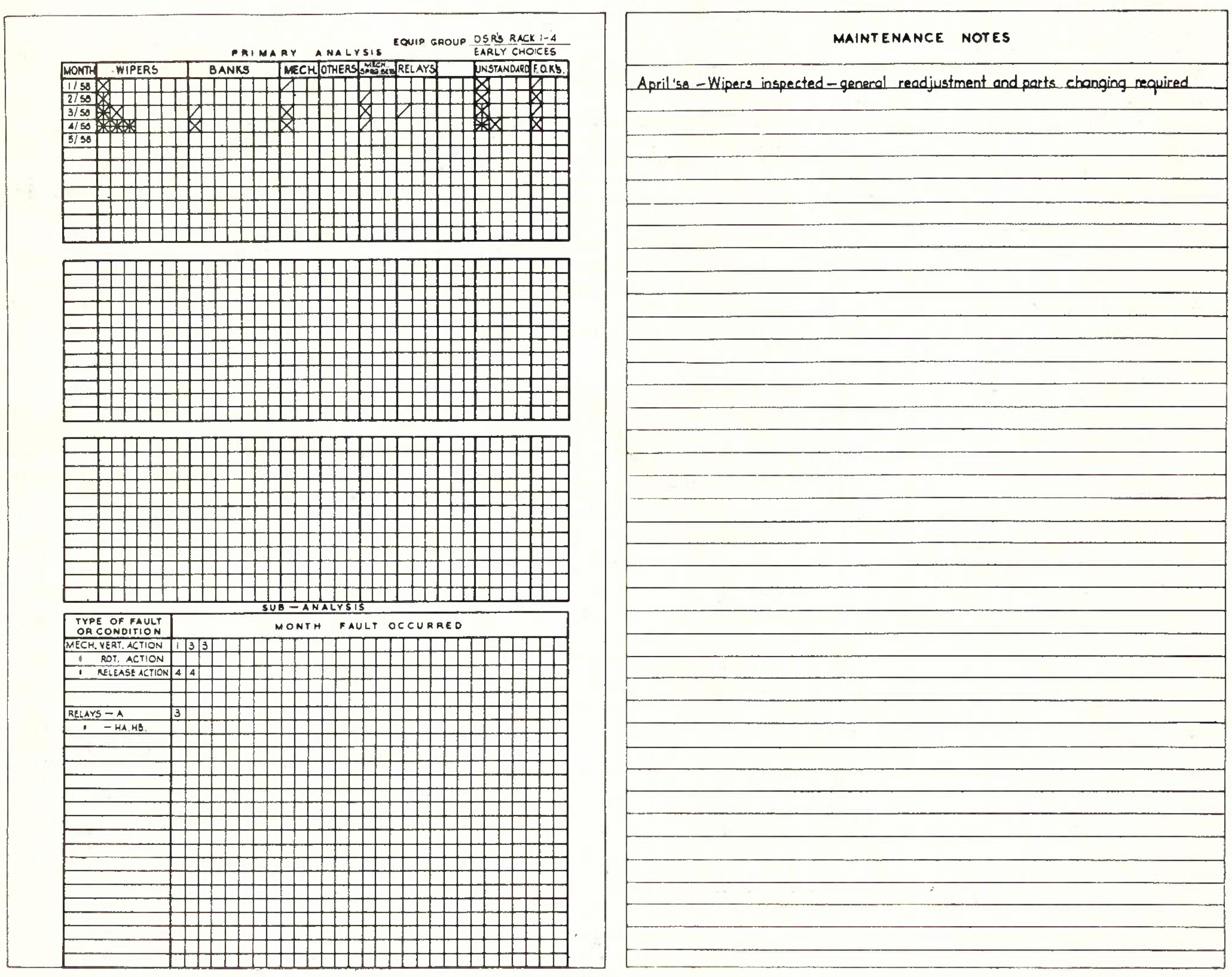


Fig. 5.—Equipment Fault Analysis.

real purpose in view, i.e., to determine the degree or extent of a specific aspect of plant deterioration, and it should discriminate between isolated cases of faulty switches as distinct from a general pattern of deterioration. As it will require the removal of switch covers in some cases it should only be applied on an "as required" basis.

From the previous remarks concerning the limitations of functional tests as an aid to determining plant deterioration, it will be seen that the inspection technique is at least one method of determining the degree of plant deterioration where it cannot be determined by methods such as marginal testing.

Fault Analysis: Analysis of faults on switching equipment is one of the most prominent equipment condition indicators used in both the A.P.O. and many overseas telephone administrations. At the outset we must be clear on the purpose for which such analysis will be used and design a system of analysis accordingly. Whilst this may be stating the obvious, there is the constant temptation to design a system of recording and then determine the uses that can be made of it.

Fault analysis can be used for two specific purposes:—

(a) To provide information on design and manufacturing weakness of items of plant.

(b) As an equipment condition indicator to aid in the direction of maintenance activity in an exchange.

With the present A.P.O. fault recording system the number of faults occurring on selectors, repeaters, D.S.R.'s final selectors, etc., is recorded daily under broad categories such as wipers and banks, relays, mechanicals, interrupter springs, off normal and cam springs and total faults. The daily entries are totalled each month and a monthly record compiled from which graphs are drawn to provide a visual indication of trends. In addition an individual history of faults is kept for all major switches. This latter record has proved its worth in identifying individual switches which are frequently failing to pass routine tests. Such switches are given a special examination and if necessary completely overhauled. In fact this is the basis on which switch overhauls or partial overhauls are done as distinct from the previous system of regular inspections and overhauls.

The rise and fall of a fault graph covering say all final selectors can be due to a number of factors other than deterioration of the equipment concerned. The performance of a routine examination such as bank cleaning, slight marginal variation in one of the testing conditions applied by a routiner, one or two new inexperienced staff members, the availability of staff for regular testing can easily cause an upward trend in the graph. Further, there is always the doubt as to whether a constant and low incidence of faults means that all is well anyhow. When the graph takes a sharp rise it does at least pose a question which may lead to an investigation. **The important thing is not to regard Fault statistics as the sole indicator of plant performance efficiency.**

Trials are at present being undertaken with a system of stroke recording as indicated in Fig. 5. Each record sheet covers only a portion of the plant, e.g., early choice D.S.R.s, and provision is made for the insertion of maintenance notes which will provide a maintenance history of the group of equipment and give clarification to the fault record. This is part of the feature mentioned earlier of dividing the exchange into equipment groups each of which contains switches having a similar service life in terms of number of switch operations per week. This system places less emphasis on total fault statistics, which can be readily compiled once per month or quarter as required.

Provision has been made for a primary analysis of faults at the top of the form with a more detailed sub analysis at the bottom to be used as required for each individual group of equipment. In general, detailed fault analysis is costly and is not always justified; hence the need for flexibility in its use.

Fault analysis tells us only part of the story. How much effort we ultimately put into it will depend on the effectiveness of other indicators such as A.T.E. tests, improved test inspection techniques, etc. If for instance we can develop a test-inspection technique which would ensure that a switch can be placed in service or later checked in service with a 99% assurance that it will function reliably for a further specified period of time, say 6 months, then the need for an elaborate fault recording system is considerably reduced.

COMMON CONTROL INDICATORS

Although not directly applicable to step-by-step equipment, it is of interest to observe the elegant use of common control indicators in the common control equipment of crossbar and 500 point selector exchanges. One such device provides a typed record of the no-progress calls handled by a register. The number of the calling party, the called party and the equipment seized during the faulty call are recorded. The powerful aid this gives to a streamlined main-

LEGEND WORK DONE BANK CLEANING LUBRICATION 2 WIPER ADJUSTMENT 3
WORK REQUIRED TO BE DONE " " 6 " 7 " " 8

EQUIPMENT GROUP	CH.	YEAR ____												YEAR ____											
		JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC
1ST. SELECTORS	E	12					7					123													
	M			12										12											
	L					12									12						8		123		
2ND. SELECTORS	E	2							123																
	M				2							123									12				
	L						123							2								8			
	E																								
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EQUIPMENT GROUP	CH.	YEAR ____												YEAR ____											
		JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC
1ST. SELECTORS	E																								
	M																								
	L																								
2ND. SELECTORS	E																								
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Fig. 6.—Maintenance Projects Record.

tenance effort can be readily imagined. Some would regard common control equipment as an essentially weak link in a switching system, and yet here is an example of where well designed common control equipment is not only reliable in itself but provides a valuable maintenance aid.

CURRENT TRIALS IN TOTAL QUALITATIVE MAINTENANCE

Some of the above-mentioned principles are incorporated in current trials in what has been called Total Qualitative Maintenance.

Several exchanges in Sydney, Melbourne, Brisbane and Adelaide are engaged in these trials and it is hoped from these to develop a system of maintenance most suited to Australian network conditions. This does not imply a return to a rigid and uniform system of maintenance. Certain features such as fault recording, work scheduling recording, statistical use of A.T.E., must be uniform for obvious reasons but the exchange supervising technician must apply the indicators and interpret the results individually for his exchange.

The departure from purely routine maintenance procedures calls for more skill in the management of exchange staff. Work scheduling becomes more difficult; Fig. 6 shows a form being used in the current trials to help overcome this particular difficulty. The equipment groups are those mentioned under Fault Recording and shown at the bottom of Fig. 2. The letters E, M and L stand for early, middle and late choice groups. This form of record gives an overall picture of the state of progress of maintenance projects such as switch lubrication, bank cleaning, wiper inspections, etc., with respect to when such work was last done. As such it draws attention to those groups which may soon be in need of further attention to the extent that the calendar is a criterion. Furthermore, it provides for the convenient recording of projects which have been temporarily deferred due to lack of material, staff, or because it is desired to incorporate such a project with the next "essential" project, e.g., switch lubrication.

It will be seen that the system aims to create uniformity within equipment groups rather than to treat the exchange as being composed of hundreds of individual switches.

SOME FURTHER CONSIDERATIONS

It is evident that qualitative maintenance is not just the abandonment of all regular maintenance activities and ignoring the experience of the past. It can be taken as a guiding rule that when an activity or record is abandoned in the transition from Preventive Maintenance to Qualitative Maintenance, one must be careful to watch for the repercussions to ensure that they are not harmful to the overall plan.

In multi-exchange networks the problem of "supervising" the grade of service given over the various junction routes requires consideration. This cannot be solved satisfactorily by each Supervising Technician from his own telephone exchange. As subscriber trunk dialling expands so does the size and importance of this problem. Again it looks as though artificial traffic equipment will come to our aid and a carefully prepared programme of test calls from selected sources to selected destinations will be required.

In the future we will be required to apply statistical methods to our problems to a far greater extent. Maintenance engineering frequently calls for repeated and numerous measurements and observations on equipment conditions or on telephone calls; such repeated measurements are often distributed in accordance with one of the elementary statistical distributions, and conventional statistical methods can be applied with advantage when evaluating such results.

A classic example of this approach is the Bell System technique of automatically measuring and recording the transmission equivalents of trunk telephone channels and applying corrective action based on a statistical analysis of the results. The method of statistical quality control for analysis of A.T.E. results, as mentioned earlier, is another good example.

In our desire to increase the efficiency of maintenance on switching equipment we must not overlook some other features of general exchange maintenance which require improvement. The development by the B.P.O. of (i) an automatic line insulation routiner which automatically tests subscribers' lines for correct resistance, and (ii) the Automatic Subscribers' Service Tester which enables a substation installation or maintenance technician to check a service by calling a test number which automatically applies the tests applied by a test desk, should both help to increase the efficiency in testing of subscribers' services.

CONCLUSION

As mentioned at the beginning of this article, maintenance engineering is assuming greater importance than has hitherto been the case. Both the economic issue and the problems presented by subscriber trunk dialling are causing this to be so. For the engineer and technician maintenance promises to become more interesting because of the introduction of analytical processes and greater emphasis on careful direction of maintenance effort as distinct from the purely routine procedures of the past.

For the staff performing the actual maintenance projects there will be greater satisfaction when the improvement to service resulting from completion of a project can be observed as an accomplished fact.

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TRAFFIC DISPERSION IN THE MELBOURNE METROPOLITAN NETWORK

*J. F. RYAN**

GENERAL

The principal method used for measuring traffic in the Melbourne Network is by means of resistor type traffic recorders. The results obtained are useful in determining the grade of service experienced by subscribers, and in devising means of relieving congestion, but are limited in their application to the design of a network which will employ register controlled crossbar techniques rather than the existing Strowger bi-motional system.

To design the crossbar network a more detailed knowledge is required of the dispersal of traffic from each exchange. To meet this and other planning needs the Call Dispersion Recorder was developed to register the proportion of calls from each exchange to other exchanges in the network. For over two years the present equipment has been in operation and has recorded the dispersal of calls from two hundred thousand subscribers.

In itself, call dispersion is only a rough approximation to telephone traffic dispersion, for, the time duration of calls varies considerably according to their social and business content. Accordingly measurements have been taken to determine the average holding time of calls between exchange groups. From the holding time measurements a function of the holding time for the various terminating groups is obtained, and this is used to weight call dispersion and give traffic dispersion. That is, the percentage of calls to each group is multiplied by the holding time function of the terminating group, the product is summed, and the individual products are reduced to a percentage. This latter percentage is a sufficiently close approximation to traffic dispersion for most planning purposes.

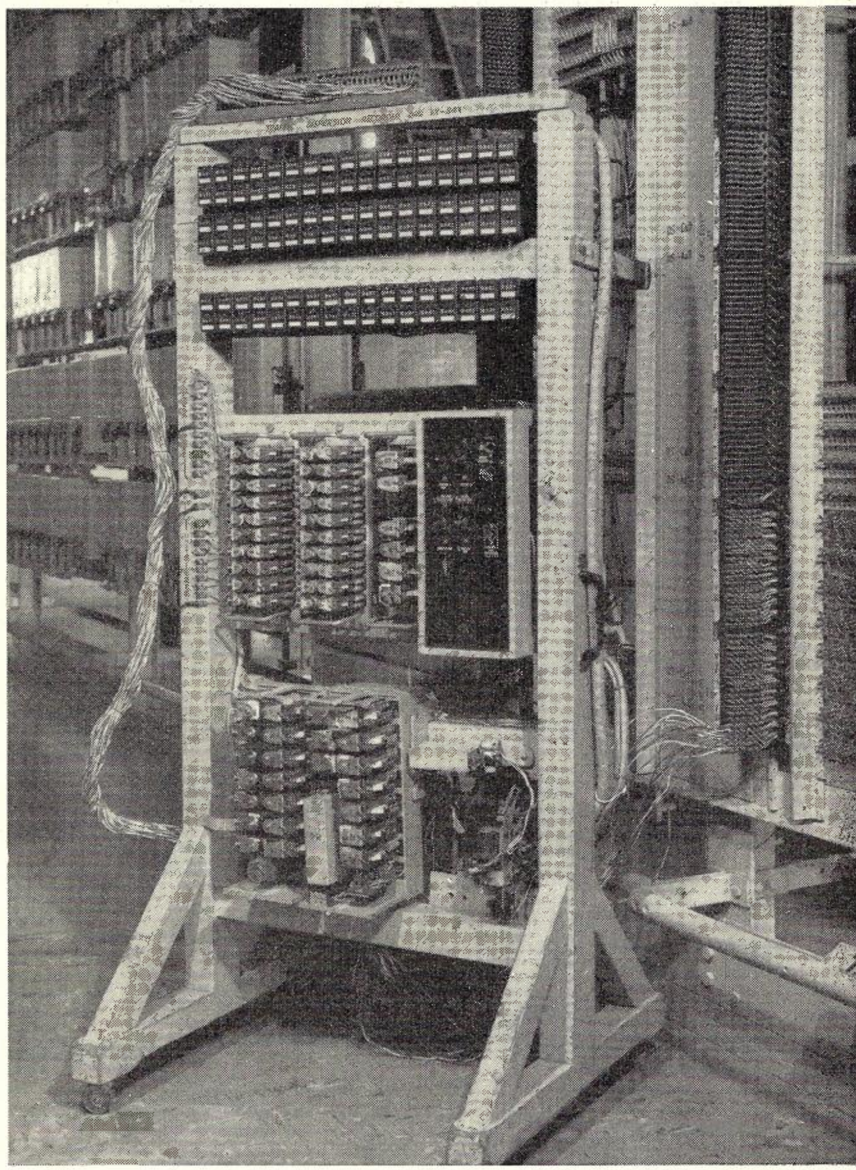

Fig. 1.—Call Dispersion Recorder.

CALL DISPERSION RECORDER

Fig. 1 is a photograph of the call dispersion recorder. This equipment which is supervised by a Senior Technician, is located in an exchange (either 2000 or pre 2000 type) for 6 days, the usual time taken to record some 5000 calls, and ensure that a good cross section of the traffic is examined. The recorder weighs only 120 pounds and is easily transported from one exchange to another.

Fig. 2 shows the circuit units which make up the recorder, namely—the pickup circuit, relay set, count storage and meters.

Pickup Circuit. From an appropriate T.D.F. in a main exchange, the input to 40 first selectors is connected to the pickup circuit and thence to the banks of a motor uniselector. When a first selector is seized by a subscriber, the motor uniselector searches for and finds the selector, and connects across its positive and

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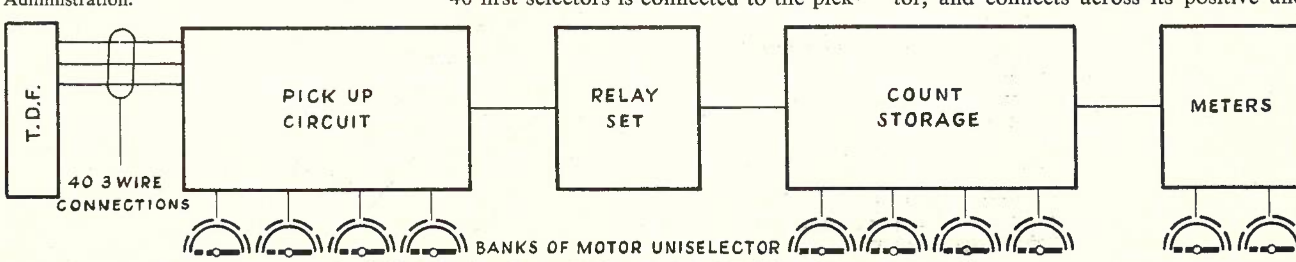

Fig. 2.—Block Schematic of Call Dispersion Recorder.

negative wires extending them through to the relay set. The connection is held until the first, second and third digits (on any required two digit combination) are dialled and identified. The connection is thrown off under PG conditions and with a pause between digits of more than eleven seconds. Only one first selector is examined at any one time. At branch exchanges the connection is made to the outgoing junctions from the junction hunter outlets.

General Relay Set: The relay set records the first digit train. It then switches to record the second digit train. It may switch to record the third digit train if more detail is required on the breakup of calls, to particular two digit prefixes. The motor uniselector is then released.

Count Storage and Meters: The digits are counted by a thyratron tube and relay circuit which mark other banks of the motor uniselector. The motor uniselector finds the marking condition and using further banks a circuit is completed for an appropriate "prefix meter" and the "total meter" to operate in series.

CALL AND TRAFFIC DISPERSION RESULTS

The call dispersion measurements are processed and are finally presented in a form similar to that shown in Fig. 3. Their significance for the Ormond exchange is discussed and then a few generalisations are made for the network as a whole.

Ormond Exchange: Results for Ormond are shown for the day reading period from 9 a.m. to 5 p.m. and for the evening hours from 5 p.m. to 9 p.m. Ormond is a residential area and the 5500 subscribers originate only slightly more traffic in the morning than in the evening busy hour. Thus in this case, the day and evening traffic figures quoted, directly show changes in the movement of traffic for the two periods of time.

Of interest is the marked reduction in the evening, of traffic to the exchanges in the F & M groups which, as Fig. 4 shows, serve the main business areas in the central and north western section of the network. There is a corresponding increase in traffic to the residential exchanges (B, L, W, X). Thus the traffic to the M group is halved, and all M levels, with the exception of the MY level, which is the access level to the Trunk Exchange, individually suffer a

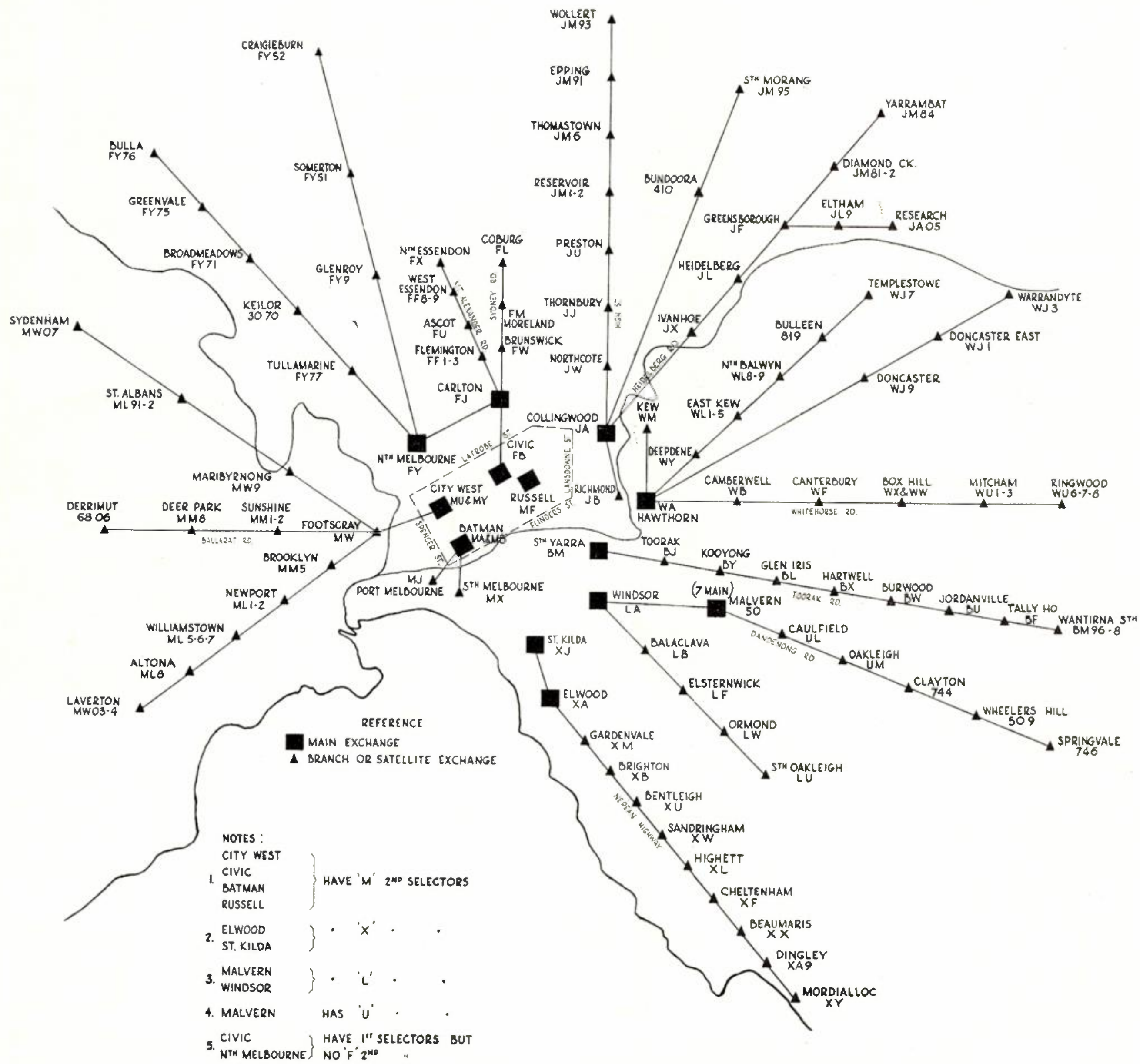

Fig. 4.—Location and Numbering of Exchanges in Melbourne Network.

	B(2)			F(3)			J(4)			L(5)			M(6)			U(7)			W(8)			X(9)				
		%D	%E		%D	%E		%D	%E		%D	%E		%D	%E		%D	%E		%D	%E		%D	%E	%D	%E
	BA*			FA*			JA	2.24	1.13	LA	2.44	2.74	MA	.92	.38	UA*			WA	.75	1.18	XA	.87	2.04		
	BB*			FB	2.97	.21	JB	1.29	.97	LB	.97	2.15	MB	2.79	.11	UB*			WB	.70	.59	XB	2.72	3.81		
	BF	.29	.21	FF	.50	.27	JF	.14	.00	LF	4.28	4.19	MF	5.28	1.56	UF*			WF	.42	.16	XF	1.00	1.18		
	BJ	.70	1.44	FJ	2.09	.70	JJ	.44	.38	LJ*			MJ	.75	.11	UJ	1.39	1.02	WJ	.14	.05	XJ	1.30	1.61		
	BL	.90	1.24	FL	.40	.91	JL	.40	.54	LL*			ML	.41	.16	UL	4.17	3.60	WL	.53	1.07	XL	1.81	2.69		
	BM	.72	.86	FM	.31	.64	JM	.11	.05	LM*			MM	.59	.38	UM	3.11	3.54	WM	.43	.86	XM	2.62	2.79		
	BU	.33	1.24	FU	.33	.70	JU	.23	.38	LU	1.92	4.19	MU	4.36	1.44	UU*			WU	.46	.48	XU	3.96	3.97		
	BW	.21	.54	FW	.73	1.29	JW	.89	.86	LW†	18.52	21.00	MW	1.25	.81	UW*			WW	.03	.05	XW	.92	1.72		
	BX	.61	1.13	FX	.23	.21	JX	.47	.81	LX*			MX	1.25	1.07	UX*			WX	.87	1.29	XX	.27	.38		
	BY	.63	.64	FY	1.05	.27	JY*			LY	1.22	1.88	MY	3.78	3.76	UY	.56	.75	WY	.36	.59	XY	.65	1.02	%D	%E
Call Dispersion		4.40	7.30		8.61	5.21		6.22	5.13		29.35	36.14		21.37	9.77		9.23	8.91		4.69	6.33		16.12	21.21	100	100
Traffic Dispersion		4.37	6.94		8.55	4.95		5.34	4.23		30.05	35.44		16.41	7.19		10.11	9.34		5.86	7.57		19.31	24.34	100	100

* Level not in use. † Local Exchange.

Fig. 3.—Call and Traffic Dispersion from Ormond (LW) Exchange.

reduction. Traffic to the local exchange and to the local exchange group increases.

It is found that the proportion of traffic originated at Ormond which terminates in the local group is typical of that normally encountered at other residential exchanges. Further, it can be seen that with the proposed prefix change of the remaining "7" (U) exchanges to the local "5" (L) prefix, and the provision of interaccess junctions from the discriminating selector repeater banks, considerably more traffic can be direct routed from Ormond.

Using results such as these it is a fairly straightforward process, by considering the traffic to each other exchange and the internal and external plant costs, to arrive at the most economic provision of direct routes from a crossbar type exchange.

Fig. 5 shows the distribution of calls with radial distance from the Ormond exchange. With the exception of a large parcel of calls to the city area, calls to other areas decrease with their radial distance from the originating exchange.

Call Dispersion in the Network: Detailed study of the observations which have been made reveal a wealth of information on traffic patterns in the network. As an example, Fig. 6 tabulates for six typical originating exchanges the percentage of daytime calls terminated within five miles of themselves. Also it shows the percentage of calls terminating within various distances from the heart of Melbourne. Civic, Richmond and Williamstown are exchanges serving business and industrial areas, whilst Clayton, Northcote and Ormond serve areas which are predominantly residential.

The table demonstrates the tapering off of traffic to the fringes of the unit fee area where there is a comparatively low subscriber density. A trend away from this may be expected with the development of suburban district business centres, establishment of factory zones and growth of population.

In showing how much traffic is terminated close to the originating exchange an indication is given of the considerable savings in external plant costs which can be achieved with the use of light gauge cable for direct routed traffic.

DEVELOPMENT

The Recorder is working in a predominantly six figure network with only a few prefixes requiring an analysis of their third impulse train. However, as the number of seven figure exchanges in the network increases, there will be need for further information on the traffic to the third digits (10,000 lines) to be recorded. Again, as with crossbar exchanges it is possible to trunk direct to 1000 line groups, the need for information on the destination of 4th. digit trains becomes apparent. An equipment as simple as the Recorder can not

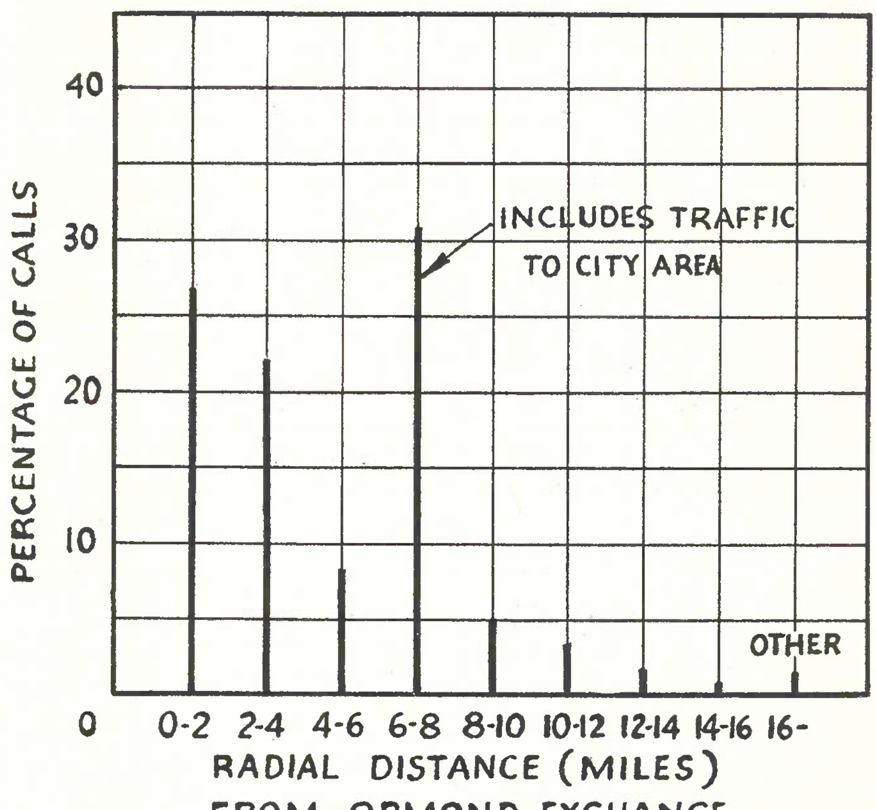

Fig. 5.—Dispersion of Calls with Radial Distance from Ormond Exchange.

cope with problems as difficult as these, but its usefulness will not diminish greatly over the next few years.

To date little has been done in the field of investigation of call dispersion in provincial city networks and the semi-automatic trunk network. It is expected that investigations in the trunk networks will lead to economies in trunk line provision as more automatic country exchanges with improved facilities are installed.

Originating Exchange	Radial distance in miles from Elizabeth St. Post Office	Percentage of calls terminated within a 5 miles radius of the exchange	Percentage of Calls terminated in areas centred on the Elizabeth St. Post Office.		
			0-5 miles	5-10 miles	10-15 miles
Civic	0	78.3*	78.3*	16.1	5.6
Richmond	2	79.6*	70.0*	23.8	6.2
Williamstown	5	68.3*	56.1	39.1*	4.8
Clayton	11	34.1*	55.8	24.7	19.5*
Northcote	4	79.8*	75.4*	18.4	6.2
Ormond	8	52.2*	44.2	50.1*	5.7
Ratio of Areas	—	—	1	3	5

* Includes local to local calls.

Fig. 6.—Dispersion of Calls from Typical Exchanges.

HOLDING TIME MEASUREMENTS

Holding time measurements have been made on main to main exchange routes.

The method used was to connect the Private wire from relay set repeaters to meters in a manner similar to that shown in Fig. 7. When a junction is carrying traffic, the earth condition applied to the Private wire causes the call meter to operate once and hold, whilst the occupancy meter will operate every time the contact closes. The holding time is then obtained as follows:—

$$\text{Holding time in hours} = \frac{\text{(traffic occupancy of junction for 1 hour)}}{\text{(Number of calls for 1 hour)}}$$

$$= \frac{\left(\dfrac{\text{occupancy reading for 1 hour}}{\text{Total reading for 1 hour}}\right)}{\text{(Number of calls for 1 hour)}}$$

$$= \frac{\text{(occupancy reading)}}{\text{(Total reading)}} \times \frac{\text{(time of observation in hours)}}{\text{(Number of calls for period of period of observation)}}$$

Some 40,000 calls have been timed and an analysis of the results indicates that the holding time of calls between two exchange groups is proportional to the product of a function of the originating exchange group f(O) and a function of the terminating group f(T). Thus, if h is the holding time in minutes of calls between two exchange groups, $h = k \times f(O) \times f(T)$ where f(O) and f(T) are tabulated below for the various exchange groups. The constant k is the mean holding time of calls in the Melbourne network and is approximately equal to 3.08 minutes.

Exchange Group	f(0)	f(T)
B (2)	1.00	0.97
F (3)	*	0.97
J (4)	*	0.84
L (5)	*	1.00
M (6)	0.87	0.75
U (7)	1.07	1.07
W (8)	1.10	1.22
X (9)	1.03	1.17
* not read		

The most important feature to come out of this table is that in function f(T) we have a simple factor with which to weight the call dispersion readings. This factor is quite independent of the nature of the originating exchange.

Other points of interest arising from the table include the following:

(a) The well known assumption that calls to and from residential groups have longer holding times than those to and from business groups is supported.

(b) The originating and terminating functions are not equal, but in general show similar trends. Thus f(T) is of the same order but less than f(0) for the M group. This could possibly be due to the large number of calls terminating on the recorded services, which having a "disconnect facility" sets an upper limit on the holding time of calls.

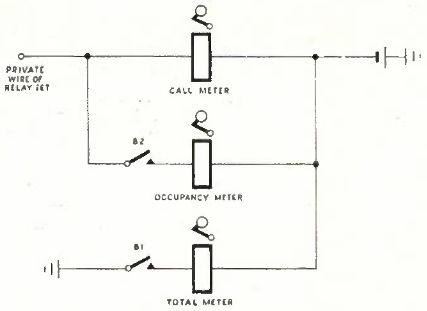

Fig. 7.—Connection of Meters for Holding Time Measurements.

CONCLUSION

Over a period, in the Call Dispersion Recorder a simple means has been devised of gathering information which can be used to supplement the existing knowledge of traffic trends in the Melbourne network.

The Recorder gives a first order approximation to traffic, which can be further developed using a knowledge of group to group call holding times. The final product is considered adequate for most planning purposes, and in particular provides the necessary information on which to base the design of the Network during the initial introduction of crossbar switching systems.

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A PORTABLE VIDEO TRANSMISSION TEST SET FOR STEADY-STATE AND TRANSIENT RESPONSE

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The processing of television signals in the laboratory, in the studio, in broadcasting or relaying, requires circuits which are capable of handling fast waveforms or, in terms of frequency response, are capable of transmitting frequencies from near zero to several megacycles per second. For the testing and empirical adjustment of such circuits numerous methods and types of equipment have been developed. The literature on this subject shows that waveform and frequency response test methods are almost equally represented and, in fact, for maximum efficiency and convenience both methods have their own fields of application. Commercial equipment available up to now is designed specifically for either waveform or frequency response tests. Some time ago a video transmission test set in which both domains are integrated was designed and constructed in the Research Laboratories of the P.M.G. Department (1). Many hours of tedious calculations, otherwise necessary to convert measurements in one domain into data in the other, were saved by the facility of measuring in either one or the other depending on the particular problem in hand. From this experience the provision of similar facilities for field application was suggested. By adapting the principle used in the laboratory test set to the conditions of field operation a versatile portable video transmission test set was developed.

SYSTEM PRINCIPLE

The basic principle used in this equipment is essentially the same as that of the laboratory set described in Reference (1) and will, therefore, be treated here rather briefly. It represents an extension of a method for the measurement of phase delay originally described by Goodchild and Looser (2).

For steady-state response tests the spectra of two identical pulses, one of which has passed through the network under test, are compared with each other by subtraction in a difference circuit. The output of this circuit will be zero for all those frequency components of the pulse spectra which have not been affected by the network and hence have equal amplitude and phase at the input of the comparison circuit. However, if amplitude and/or phase distortion is present, the difference circuit will show an output for those frequencies which are affected. This is reduced to zero again by appropriate amplitude and/or phase adjustments of the comparison pulse. These adjustments are then a measure of the amplitude and/or phase response of the network under test at the particular frequency (or frequencies).

For transient response tests the test waveform is displayed on a suitable CRT-indicator, the time base of which is variable in speed over a large range, and the relative delay between time base and test pulse can be shifted in a quantitatively defined manner. The latter facility permits very accurate measurements of such parameters as rise time of step functions, pulse width, overshoot duration and ringing frequencies. These measurements of transmission characteristics may be carried out on any active or passive network in the frequency range of the pulse spectrum.

In addition, the portable test set facilitates the making of pulse reflection tests on coaxial cables for the determination of impedance irregularities, for example, faults in joints and the cable, and inaccuracy of terminating impedances. The principle used for these tests is described in detail in Reference (3). A test pulse is fed to one diagonal of a bridge network which contains in one arm the coaxial cable and in the other a network which simulates the input impedance of the cable over the frequency range of the test pulse. If the input impedance of this network is equal to that of the cable, the test pulse is balanced out across the output-diagonal of the bridge and only reflections along the cable are indicated by the CRT-indicator unit.

PHYSICAL IMPLEMENTATION

The physical implementation of the above principles in the operational equipment is governed by the electrical characteristics of the networks to be tested and the tolerances imposed on the realisation of such characteristics on one hand, and on the other by the requirements of easy transportation, protection of the components in transport, convenience in setting up, operation and maintenance.

Networks likely to be tested in the field with this equipment are TV relay links (radio and coaxial cable) and their associated components, video sections of TV-transmitters, fixed and variable equalisers, video amplifiers, etc. In these tests it is of no significance whether at any stage the video signal is modulated onto a carrier, as long as the test takes place at video input and video output.

Although the Australian TV broadcasting channel has a nominal video bandwidth of 5 Mc/s, relaying and other equipment is generally designed with a larger bandwidth, in the order of 7 to 8 Mc/s. Since the cut-off characteristic of these networks is often of importance and in order to minimise the effect of the test equipment performance, 10 Mc/s was considered a suitable design objective for the upper cut-off of the frequency range of the equipment. However, in order to achieve a greater accuracy in cable reflection tests the cut-off frequency was increased to 15 Mc/s for this case by means described later. The low frequency response of TV systems is of considerable importance too. Therefore provision has been made to test the response in this frequency range by means of a 50 c/s square wave which has been generally adopted as the most convenient way of testing and specification.

In steady state response tests, amplitude and phase-delay are read directly in db and milli-microseconds respectively with an inherent equipment accuracy equal to or better than $\pm$ 0.2 db and $\pm$ 3 m μsec. without reference to calibration charts. A sine-squared pulse of 100 Kc/s repetition rate and 50 millimicroseconds width is used to generate the required frequency spectrum, and thus measurements can be made at spot frequencies 100 kc/s apart. The null-balance reading sensitivity varies somewhat over the frequency-range as a result of the system principle used, variations in pulse spectrum, receiver sensitivity, and network losses. Quantitative data on this point will be given later.

For transient response tests sine-squared pulses of 50 and 100 millimicrosecond width and a rectangular pulse of 1 μsec width and 60 m μsec rise-time, are available.† A rectangular pulse rather than a symmetrical square wave was used to save power supply capacity and thus reduce weight. The 100 m μsec pulse represents one picture element, or T-pulse (4). For routine tests sometimes a 2T-pulse is desirable, (that is, 200 μsec wide) for which a shaping network according to Thomson (5) may be used. The CRT indicator unit was especially developed for this equipment, since it was felt that a commercial oscilloscope would have been more difficult to operate in the field. A detailed description of the individual components will be given later.

Physically, the main equipment is housed in four cases made of light gauge aluminium in which, where practicable, the equipment components are mounted as detachable subunits. Each case contains its own power supply. Interconnections between cases are made by means of coaxial cable lengths which are stored for transport in the covers of two suitcases. The distribution of the equipment components over the four cases was made from a functional point of view so that the minimum of equipment was required at any one location for any one test. Of course, some compromise was inevitable, if the equipment was not to be divided into more individual units.

Arrangements for Steady-State Tests: The actual arrangement of the units is shown in Figs. 1 to 3. Fig. 1A depicts the components required for **steady state testing** in block schematic presentation. In accordance with the comparison principle there are two identical pulses generated by two identical pulse generators. Both are fed from one common master oscillator of 100 kc/s (for loop tests), one directly, the other through a phase

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* Mr. Seyler is a Divisional Engineer in the Research Laboratories.

†The times quoted are as indicated on the screen of the CRT-indicator, and hence represent the cascaded value of actual pulse characteristic and indicator transfer function.

shifter, and are followed by wide band attenuators with up to 99 db attenuation in steps of one db (for smaller variations provision is made in the pulse generators themselves). The network under test is inserted in the non-phase-shifted branch which is called the "Network Branch" while the phase-shifted branch is called the "Comparison Branch". This arrangement ensures that the delay read on the phase shifter has always the same sign as that of the network.

If end-to-end tests are being made the master oscillator is, of course, at the input end, together with the pulse generator and attenuator of the network branch. Consequently a synchronous 100 kc/s sine wave must be generated as reference for the comparison branch at the output end. This is achieved by "extracting" from the signal arriving there the fundamental 100 kc/s component, by means of the "100 kc/s Extractor". In doing so, the absolute delay between the input-pulse and the output-pulse is no longer measurable, but this is irrelevant, because only the delay dispersion over the frequency range is of importance. The outputs of the two branches are then subtracted from each other in the "Mixer" (difference circuit) and the difference signal fed to the selective detector. If visual monitoring is desired (which is recommended, particularly until the operating personnel are thoroughly familiar with the equipment) the CRT-indicator unit is also connected to the mixer output.

Fig. 1B shows an actual connection diagram for **steady-state loop testing.** In this diagram the contents of the individual units (cases) become obvious. "Unit 1" contains the components of the network branch, that is, Pulse Generator and Attenuator with its Power Supply. In "Unit 2" the components of the comparison branch are housed, that is, Pulse Generator, Phase Shifter, and Attenuator, and in addition the Mixer (difference circuit) again with Power Supply. Both units contain a Master Oscillator on the same panel as the pulse generator and the one not in use is switched off. The Selective Detector, a modified communication receiver, represents "Unit 3" which has the 100 kc/s-Extractor built-in, and "Unit 4" contains the CRT-Indicator with associated amplifiers, time base and power supplies. The interconnections between the units are indicated by full lines and are self explanatory when compared with the block schematic Fig. 1A. The components not used for the particular test are shown shaded, for example, in Fig 1b, the master oscillator in Unit 1 and the 100 kc/s extractor in Unit 3.

Fig. 1C gives the configuration for **steady-state end-to-end testing.** Unit 1 is at the input end of, say, a relay link and the remainder of the equipment at the output end, that is, where the actual measurement is performed. For this the master oscillator in Unit 1 is in use and consequently that of Unit 2 is turned off. All other components are in use.

Arrangement for Transient Response Tests: The equipment set-up for transient response tests is shown in Fig. 2. The equipment components used and their functional connections are depicted in the block schematic Fig. 2A.

Again a 100 kc/s oscillator is used to control the repetition rate of the test waveforms generated in the Waveform Generator. (Note that here the more general term is used for what is physically the same unit as the "Pulse Generator" of Fig. 1). The test waveforms are applied through a wide band attenuator to the network under test, facilitating the setting of the waveform amplitude in accordance with the input requirements of the network. The network output is then connected to the vertical deflection (Y) input of the CRT indicator unit. The relative timing between test waveform

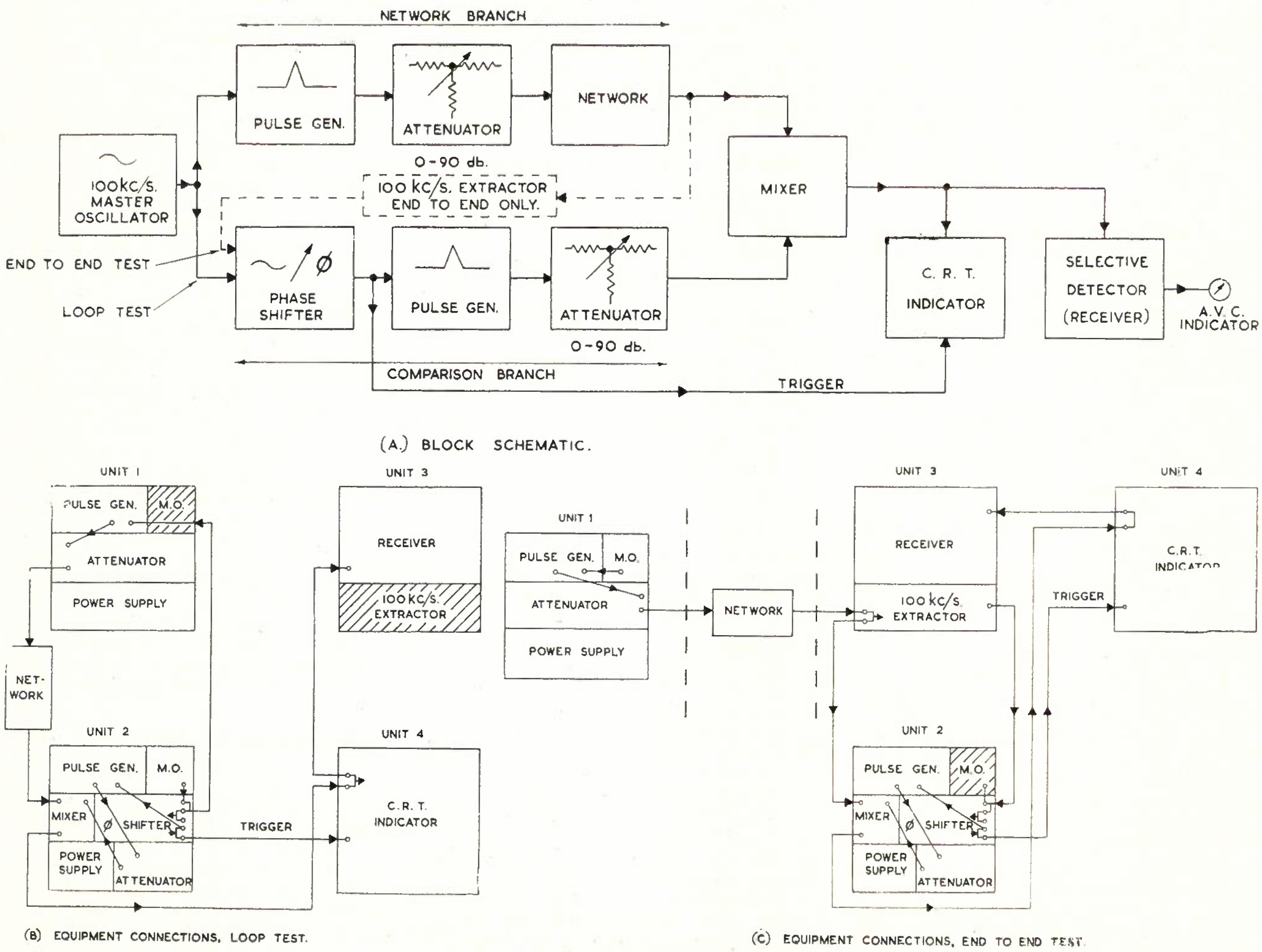


Fig. 1.—Steady State Response Test.

and the CRT time base is made variable over the duration of a full period of the waveform repetition frequency. This is made possible by controlling the time base-start from a 100 kc/s sine wave which has passed the phase shifter. Since this is accurately calibrated in delay times (as also required for phase delay measurements, time measurements of waveform sections can be carried out with high accuracy, independent of time base linearity and calibration. For end-to-end tests the network output is fed to the 100 kc/s extractor to derive the 100 kc/s sine wave required for the time base drive through the phase shifter.

Figs. 2B and C show the actual physical components of the test set used for the two cases of transient response testing. In the loop test set-up only Unit 2 and Unit 4 are required and are fully used. In the end-to-end test Unit 1 serves purely as a test signal generator at one end. At the other end, in addition to Unit 4, the extractor sub-unit in Unit 3 and the phase-shifter sub-unit in Unit 2 are required for the complete test.

The desired test waveform is selected in each case by connecting the test object to the output of Unit 2 or 1 respectively, and the appropriate time base speed is chosen by means of the selector switch on Unit 4 provided for this purpose.

Arrangements for Pulse Reflection Tests: In Fig. 3A the block schematic is shown of the arrangement for pulse reflection tests on coaxial cables, etc., to determine impedance irregularities in the cable itself or in joints and terminations. The measurement yields information about the location and nature of the reflection.

As in all other cases the primary timing source is again a 100 kc/s sine wave. For longer cable sections a different arrangement applies. This drives the pulse generator and, through the phase-shifter, the time base of the CRT-indicator. The test pulse is fed through a wide band attenuator to the bridge network in which the test pulse is balanced out and thus prevented from reaching the indicator which would cause serious overloading of the deflection amplifier. This is achieved by placing the input of the cable under test in one arm of the bridge and a network with equal impedance characteristic in the other. Theoretically, no output will be obtained across the bridge output diagonal during the test pulse, but pulses representing reflections and hence occurring later in time will appear at the output. These are fed to a preamplifier and from there to the Y-amplifier of the CRT-indicator. The preamplifier serves a twofold purpose. It increases the sensitivity of the equipment to the desired magnitude and by its specific amplitude frequency response extends the effective measuring band width to 15 Mc/s.

At the end of the cable under test there is a terminating network which matches the cable impedance as closely as possible and hence prevents end reflections. It also serves for calibration of the reflection amplitudes by providing the possibility of introducing a small defined mismatch.

Fig. 3B shows the actual connection of the physical units. Unit 2 is used as test pulse generator and time base phase shifter and Unit 4 provides the indication. The preamplifier is combined with the bridge network and cable simulating network in the "Preamplifier Unit". A small box with suitable connector houses the cable "Termination" used at the far end.

The preamplifier Unit and Termination are considered as accessory components in addition to the four basic suitcase units housing the standard equipment.

SYSTEM DESIGN

The system design was governed by a number of factors resulting from the purpose for which the equipment was to serve. Several of these factors were opposed to each other and required compromise solutions to achieve satisfactory performance. For example, throughout the whole equipment the main opposing factors were to generate and manipulate fast waveforms with high timing stability (which, as is well known, requires large currents flowing in valves and circuit components) and still to keep the capacity of the respective power supplies such that their weight did not seriously impair the portability of the equipment. Further the availability of components had to be considered and this often governed a particular circuit design; the mechanical details of construction and convenience of operation and set-up guiding the subdivision of the whole equipment required circuit configurations suitable for coaxial cable connection and matching. These and other considerations of a general nature will become more obvious in the subsequent discussions of the individual system components.

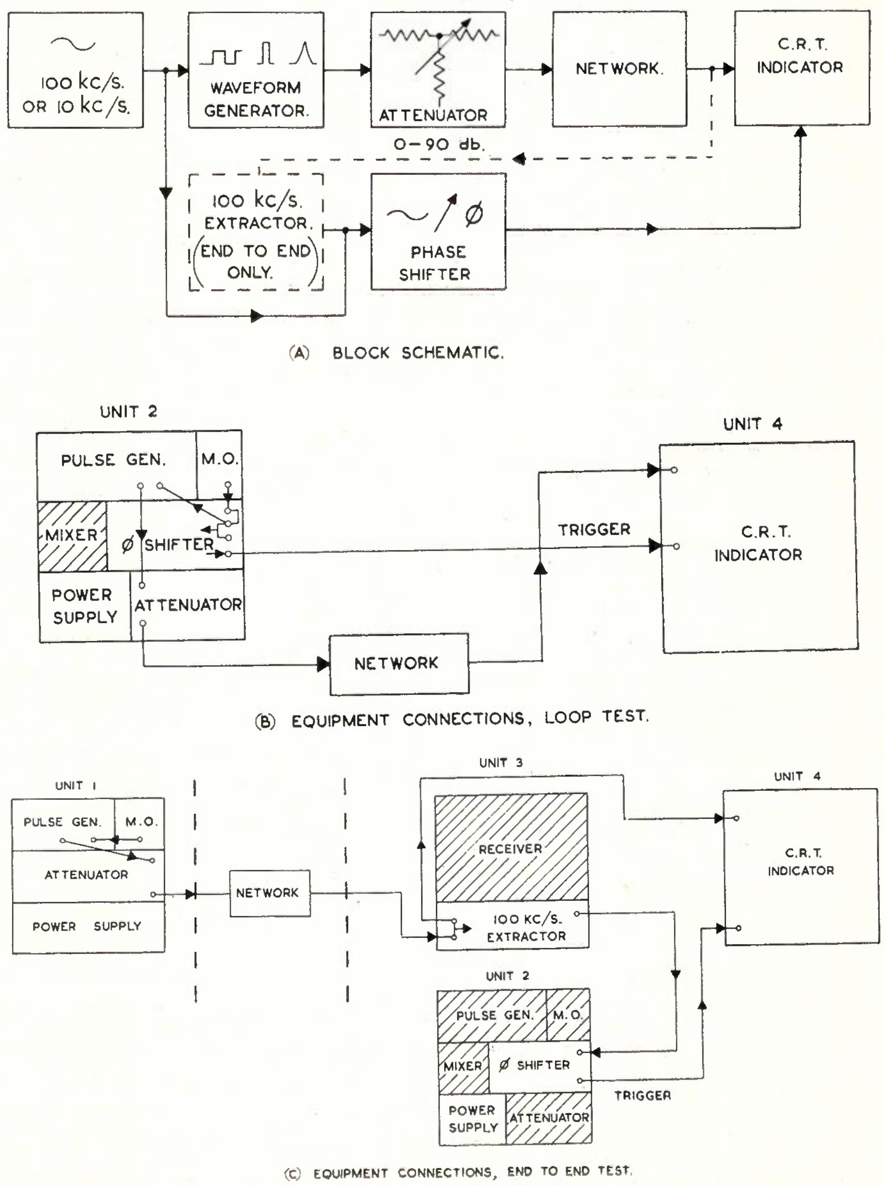


Fig. 2.—Transient Response Test.

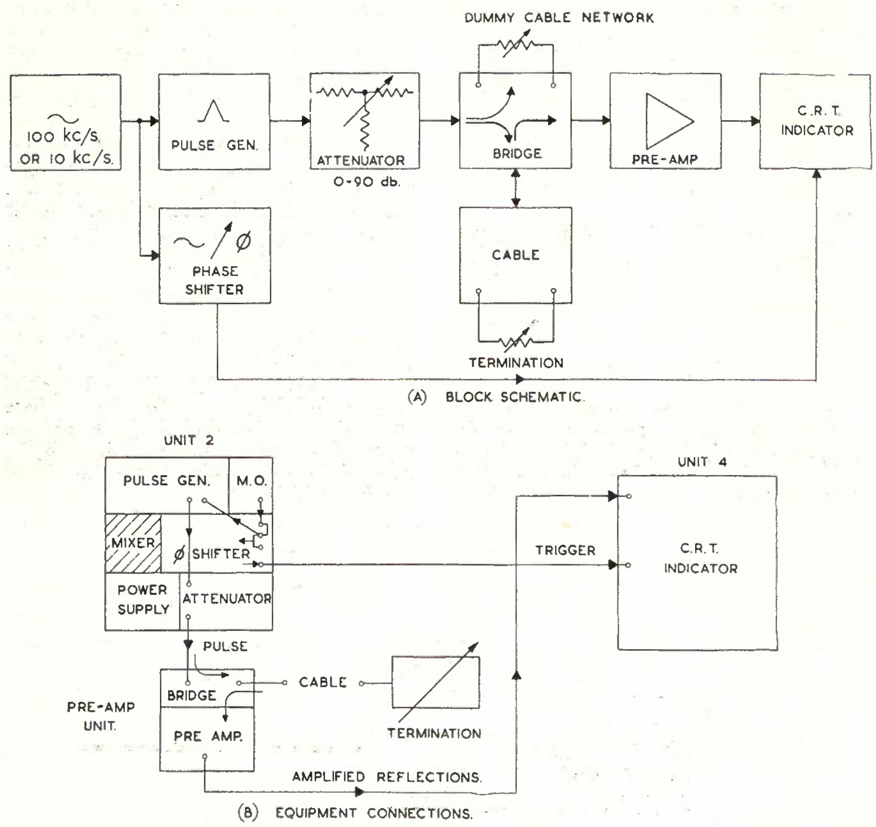


Fig. 3.—Pulse Reflection Test.

Waveform Generators: As was shown previously, the system principle applied to steady state measurements is based on the availability of two identical pulses, serving as test and comparison signal respectively. Since for end-to-end tests these are required at two different locations, two pulse generating units have been used. These serve also as waveform sources for transient tests and are identical in all respects, thus rationalising design and production work.

For economy of power consumption blocking oscillators (6) were chosen as actual pulse generating stages. In order to obtain the desired timing stability (freedom from jitter) and pulse-width, the blocking oscillators have to be triggered by fast waveforms. The blocking oscillator generating the 100 m μsec pulse serves at the same time as trigger stage for the narrow (50 m μsec) pulse generator and for the 1 μsec rectangular pulse generator.

Fig. 4 shows a block schematic diagram of the whole sub-unit. For reasons of high stability the 100 kc/s master oscillator is crystal controlled. It can be switched to 10 kc/s for specific applications, but then an ordinary LC-oscillator circuit is used. The oscillators supply a sine wave of 5V p-p to drive the pulse generating circuits. This sine wave is amplified before it is applied to a regenerative squaring stage which generates a fast triggering waveform. A reference synchronising pulse is available through a buffer stage, if other circuits should be triggered from this source. A second output from this stage triggers the first blocking oscillator from which the 100 m μsec pulse is obtained. It has been found that by suitable circuit configuration an approximately sine-squared pulse can be generated across a small resistor in the cathode of the blocking oscillator. If this resistor is small enough, in this case less than 75 ohm, it will not interfere with the regenerative action of the circuit. The advantage of this arrangement is that the output has a low source impedance and is isolated from the feedback transformer in the blocking oscillator. Thus the output load has a minimum effect on the generator and the waveform is substantially free from the usual spurious overshoots generated by the pulse transformer.

The second blocking oscillator supplying the 50 m μsec pulse differs from the first one only in respect of the pulse transformer used. The pulse transformers in the production model will be potted in Araldite and equipped with a Noval-type valve socket. From the experience gained with the developmental model, this was found necessary because small differences in wiring and thus lead inductances and capacitances had noticeable effects on pulse shape and speed.

Although normally square waves are used to determine the step function response of networks, a rectangular pulse of 1 μsec was chosen here. This is justified by the fact that under normal conditions any distortions in the video signal should not extend beyond 1 μsec after the transient. This choice brought about considerable savings in current consumption, exploited further by designing the output stage so that it is cut off between pulses. As a result the test pulse has negative polarity. This may require some caution to be exercised by the operator when using this test waveform, because only half the dynamic range of any equipment under test can be used when compared with the operating conditions for a symmetrical square wave. However,

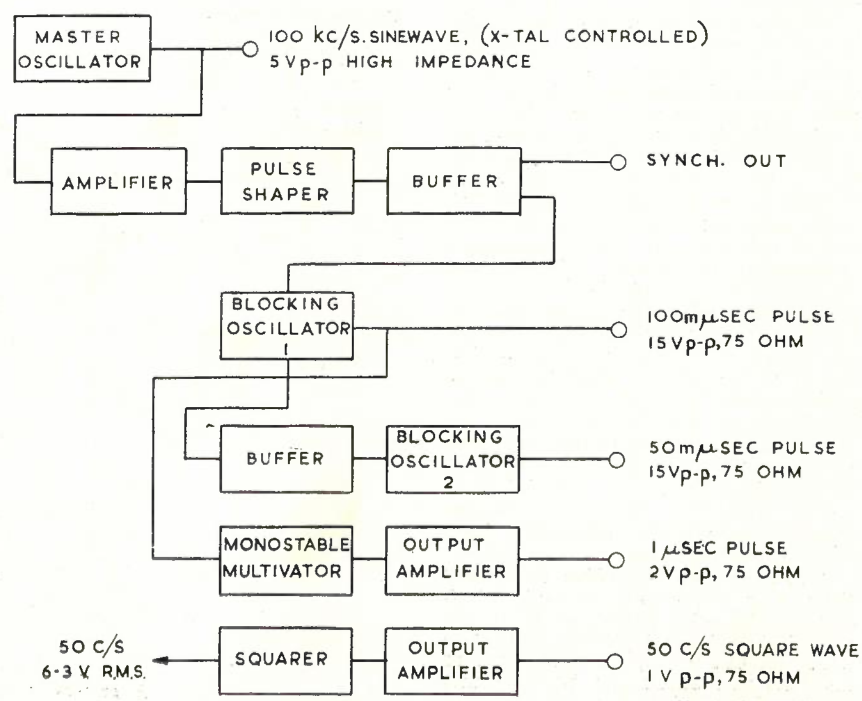


Fig. 4.—Waveform Generator.

up to now, this has not been found to be a serious disadvantage.

The 1 μsec pulse is generated by a monostable multi-vibrator circuit. Because only the leading edge of the waveform is triggered, this is slightly faster than the trailing edge which is timed by the time constant of the multi-vibrator circuit.

A regenerative squarer stage followed by an output and shaping stage is used to generate the 50 c/s square wave used for low frequency testing. The driving waveform for this circuit is a 50 c/s sine wave obtained from the filament transformer which provides the heater voltages for the valves of the unit.

All DC voltages used in the waveform generator are electronically regulated. In spite of the fast waveforms generated by the unit and their comparatively large amplitudes into 75 ohm impedances, the circuit technique employed resulted in only 60mA current consumption at + 250 V. and 13 mA at 300 V.

Phase Shifter: For phase delay measurements in steady state response tests and for accurate time measurements in transient response and cable reflection tests, a calibrated time delay is required. This is obtained by shifting the phase of the 100 kc/s sine wave which drives the waveform generators and CRT time base. It is desirable to vary the phase of this sine wave by 360°, equivalent to 10 μsec delay of the respective waveforms.

Whilst in the laboratory test set (1) the phase shifter is a mechanical unit of high precision, for the portable test set this was considered too bulky and cumbersome and, because of the somewhat less stringent requirements could be constructed differently. Further, in the laboratory test set the phase is shifted continuously over the whole range by a single control, while in the portable equipment this is done by three controls. The first one provides a shift of 180°, that is 5 μsec, by operating a two-position switch; the second control permits phase variation in 10 steps of 18°, that is, 0.5 μsec; and the third control gives a continuous variation over the range of one step of the second control, that is, over 0.5 μsec. This subdivision determines the construction of the phase shifter which is shown in block schematic in Fig. 5.

The 180° phase shift is carried out by an electronic phase splitter consisting of a cathode coupled triode pair.

For the 18°, that is, 0.5 μsec, steps a switched constant-k delay network is used and the continuously variable delay of 0.5 μsec range is obtained from a commercial type variable delay line. Its actual range is slightly more than 0.5 μsec thus permitting overlapping with the coarse delay steps. The dial of this is calibrated in divisions of 2 m μsec.

The unit is required to have equal input and output amplitude. To obtain this the delay sections are followed by a low-noise amplifier stage and cathode follower. The output amplitude is practically constant, independent of phase shift. This is important, because amplitude variations of the sine wave produce spurious phase shift of the pulse waveforms due to the trigger mechanism of the waveform generators.

The calibration and adjustment of the various delay networks can be carried out without using any other test equipment. For this purpose the test set is connected as for a steady state response test. From the principle of the equipment it is obvious that, when two pulses of equal amplitude are subtracted from each other and one is phase shifted through one pulse period (10 μsec), the output of the difference circuit will become zero for any particular pulse-harmonic N = n x 100 kc/s every time the phase angle of the driving 100 kc/s sine wave is $\beta_0 = 360/n$. Thus, if the receiver at the output of the difference circuit is tuned into 200 kc/s and the output is zero for zero phase shift, when the 180° switch is operated the output should be zero again. (If not, the circuit requires adjustment). Similarly, if the receiver is tuned into 2 Mc/s, that is, N = 20 x 100 kc/s, the output should be zero for incremental phase shifts of 18°. Hence, this frequency is used for adjusting the 10-step delay section, for which null-balance should exist throughout all 10 switch positions, if the individual sections are correctly adjusted.

For the calibration of the continuously variable delay line, as high as possible a frequency should be employed in order to obtain as many as possible zeros over the range of its variation. Sufficient harmonic amplitude from the test pulses is still available at 20 Mc/s for this purpose. This gives a zero every 1.8° of phase shift or, in terms of delay, every 50 m μsec. Thus 10 calibrating points are obtained for 0.5 μsec delay. To achieve a greater density of calibration points on the dial, an uncalibrated small delay may be introduced to shift the first zero-point slightly, say 10 m μsec, and from there 50 m μsec increments may be marked again, and so on.

It was found that the delay line used in the developmental model showed a maximum deviation of ± 3 m μsec from a linear scale. This is satisfactory for operational applications being ±3% of the duration of a picture element. For more precise measurements reference may be made to an error curve.

Attenuators, Difference Circuit and Selective Detector: Amplitude response measurements in steady state tests, in accordance with the comparison principle used, require the availability of calibrated attenuators. Depending on whether the network under test has gain or loss, the comparison pulse or the test pulse must be attenuated. Attenuators are also necessary to adjust the test pulse amplitude for transient response tests to conform with the input requirements of the network under test. Further, in cable reflection tests attenuators may be used to calibrate the amplitude of the reflected pulse.

For this purpose the units 1 and 2 each contain a set of commercially produced attenuators variable in steps of 1 db from zero to 99 db. The particular type used is specified to have negligible amplitude and phase variations for any attenuation and frequencies up to 50 Mc/s, consequently their effect should be negligible in the frequency range of the equipment. In order to determine amplitude variations smaller than 1 db in the response of the test object, the amplitude of the narrow pulse can be varied continuously over approximately 0.6 db by a control on the waveform generator itself. This operates on the cathode current of the blocking oscillator valve by varying the screen potential.

The subtraction of the comparison pulse from the test pulse required for the analysis of the network steady state response is carried out in the difference circuit, also referred to as mixer circuit. This circuit has to fulfil the essential conditions of subtracting two frequency spectra exceeding 10 Mc/s as upper frequency, with a minimum of distortion. In other words, except for a phase reversal from one input to the output, the transfer characteristics from both inputs to the output should be as identical as posible. These conditions were met satisfactorily by using a cathode coupled pentode pair as differential amplifier (7) in which the high impedance in the common cathode circuit is realised by means of a pentode valve. The function of this amplifier is further improved by using a balance to unbalance wide-band transformer in the output circuit.

The harmonics of the difference-signal obtained at the output of this circuit, if the network under test distorted the test signal, are then, in accordance with the principle of measurement, detected in a selective detector. This is only required to serve as null-indicator. It was found that a sensitive communication receiver, which covers the frequency range from 100 kc/s to about 20 Mc/s is quite suitable for this purpose. The type used here was modified to present a 75 ohm impedance to the mixer output and was equipped with an AVC-current meter of 25 μA full scale deflection. The dial of this meter is subdivided into 0.5 μA divisions.

It was shown in reference (1) that for any pulse harmonic $n\omega_0 = 2\pi n 10^5$ c/s,

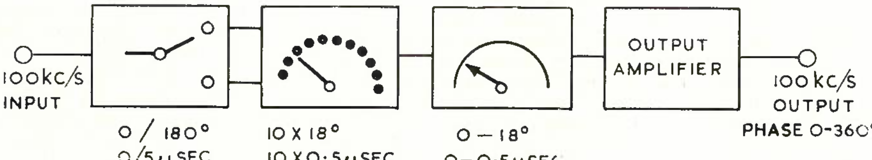


Fig. 5.—Phase Shifter.

the voltage at the mixer output is given by
$R\ (n\omega_0) = (\ (A_1(n\omega_0) - A_2(n\omega_0) \cos n\beta_0)^2 + (A_2(n\omega_0) \sin n\ \beta_0)^2)^{1/2}$ .... (1)
where $A_1\ (n\omega_0)$ and $A_2\ (n\omega_0)$ are the amplitudes of the harmonics of the comparison pulse and test pulse respectively and $n\beta_0$ is the phase shift of the nth. harmonic of the test pulse relative to the comparison pulse expressed by the phase shift β_0 of the fundamental.

Hence, if the particular harmonic at which the response is to be measured has no relative phase shift, but an amplitude difference exists, the mixer output voltage becomes
$\Delta\ R_A = A_1\ (n\omega_0) - A_2\ (n\omega_0)$ .... (2)
and for an amplitude deviation of 0.2 db
$\Delta\ R_A = 0.02\ A_1\ (n\omega_0)$.

The actual value of this voltage is given by the amplitude of the pulse harmonic at the pulse generator output $A'_1\ (n\omega_0)$ the attenuation of the network under test G_N and the transfer gain of the mixer G_M as
$\Delta\ R_A = 0.02\ A_1'\ (n\omega_0)\ G_N\ G_M$ .... (3)

For the test pulse used the amplitude of the harmonics for small n is 0.15 V. p-p falling gradually to half that value at 10 Mc/s. G_M is 0.27 and assuming an attenuation of –30 db that is $G_N = 1/30$ for the network under test, the receiver input voltage for 0.2 db amplitude deviation becomes
$\Delta\ R_A = 27\mu V$ at 100 kc/s
$= 13.5\mu V$ at 10 Mc/s

These values are well within the capability of the receiver used.

On the other hand, assuming equality of amplitudes but a phase difference of $n\beta_0$, the mixer output voltage from equation (1) becomes
$\Delta\ R_p = 2A\ (n\omega_0) \sin (n\beta_0/2)$ .... (4)

With the same numerical values for pulse and network as above this is $R_p = 2.7 \times 10^{-3} \sin n\beta_0/2$ (at 100 kc/s).

For a phase delay deviation of $n\beta_0/n\omega_0 = 3$ mμsec, $n\beta_0/2 = 3n\pi \times 10^{-4}$ hence sine $n\beta_0/2$ may be approximated by $n\beta_0/2$, giving for $\Delta\ R_p$ from 100 kc/s to 10 Mc/s (n = 1 .... 100),
$\Delta\ R_p = 2.5\ \mu V$ at 100 kc/s,
125 μV at 10 Mc/s.
Although the voltage available at 100 kc/s is at the limit of the existing receiver sensitivity, it is generally possible to obtain a satisfactory reading. For all the figures quoted it should be borne in mind that an attenuation of 30 db is rarely encountered under operational conditions. Hence, normally higher voltages are available with the result that the accuracy of measurement becomes only dependent on the accuracy with which phase delay and attenuation can be set and on possible circuit drifts during the measuring period.

CRT Indicator Unit: The CRT indicator unit of the test set has to fulfil several functions. In conjunction with transient response tests it serves as indicator of the test waveforms for the measurements of such waveform characteristics as rise time, pulse width, overshoot, tilt, etc. For pulse reflection tests reflections are indicated and measured as regards their delay, amplitude and shape. In steady-state response tests it serves to monitor visually the output of the difference circuit.

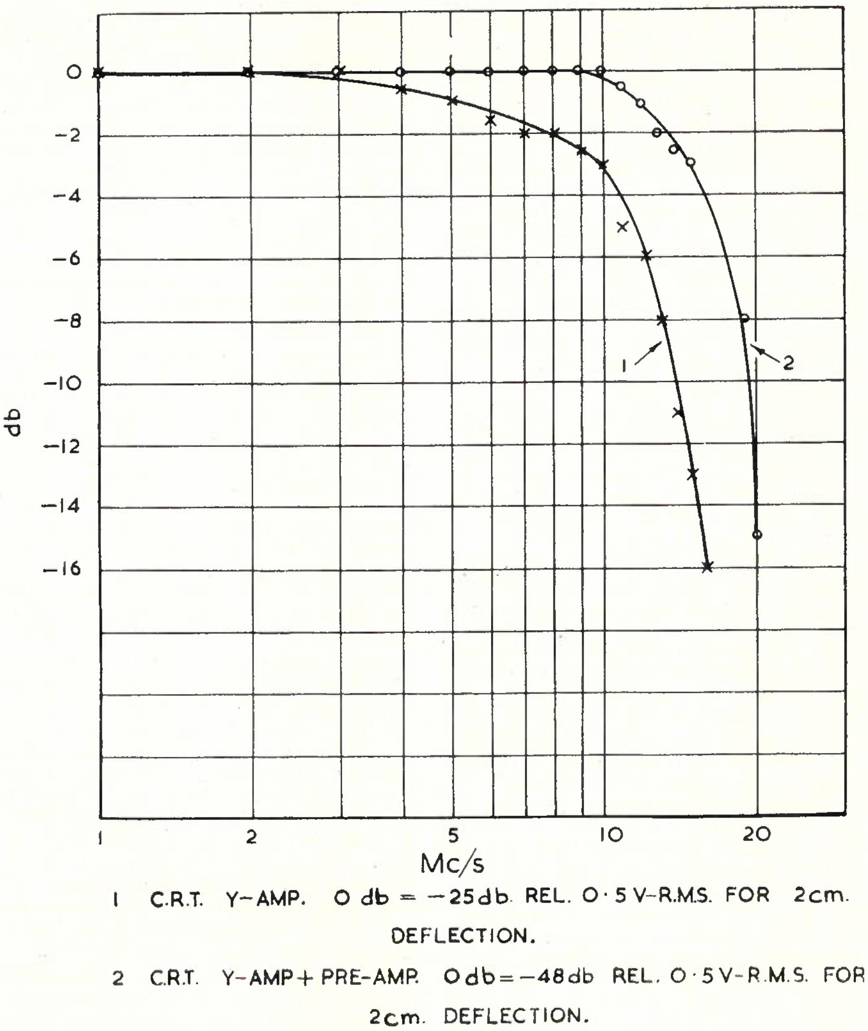


Fig. 6.—High Frequency Cut-off Characteristic of C.R.T. Without and With Pre-amplifier.

The variety of these functions is mainly reflected in the range of time bases required and the method of synchronisation and time base calibration. It was in order to simplify the operation of the CRT Unit in this respect that a special unit was developed rather than a commercial type employed. The time base is switched over a range of speeds from 1 μsec to 100 μsec for full screen deflection and one of 40 msec. A small variation of speed is provided in each switch position, but not to the extent of overlapping of ranges. Normally time base synchronisation is by means of a 100 kc/s sine wave which can be shifted in phase relative to the displayed waveform. The phase shifter used for this purpose is the same as is used for phase delay measurements (Unit 2) and is calibrated in steps of 2 m μsec over a range of 10 μsec. This makes it possible to make precision measurements of the waveform's time parameters by shifting the waveform section to be measured past a vertical cursor line in front of the CR-tube and reading the respective figures off the phase shifter dial, thus obviating the calibration of the time base. The time base is, for these measurements, chosen for optimum presentation.

For routine and survey measurements and also when tolerance templates with specified time base-speed are used, for example, for equalizer line-up, etc., the time base itself may be calibrated. In order to avoid confusion in this mode of operation the frequency of a calibrating oscillator is automatically switched with the time base speed such that the period of the calibration waveform is in all cases one tenth of the time base durations. Thus when ten calibration periods are indicated in the marked space on the screen, the time base duration corresponds accurately with the chosen switch position. To display the calibration waveform a key is pressed which at the same time removes the test waveform from the screen.

Apart from synchronisation by the 100 kc/s sine wave, provision is made for synchronising from a pulse source. In all cases a triggered time base is used and when the duration of the time base exceeds the repetition rate of the synchronising waveform, a frequency divider comes into operation automatically. In the position 40 msec of the time base, which is required for tests by means of a 50 c/s square wave, the time base is synchronised internally from 50 c/s.

Vertical deflection is obtained through a deflection amplifier having a pass band up to 10 Mc/s (– 3 db) and a deflection sensitivity of 0.04V p-p per cm. A stepped attenuator is provided with four steps of 10 db and also a continuously variable one overlapping the steps of the coarse attenuator. The input impedance to the vertical amplifier in accordance with the overall practice of the test set is 75 ohm.

As for any oscilloscope, brightness, focus, horizontal and vertical shift controls are provided. Critical circuits subject to performance variations due to valve and component ageing are equipped with preset controls. The unit contains all necessary power supplies for its operation and where necessary these are electronically regulated.

Preamplifier, Bridge and Time Base Delay Unit: The system components described in this paragraph are required for coaxial cable reflection tests only and are contained in a small accessory unit. Moreover, some of the test sets will not contain the time base delay unit which is used only on cable lengths exceeding 5000 ft. (0.9 miles).

The preamplifier sub-unit operates in tandem with the vertical deflection amplifier of the CRT unit, which is designed to pass very low frequencies as well as the high frequencies required for the transient response tests. The performance of such an amplifier is always subject to compromise as far as gain-bandwidth and valve (power) requirements are concerned, particularly when deflection voltages of more than 100 volts are required, as is the case for the type of cathode ray tube employed. For cable reflection tests the low frequency response requirements can be relaxed since only narrow pulses are to be displayed. In addition, for a better time resolution a higher upper frequency cut-off and for a greater indicating sensitivity, more gain is desired. Both these tasks are achieved by the preamplifier. Its frequency response is shaped so that it is approximately complementary to that of the CRT deflection amplifier in the range above 8 Mc/s and provides additional amplification by a factor 14 in the flat response range. Thus an overall response is achieved, as shown in Fig. 6, with the —3 db points at 400 c/s and 15 Mc/s. The deflection sensitivity for the cascaded amplifiers is then 2.8 m Volt p-p per cm. The preamplifier may also be used for transient tests on wide-band networks where a good approximation to a unit impulse response is desired.

Another sub-unit used in conjunction with cable reflection tests is the bridge or hybrid network. This facilitates the balancing out of the test pulse at the input end of the cable, so that the indicator unit is not overloaded by the test pulse. The bridge network is physically incorporated with the preamplifier since both will always be used together.

The four arms of the bridge network have a nominal impedance of 75 ohm (Fig. 7), consequently, across the diagonals the same impedance exists. One arm of the bridge is formed by the input impedance of the cable under test and

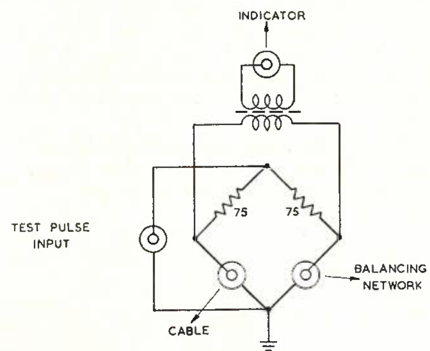


Fig. 7.—Bridge Network.

the corresponding arm in the other branch by a balancing network simulating the cable input impedance (8). The test pulse is fed into the bridge across one diagonal. Then, if the simulating network is identical with the cable under test, no output is obtained across the other (indicator) diagonal of the bridge from the test pulse, but any reflected pulses arriving after the test pulse will cause an output across this diagonal. Since the indicator diagonal is balanced to earth, but the CRT indicator unit input is unbalanced, a balance to unbalance pulse transformer is placed in this bridge diagonal. Owing to the impedance conditions which require all arms and diagonals of the bridge network to be 75 ohms, a loss of 12 db is incurred by the reflected pulses relative to the test pulse, that is, between input and output diagonals.

In order to achieve an optimum suppression of the pulse in the indicator output, not only the balance network must be adjusted carefully for resistive and reactive matching of the cable input, but also direct coupling between bridge input and output via stray capacitances must be prevented by suitable component arrangement and shielding measures. In this equipment a suppression of at least 60 db has been obtained consistently for different cables and test conditions.

In addition to these two sub-units some models of the set will contain a third sub-unit in the accessory unit described in this paragraph. This is an extended time base delay facility for measurements on coaxial cable lengths exceeding 0.9 miles, and up to 9 miles. In the standard model the test pulse repetition frequency is 100 kc/s and delay is provided for one period of this frequency, that is, for 10 μsec (Unit 2). Cable lengths for which the maximum delay of any reflected pulse exceeds the time of one pulse period could produce patterns on the CRT indicator screen which would contain superpositions of reflections resulting from more than one pulse. Hence it is necessary for the testing of such cables (for example, whole repeater sections) firstly to reduce the pulse repetition frequency and secondly to provide for a calibrated delay between the time base trigger and the test pulse which extends over one period of the reduced pulse repetition frequency. Both these functions are incorporated in the time base delay sub-unit.

The block schematic diagram of this unit is shown in Fig. 8. Its circuit consists of two identical branches which differ only in the timing of their input and output signals. The "Time Base" branch may be considered as the time

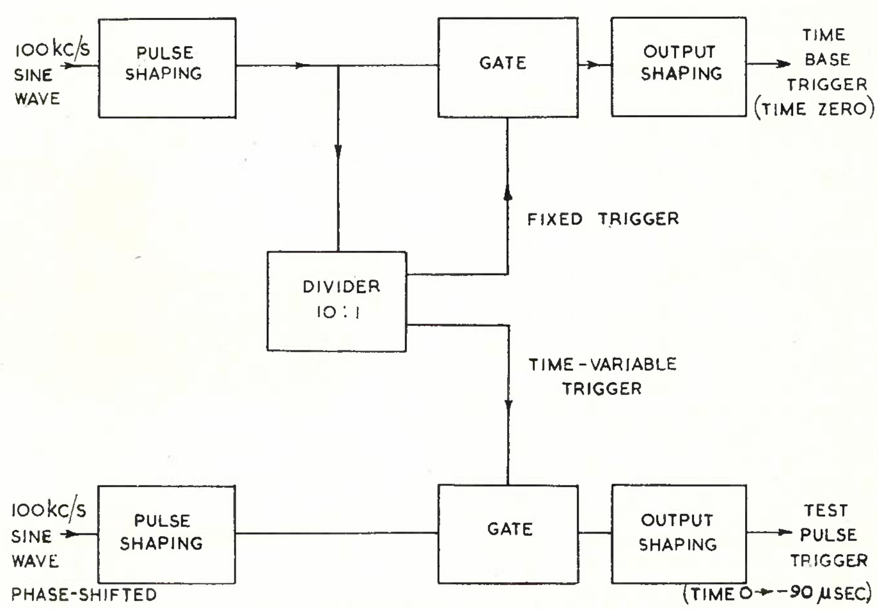


Fig. 8.—Pulse Repetition—Frequency Divider and Trigger Advance Unit.

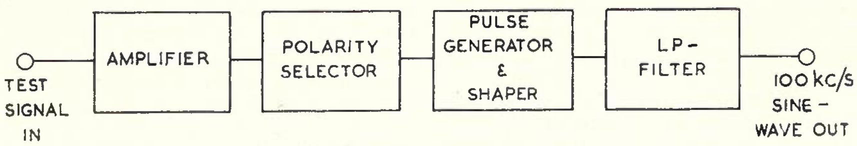


Fig. 9.—100 Kc/s Extractor.

reference branch, relative to which the signals of the "Test Pulse" branch are variable in time. Functionally the time of occurrence of the test pulse can be advanced in a defined way relative to the start of the time base. (This naturally, is equivalent to delaying the start of the time base relative to the test pulse). Hence, it is possible to display any part of the reflection pattern following the test pulse on an abbreviated time base for inspection of detail and measure the distance of any reflection with a high degree of accuracy by reading the relative delay between test pulse and time base trigger.

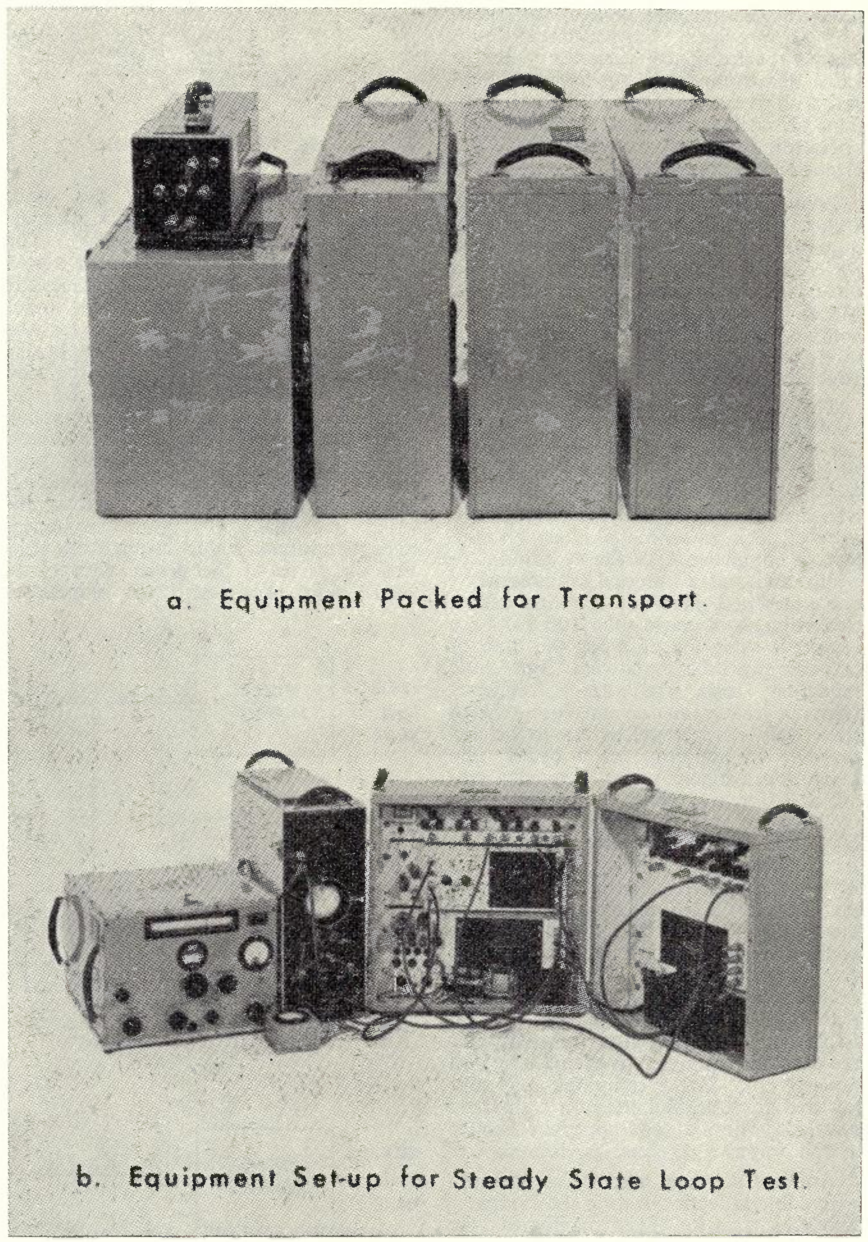
In both branches pulses are derived from 100 kc/s sine waves obtained from the phase shifted and non-phase shifted outputs of the phase shifter sub-unit in Unit 2. The non-phase shifted pulse serves as synchronising trigger of a 10:1 divider circuit. This is an astable multivibrator. The mark-to-space ratio of its output waveform is variable in steps of 10 μsec, each step being synchronized by one of the 100 kc/s pulses. From this multivibrator a fixed trigger pulse and a time variable trigger pulse of 10 kc/s repetition rate are obtained. These trigger pulses activate a gate in each branch by means of which every 10th of the train of 100 kc/s pulses is selected and passed to the output pulse shaper. This arrangement ensures that the output trigger pulse has a high timing stability without extreme requirements on the stability of the multivibrator. Since the selector gate in the test pulse branch is time shifted in 10 μsec steps, successive pulses are selected from the 100 kc/s train. These pulses themselves are variable in time over a range of 10 μsec. Consequently, the timing of the output trigger pulse for the test pulse is continuously variable over 100 μsec, that is, one period of its repetition frequency, relative to the trigger pulse for the time base. Due to the finite rise time of the gate, an easily detectable period of uncertainty of trigger of about 50 m μsec exists at the end of each 10 μsec period.

100 kc/s-Extractor for End-to-End Tests: If the equipment is used for end-to-end tests on transmission networks, (for example, Relay Links) the primary 100 kc/s timing oscillator is naturally at the input end of the network. At the output end, however, a 100 kc/s sine wave is required to drive the CRT-indicator time base and the waveform generator producing the comparison pulse through the 100 kc/s phase shifter.

This 100 kc/s sine wave is extracted from the received test signal, by means of the extractor sub-unit.

This sub-unit is housed in the receiver Unit 3. It is required that the extracted sine wave should have a high phase stability relative to the received test signal, because any phase fluctuations would falsify the measurement of phase delay and produce jitter and drift on waveform displays. Distortions of the received test signal should not affect the amplitude or phase of the recovered sine wave.

To achieve this the received signal is amplified first to obtain a fast trigger action of the subsequent pulse generator (Fig. 9). In order that the extractor will operate from either positive or negative signals, a polarity selector stage is inserted between the amplifier and pulse generator. It is the purpose of the pulse generator to generate a waveform which is independent of the incoming test signal in regard to amplitude and shape, but is rigidly phase-locked to this signal and is not affected by any overshoot and ringing present as result of distortions caused by the transmission network. These requirements have been satisfied by using a cathode coupled monostable multivibrator with a fast regenerative action. Since any variation in the width of the pulse generated by this device would cause objectionable variations in the amplitude and phase of its spectrum components, the pulse width is stabilized



a. Equipment Packed for Transport.

b. Equipment Set-up for Steady State Loop Test.

Fig. 10.—Physical Appearance of Test Set.

by means of a delay line (6). The fundamental frequency of 100 kc/s is then filtered out of the pulse spectrum in an m-derived low pass filter and fed through a cathode follower to the output.

Power Supplies and Circuit Monitoring: Three main points have been governing the design of the power supplies which provide the necessary voltages for circuit operation. Firstly, all units are to be self contained and to be operated from an A.C. supply with a nominal voltage of 230 V, secondly, because of the high stability requirements of circuit operation, the D.C. supply voltage has to be electronically regulated in most cases and, thirdly, as far as possible a standard circuit design should be adopted for simplicity of maintenance and production.

To accommodate major deviations from the nominal A.C. supply voltage, all mains switches have several positions selecting different tappings of the transformer primary windings when in the "ON" position. This ensures that the valve filament voltages are as close to their nominal value as practicable, with a consequent improvement in valve life and circuit performance.

The electronic regulators employ a modified cascode circuit as control circuit which is of the same design for all units. Variations in the required current capacity of the various units are met by modifying the number of series regulator valves connected in parallel (rather than using different valves) and by selecting a transformer and rectifier of matching power capacity.

Although it would be advantageous to use semiconductor rectifiers in this application, valve rectifiers are still employed, because at the time of development no suitable types were available in this country.

Provisions are made in each unit to select by means of a switch essential circuit voltages for the monitoring of circuit performance to assist in fault-finding and maintenance. A meter is supplied to be plugged into an outlet provided on each unit and connected to the selector switch.

OPERATING EXPERIENCES AND EXAMPLES OF APPLICATIONS

During a period of about two years a development model of the equipment has been used in a number of field applications and in the laboratory. As may be expected the operating of the development model under field conditions showed up some weaknesses in components and design which, however, could be remedied satisfactorily without drastic changes as to construction. The modifications that were found necessary, mainly concerned the choice of more suitable circuit components, such as, for example, high stability resistors, and additional ventilation and mechanical strengthening of some units.

After frequent transportation in trucks, cars and aircraft, the equipment still performed satisfactorily. When used by personnel other than the laboratory staff, it was found that officers quickly became familiar with the operating procedure. In all cases the inherent self-checking facilities of the equipment made it possible to verify that the equipment was in satisfactory condition and that the results obtained were reliable.

After a warming-up period of one half to three-quarter hours, temperature drift was usually negligible. The equipment was frequently in operation for periods of eight hours at a time without detrimental effects, even under high ambient temperature and humidity conditions.

The physical appearance of the equipment is depicted in Fig. 10 (a) and 10 (b) the former showing the individual units packed for transport and the latter the equipment set-up for a loop steady state test as per Fig. 1 (b). To the left is the receiver Unit (Unit 3) followed by the CRT Unit (Unit 4), Unit 2 containing waveform generator and phase shifter sub-units, and finally Unit 1.

A typical test record of transient and steady state response is shown in Fig. 11. This was obtained from an overall test of a TV broadcast transmitter.

To allow the transmitter equipment to work under normal operating conditions, the test signals of the Video Transmission Test Set were combined with specially shaped horizontal synchronizing pulses (9).

The test record obtained from a pulse reflection test on a four-tube .375 inch coaxial cable is shown in Fig. 12. This record is typical for a cable which has no serious discontinuities in impedance and is satisfactory for the intended application. The calibration for 60 db return loss on either side of the trace demonstrates the high sensitivity of the equipment. On the left end of each trace the break-through pattern due to imperfections of test-pulse suppression may be seen.

Finally Fig. 13 depicts a transient response record obtained from a TV broadcast transmitter. The response shows clearly the effect of equalizing the distortions introduced by the vestigial sideband filter by means of a phase equalizer. The sinusoidal waveform on the bottom of Fig. 13 (c) is a 5 Mc/s timing waveform for reference purposes and is valid for all three response records.

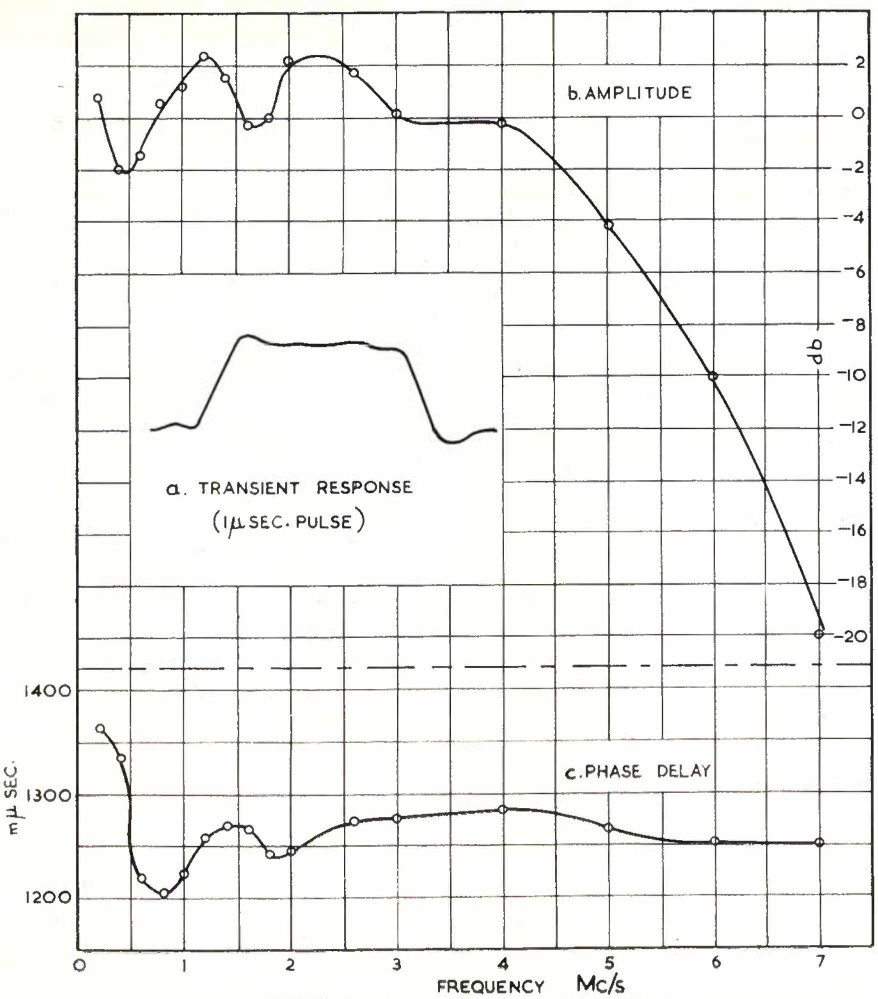


Fig. 11.—Typical Transient and Frequency Response Record.

CONCLUSION

A Video Transmission Test Set was designed and constructed by the Research Laboratories, which permits steady state and transient response tests of television and other wide band transmission networks, up to 10 Mc/s bandwidth to be made. In addition pulse reflection tests

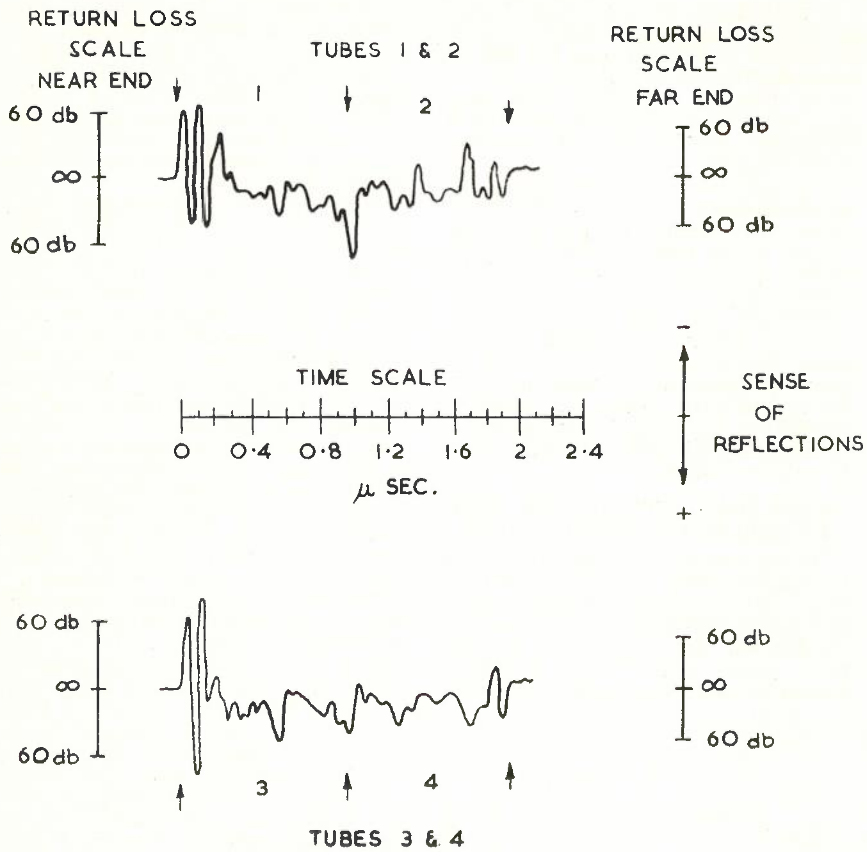
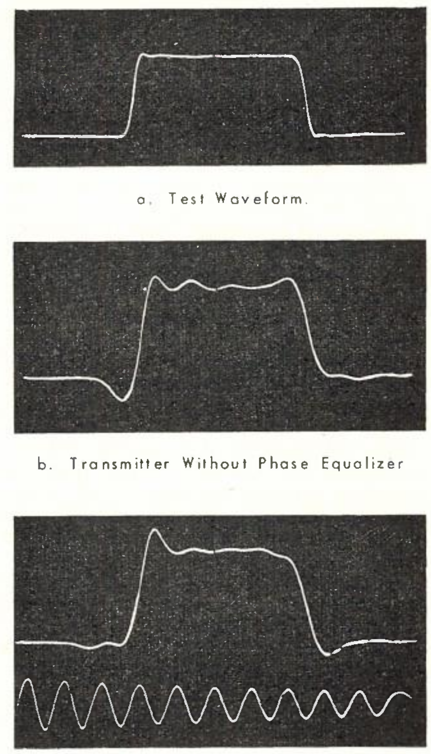


Fig. 12.—Typical Cable Reflection Test Record.



a. Test Waveform.

b. Transmitter Without Phase Equalizer

Transmitter With Phase Equalizer.

Fig. 13. — Step Function Response of T.V. Transmitter.

on coaxial cable installations can be carried out with the equipment. A development model of the test set was used in numerous field applications and stood up well to the hazards of transportation and climatic conditions. A number of these sets are at present in production for use by the operating sections of the Department.

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A DIAL TESTER FOR THE TEST DESK

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REQUIREMENTS

The dial tester to be described in this article is a new design intended for the Test Desk. Some of the more important requirements which were to be met are listed below:

(i) The tester should be capable of measuring all of the parameters (speed, ratio and count) in one single train of impulses.
(ii) There should be provision to indicate if any single make period or any single break period in the impulse train is distorted, that is, outside permissible limits of length.
(iii) Test results should be indicative of the condition of the distant dial alone and be as free as possible of errors induced by line characteristics.
(iv) The design should be relatively simple, in order to minimise maintenance difficulties, and be quick to operate.
(v) It should not require readjustment to compensate for the resistance variations between different subscribers' lines, or for variations in the battery supply voltage.

DESIGN CONSIDERATIONS

There were several possible systems which would meet the majority of the above requirements. The first to be studied was a completely electronic design. This proved to be technically feasible but it was discarded on the score of cost and maintenance difficulties. The next design to be considered was a compromise, using both electronic and electro-mechanical components. This resulted in the design discussed below.

SELECTED SCHEME

The tester is simple to use. Three initial adjustments are required. It can then be used for long periods on various circuits without further adjustment. After connecting the tester to a line, a train of impulses can be tested immediately and the impulse ratio, count, and speed determined. In order to obtain a speed reading it is necessary to dial "O" into the tester. If any impulse has been clipped or broken into parts, a red lamp is lighted on the instrument, indicating that a faulty impulse has been detected.

EQUIPMENT LAYOUT

To operate the tester, regulated 50V positive and 50V negative battery supplies are needed. Power is turned on by operating key KP a few minutes before the equipment is required to be used. The equipment is then adjusted as described later before being put into service. These initial adjustments compensate for errors which would otherwise be caused by valve and component ageing as well as various temperature effects.

Indicator lamps are provided on the tester to indicate the quantity (ratio, count or speed) being displayed at any time. This is advantageous on fully automatic equipment such as this because the testing cycle is performed without any guidance from the operator. The four main lamps are designated Reset, Ratio, Count and Speed, and only one is lighted at any time. The illumination of the Reset lamp is an indication to the operator that the tester is connected to a line and in a proper condition to test a train of dial pulses. A further lamp is designated Distorted Impulse Received. This lamp is lighted if a distorted make period or a distorted break period is detected anywhere in the impulse train.

RATIO TEST

In order to obtain immunity from line resistance changes, it was necessary to interpose a relay between the line and the test set. This relay did not affect the speed or count tests but it did affect the accuracy of the ratio tests. Some typical results obtained on ratio tests are shown in the table Fig. 1.

Line Resistance	Test Set Reading			
	Line Relay in Heavy Adjustment		Line Relay in Light Adjustment	
	Speed 9 i.p.s.	Speed 11 i.p.s.	Speed 9 i.p.s.	Speed 11 i.p.s.
Zero	33.5%	34%	34.5%	35%
800 ohms	35%	35%	36%	36.5%
1500 ohms	34.5%	35%	36.5%	37.5%

Fig. 1.—Ratio Test Results.

Dial Make Ratio = 32%.
Battery Voltage = 52V.
Spark Quench = 2uF + 30 ohms.

The spread of these readings is about ± 2% from the median value. When the tests were repeated with the supply voltage reduced to 46 volts, the maximum error (including the 52 volt tests) rose to ± 2.5%.

In order to minimise readjustments necessitated by fluctuations in either of the supply voltages, simple stabilisers are fitted at various points in the circuit. The stabilisers used are Zener diodes. These devices can be conveniently used to provide stabilised supplies with voltages from about 3 volts upwards.

COUNT AND SPEED TEST

When the problem of measuring simultaneously the impulse speed, ratio and count was first considered, it became apparent that if the operator was going to be able to interpret the readings accurately, some form of storage must be adopted. If the readings were only made available during the time taken by a train of 10 impulses, then the operator would have only one second in which to note and remember 3 different results. This was obviously impracticable. Storage, therefore, became necessary. The easiest readings to store were the count and speed.

The method adopted for storing the impulse count is the same as that used in the existing tester design to drawing CE.462. A uniselector is stepped once for every impulse received and it is arranged to stay in position for about two seconds after impulsing ceases. This gives the operator time to observe the wiper position from a monitoring lamp strip before the tester automatically resets itself. CE.462 uses a specially calibrated meter scale to determine the wiper position but the lamp strip arrangement as is used in some locally modified test desks is preferable.

The speed information is conveniently stored as a charge on a large (10 μF) capacitor. The amount of the stored charge is a function of the time taken by nine complete impulses of the incoming train. The nine complete impulses are measured from the end of the first break period to the end of the tenth break period. This covers exactly nine make periods and nine break periods. The charge on the capacitor is preset before the end of the first break period and it is then arranged to change in a known manner for the timed period. At the end of the nine impulse interval the charge on the capacitor is read off by means of a specially calibrated vacuum tube voltmeter. This gives a steady reading after the tenth break period has passed and allows the operator ample time to note the results. The vacuum tube voltmeter utilises the standard 400 μA test desk meter as the readout device.

There are several possible methods of using this technique to give a usable calibration law to the V.T.V.M. The most desirable would give a perfectly linear speed scale occupying the whole of the

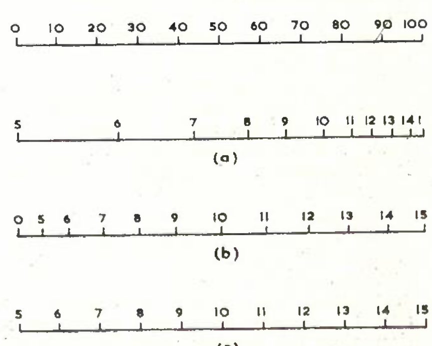

Fig. 2.—Speed Scales for Meter.

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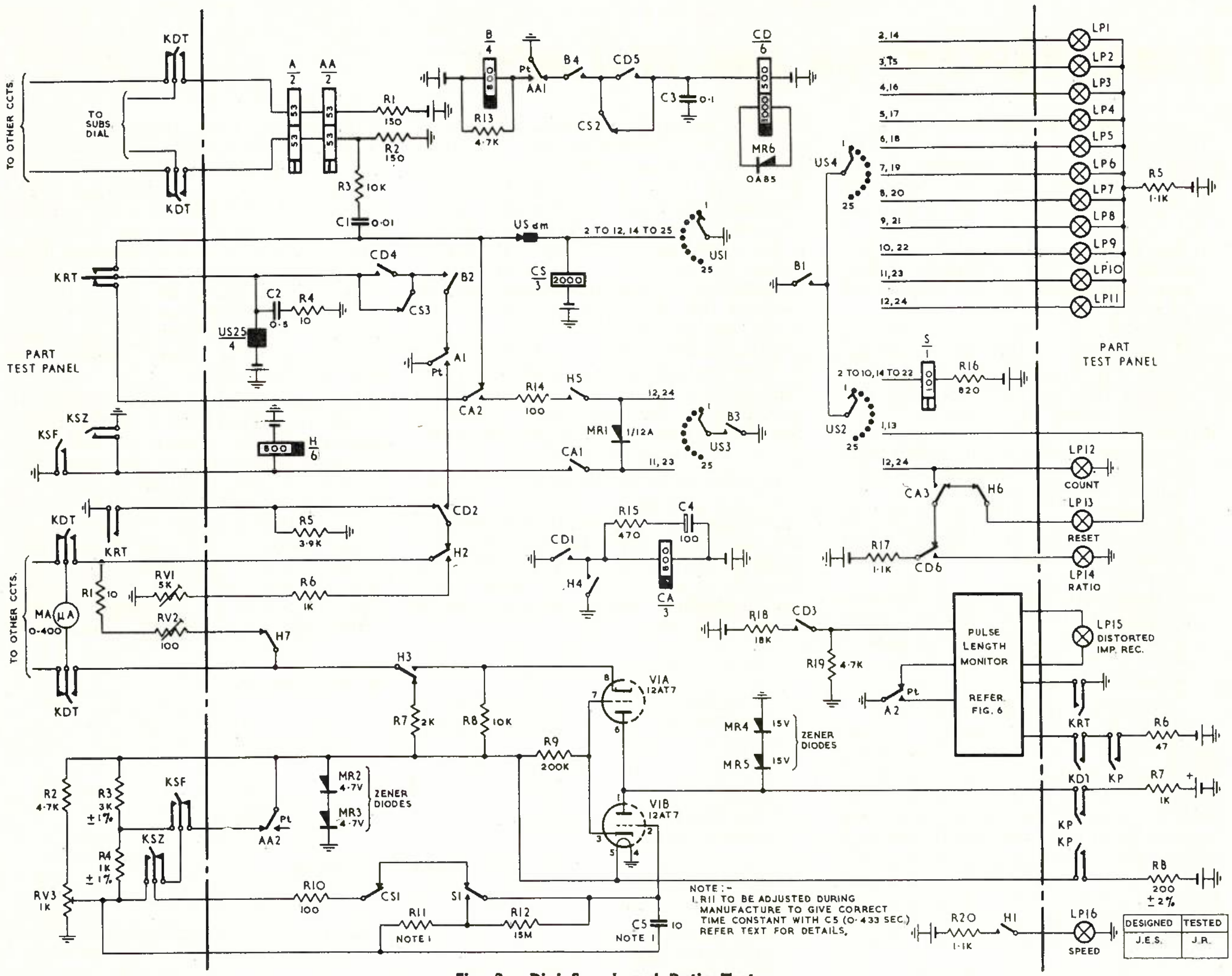


Fig. 3.—Dial Speed and Ratio Tester.

meter face and covering the range 5 to 15 i.p.s. (See Fig. 2(c)). The arrangement finally adopted does not quite achieve this.

If a constant current were used to charge (or discharge) the timing capacitor, a scale such as that shown in Fig. 2(a) would result. The reason for this is apparent when the operation of such a system is considered. A constant current applied to the timing capacitor would cause the rate of change of capacitor voltage to be a constant, say X volts per second. If the V.T.V.M. had a linear characteristic then its meter pointer would move at a linear rate. Now, the time taken by 9 impulses at a speed of 15 i.p.s. is 0.6 seconds, at 10 i.p.s. it is 0.9 seconds, and at 5 i.p.s. it is 1.8 seconds. Therefore, since the meter pointer would move at a steady speed, the pointer position at 0.9 seconds would be closer to the 0.6 seconds position than it would be to the 1.8 seconds position. If 0.6 seconds were made to correspond with a full scale deflection and 1.8 seconds to a zero scale deflection, then 0.9 seconds would correspond with the three quarters full scale position. This scale shape would not be very attractive and two other methods were examined.

The first method to be tried (see Fig. 3) was a scheme which modified the capacitor timing circuit so that an exponential rate of change of the capacitor voltage was obtained. By choosing the time constant of the discharge circuit to be 0.433 seconds (for derivation see Appendix), and adjusting the V.T.V.M. appropriately, a scale such as that illustrated in Fig. 2(b) was obtained. As can be seen, the graduations are approximately linear over the region 15-7 i.p.s. and severely non-linear beyond this region. Some test results with this circuit are given in the table of Fig. 4.

Input Impulse Speed	Reading Obtained on Meter Scale
5 i.p.s.	5.2 i.p.s.
6 ,,	6.2 ,,
7 ,,	7.2 ,,
8 ,,	8.1 ,,
9 ,,	9.1 ,,
10 ,,	10.1 ,,
11 ,,	11.1 ,,
12 ,,	12.1 ,,
13 ,,	13.1 ,,
14 ,,	14.0 ,,
15 ,,	14.9 ,,

Fig. 4.—Speed Tester Performance.

Development of another method of speed testing is proceeding and improved scale shape and accuracy should be possible.

CIRCUIT OPERATION

Calibration

After operating key KP, a reasonable warm up time (say 10 minutes) should be allowed. The initial adjustments should then proceed as follows:

Operate key KRT and adjust the meter pointer to full scale by means of the Ratio Full Scale Adjust control. (RV2) Restore KRT.

Operate key KSZ and set the meter to zero scale by means of the Speed Zero Adjust control (RV3). Restore KSZ.

Operate key KSF and adjust the meter to full scale by means of the Speed Full Scale Adjust control (RV1). Restore KSF.

The tester is now ready for use.

[If the speed timing capacitor and resistor have not the correct time constant (0.433 seconds) correction is effected as follows. This adjustment would normally be carried out during manufacture and only needs an annual check.

(i) Set up the tester as described above.

(ii) Connect an accurate impulse generator of known speed across the tester input, and arrange a temporary short circuit across its impulsing contacts.

(iii) Operate key KRT momentarily until the Reset lamp glows.

(iv) Remove the short circuit from the impulsing contacts and when the Speed lamp glows note the meter reading.

(v) Repeat (ii), (iii), and (iv) several times and note the mean reading. If the mean speed reading obtained is too low then the speed timing resistor R should be **increased** slightly in value and the whole procedure repeated. A few trials will yield the desired result.]

Normal Operation

Relays A and AA operate immediately a line loop is applied.

A1 Has no function.

A2 Presets the break timing capacitors in the pulse length monitor. A detailed description of this unit is given in a later section.

AA1 Operates relay B.

AA2 Removes the 10 volt charging source from the speed timing capacitor. This allows its charge to leak away via the 15 megohm resistor.

Relay B operates

B1 Completes the path for the "Reset" lamp.

B2 Prepares a path for the operation of the uniselector.

B3 Prepares the path for the operation of relay H.

B4 Prepares the path for the operation of relay CD.

When the first break in a train of impulses is received relays A and AA release.

A1 Operates the uniselector magnet.

A2 Starts the timing circuits for the break length monitor and prepares the timing circuits for the make length monitor.

AA1 Operates relay CD.

AA2 Charges the speed timing capacitor.

Relay CD operates

CD1 Operates relay CA.

CD2 Prepares the meter circuit to measure impulse ratio at A1 contacts.

CD3 Supplies 10 volts to the pulse length monitor.

CD4 Prepares a maintaining path for the uniselector drive magnet before CS operates.

CD5 Prepares a maintaining path for the CD relay before CS operates.

CD6 Extinguishes the Reset lamp and lights the Ratio lamp to indicate that the meter is now reading impulse ratio.

Relay CA operates

CA1 Prepares the operate path for relay H.

CA2 Breaks the homing circuit for the uniselector and prepares a stop circuit which will prevent it driving past the 12th contact. This is necessary when the tester is used to check the output of an impulse generator or some other continually impulsing source.

CA3 Prepares the circuit for the Count lamp.

At the end of the first break period relays A and AA reoperate.

A1 Releases the uniselector magnet and completes the meter circuit for ratio testing.

A2 Operates the timing circuits in the pulse length monitor.

AA1 Re-energises the B relay circuit.

AA2 Removes the charging source from the speed timing capacitor.

The uniselector armature now drives the wipers forward one step.

US1 Operates relay CS.

US2 Operates relay S.

US3 No function.

US4 Completes the circuit for count lamp No. 1.

Relay S operates

S1 Commences the discharge of the speed timing capacitor via the speed timing resistor.

Relay CS operates

CS1 Holds open the charging path for the speed timing capacitor.

CS2 Puts relay CD under control of its own contact.

CS3 Puts the uniselector drive circuit under the control of the CD relay.

As further impulses are received the uniselector rotates and finally stops, indicating its position on the count lamp strip. This can then be read to determine the digit dialled.

Relay CD releases

CD1 Allows CA to release slowly.

CD2 Removes the meter circuit from the A relay contact.

CD3 Removes the 10 volt operating bias from the pulse length monitor.

CD4 Opens the uniselector magnet circuit to prevent stepping should any further impulses be received prematurely.

CD5 Breaks the CD relay operate circuit to prevent further operation until the tester has been reset for the next test.

Relay CA releases slowly.

CA1 Has no function.

CA2 Completes a homing circuit for the uniselector which now drives to its home position. A part of the uniselector magnet surge voltage is fed to line via a capacitor and resistor as a signal to the distant technician that the tester has reset and is now ready to receive further impulses.

CA3 Extinguishes the Count lamp and completes the circuit for the Reset lamp.

The tester is now reset and all relays restored excepting A, AA and B.

If the number of impulses received had been 10, then after the end of the 10th impulse relay S releases and relay H operates from the wipers of the uniselector.

S1 Removes the discharge path from the speed timing capacitor.

The input grid of the V.T.V.M. is now virtually open circuit excepting for the 15 megohm resistor. The small leakage current produced by this resistor tends to prevent the slow rise in capacitor voltage which occurs with circuits of this type immediately after a rapid discharge has ceased.

After the initial slow rise period has passed (about 4 or 5 seconds with this particular capacitor) the capacitor voltage starts to drop slowly because of the leak in the 15 megohm resistor. This effect is not serious, however, as ample time is available to note the speed reading before it drifts excessively.

The double cathode follower arrangement used in the V.T.V.M. design reduces grid current effects to negligible proportions in this circuit.

The test desk meter is connected into the V.T.V.M. circuit by means of relay H which is operated from US2 as described earlier.

H1 Completes the circuit for the Speed lamp. This indicates that the mean speed of the impulses may now be read on the appropriate meter scale.

H2 Provides a preset calibrating resistance for use in the V.T.V.M. circuit..

H3 Connects the meter onto the output cathode of the 12AT7.

H4 Provides a holding path for relay CA. This prevents the tester resetting automatically until the Reset key KRT has been operated.

H5 Completes a stop circuit for the uniselector which operates if more than 11 impulses are received. This device permits the tester to be used to measure the impulse speed of any continuous impulse source.

H6 Holds the Reset lamp circuit open. This makes the lighting of the Reset lamp dependent upon the condition of the H relay and ensures that relay H is normal before any new test can proceed.

If 11 or more impulses are received the selector magnet is held operated after the 11th break period by the earth provided at B3. This prevents any further stepping until the tester has been reset with key KRT.

PULSE LENGTH MONITOR

This portion of the dial tester has been treated separately because it forms an impulse testing device by itself. Its purpose is to monitor all incoming impulses and examine each make period and each break period individually. Unless each

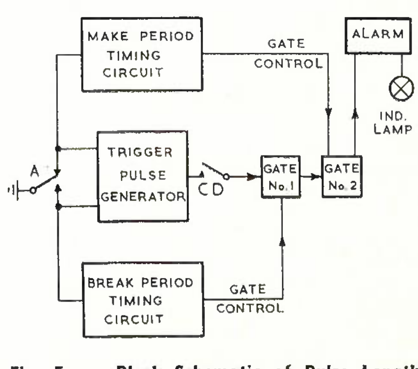


Fig. 5. — Block Schematic of Pulse Length Monitor.

make period and each break period are within preset limits a red indicator lamp is lighted indicating that a faulty impulse has been detected.

The particular merit of this arrangement is that it will readily detect a single distorted impulse anywhere in a pulse train of any length.

The four preset limits required are:

(i) Minimum permissible break period.
(ii) Maximum permissible break period.
(iii) Minimum permissible make period.
(iv) Maximum permissible make period.

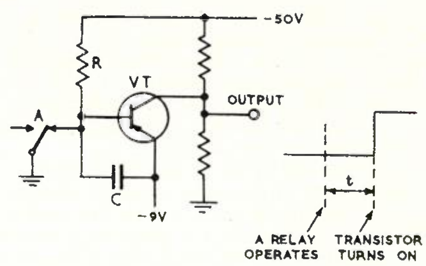
Any one of these four limits can be adjusted independently of the other three.

The basic arrangement of the monitor is shown in Fig. 5. The detailed circuit is shown in Fig. 6.

The trigger pulse generator shown in Figs. 5 and 6 is designed to produce a positive trigger pulse every time the lever spring of the A relay makes connection with either of the side contacts. This positive trigger pulse is fed to the series connected gates to the alarm circuit. The gates are normally 'open', but they are periodically biassed 'shut' by means of long rectangular bias pulses from the timing control circuits. Each control circuit produces an off bias (which shuts its associated gate) for the interval between the minimum permissible dial pulse length and the end of the particular pulse. If the maximum permissible dial pulse period elapses and the dial pulse being monitored has not been completed, the control circuit removes its off bias. The end of dial period trigger pulse will then be able to get through to the alarm circuit. If the dial pulse ends before the minimum permissible period has elapsed then the trigger pulse would find the gates open and operate the alarm circuit.

The CD relay contact shown in Fig. 5 is diagrammatic only. Its purpose is to prevent the positive trigger pulse generated at the beginning of the first break period from operating the alarm circuit. In the arrangement shown in Figs. 3 and 6 the CD relay contact is arranged to control the battery supply to the trigger pulse generator. Hence it is only whilst the CD relay is operated that the pulse length monitor is operative.

The trigger pulse generator consists of a network of diodes, resistors and capacitors. The capacitors on each side of the circuit are charged one at a time after the earth is removed from their associated A relay contact. When the earth is reapplied, by the lever spring moving back again, the capacitor on that side of the circuit is discharged rapidly via the contact earth. This rapid discharge appears across a load resistor at the output of the generator as a short positive pulse somewhat less than 10 volts in amplitude.



DELAY (t) ≈ 0·2 RC SECONDS

Fig. 7.—Basic Timing Circuit.

The basic timing element used in the circuit to control the gate bias potentials is shown in Fig. 7.

When the A relay contact earths the base of the transistor the transistor is cut off. Upon the lever spring moving away the capacitor C commences to discharge via the resistor R. Ultimately it loses all

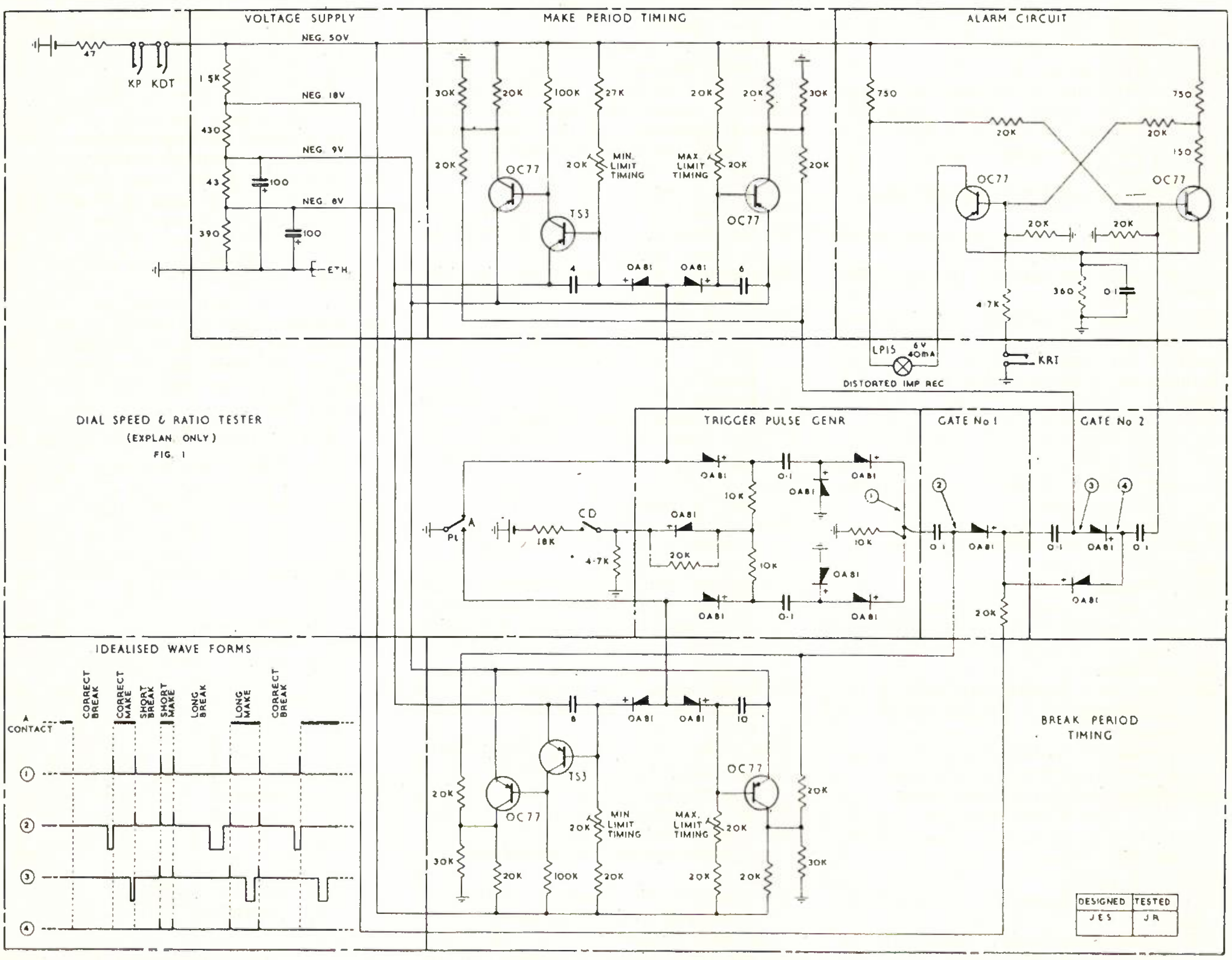


Fig. 6.—Circuit of Pulse Length Monitor.

of its charge and commences to charge up again the opposite way. It does not charge up more than about 0.2 volts in this direction before the emitter diode of the transistor becomes forward biassed and the transistor conducts heavily. The sudden increase in collector current causes a large positive going step to appear in the collector voltage waveform. This positive step is applied, in the case of a minimum period timer, to a phase inverting stage. This produces a negative going step which is applied to the gate control lead where it biases 'off' the gate diode. The positive step from the associated maximum period timer is applied directly to the gate control terminal at the same point as the output from the minimum period timer.

The circuit is arranged so that when a negative control pulse and a positive control pulse are applied simultaneously to a gate control input, the net effect is zero. The gate is normally 'open'. It is biassed 'shut' by the minimum period timer. Then it is effectively biased 'open' again by the maximum period timer, or by the restoration of the minimum period timer to its normal unoperated condition. In normal operation on good impulses the minimum period timer is reset to normal before the maximum period timer can operate. This occurs every time a dial pulse is monitored which is within the permissible limits.

The alarm circuit consists of a bistable arrangement of two transistors. In each stable state only one of the two transistors is conducting. When the state of the circuit is changed by the receipt of a trigger pulse the conducting transistor is turned off and the non-conducting transistor turned on. The indicator lamp is placed in series with the normally non-conducting transistor so that the receipt of a trigger pulse is signalled immediately by the lighting of the lamp.

CALIBRATION OF PULSE LENGTH MONITOR

There are several possible calibration procedures for the pulse length monitor but one of the simplest is that outlined below. It requires only a ratio meter and an impulse source with smooth and continuous control over the make ratio. A speed of 10 impulses per second is convenient to use as the make time and break time can be readily deduced from a knowledge of the make ratio.

The make timing circuits can be set by varying the make period of the input pulses over the desired range, and adjusting the minimum limit and maximum limit controls until the alarm circuit operates for all make pulses outside of this range. In order to carry out this test free of interference from the break timing circuits it is first necessary to prevent trigger pulses being generated at the end of each break period. This is most easily done by temporarily removing the lead joining the trigger pulse generator to the make side of the A relay contacts. With trigger pulses now being generated only at the end of each make period, the make timing circuits can be easily adjusted.

When the make period limits have been set the trigger pulse generator lead is restored to the make side of the A relay contacts and the lead from the break side removed. This now allows the break period limits to be adjusted without interference. The contact lead can later be reconnected whereupon the monitor is ready for use.

When the impulse generator is connected to the input terminals of the equipment a spark quench circuit of $2\mu F + 30$ ohms is required. This simulates more closely the impulsing condition from a telephone dial. When checking the impulse generator make ratio on the ratio meter the spark quench and tester input must be disconnected from the impulsing contacts. Otherwise, misleading resudts may be obtained.

An accurate ratio meter may be made up from a moving coil voltmeter, a few dry cells and a variable resistor. The components are all connected in series, including the impulsing contacts. The meter is firstly adjusted to read full scale with the impulsing contacts short circuited. Then, when the short circuit is removed an accurate make ratio reading will be obtained. If the meter scale is calibrated 0-100 and the impulse speed is 10 i.p.s. a make ratio reading of 40 can be immediately interpreted as a make time of 40 mS and a break time of 60 mS.

DISCUSSION

The above description covers the major features of the dial testing equipment illustrated in Figs. 3 and 6. The principal shortcomings of the design are

(a) Speed scale non-linearity.
(b) Slow drift in the speed reading.
(c) Distortion of the impulse ratio reading.

The speed scale non-linearity and slow time drift are only capable of improvement at the expense of more complicated circuits. Admittedly non-linear scales are difficult to read, but the scale shown in Fig 2(b) is nearly linear from 7 to 15 i.p.s. and it can be easily read in this range. Since the major divisions are widely spaced and a steady reading is available for about 4 or 5 seconds interpolations to 0.2 i.p.s. are easily available if required.

A feature not shown on Fig. 3 is a key which will change the speed scale range (normally 5-15 i.p.s.), to 10-30 i.p.s. This is expected to be useful in setting the speed of some high speed impulse generators used with automatic routiners.

Drifts in the speed and ratio readings can occur if large changes in either of the supply battery voltages occur. The Zener diode stabilizers fitted can only reduce the effect of such changes; they cannot overcome them completely. If the zero and full scale adjustments with keys KRT, KSZ and KSF are checked periodically, long-term drifts in supply voltage as well as valve and component ageing effects can be minimised.

The pulse length monitor could be used alone to check impulses if a 'go' and 'no go' type of test were required. In this application it must be noted that the pulse length monitor will pass impulses which could not pass a speed and ratio type of tester and vice versa. This is due to the fact that the shapes of the acceptance areas on a target diagram are different for each type of tester. This may not prove to be permissible in some applications.

CONCLUSION

A practicable answer to the problem of easily, rapidly and accurately determining the condition of a distant telephone dial has been evolved. In the development of the design compromises were made, mainly in an endeavour to keep the apparatus simple, stable and capable of easy maintenance in the field.

ACKNOWLEDGMENTS

Thanks are due to Mr. G. A. M. Hyde for his valuable guidance, to Mr. J. A. Pryor for many helpful discussions, and to those members of the Telephone Equipment Circuit Laboratory staff who so ably constructed and tested the equipment.

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APPENDIX

The following illustrates the method used to determine the speed scale calibration points shown in Fig. 2(b).

Consider a capacitor (C) discharged through a resistor (R) for t seconds.

The final voltage (v) after discharge is given by

$$v = Ve^{-[t/RC]}$$

where V = initial voltage before discharge
t = time of discharge
e = 2.71828
R = resistance in ohms
C = capacitance in farads.

This may be transposed to give the expression

$$t = RC \log_e \left|\frac{V}{v}\right| \qquad (1)$$

Now, if t be taken as the time for 9 complete impulses at a rate of S impulses per second then

$$t = \frac{9}{S} \qquad (2)$$

Equating (1) and (2) we get

$$\frac{9}{S} = RC \log_e \left|\frac{V}{v}\right| \qquad (3)$$

Since full scale voltage (v_{fs}) is desired for a speed reading of 15 i.p.s. the capacitor voltage after 9 impulses at this speed is put equal to v_{fs}.

Then, the voltage after 9 impulses at a speed of 10 i.p.s. can be put equal to $\frac{1}{2}v_{fs}$, since this calibration mark is desired exactly at the scale centre.

Now substituting for the case of 15 i.p.s. in equation (3) we get

$$\frac{9}{15} = RC \log_e \left|\frac{V}{v_{fs}}\right| \quad \ldots\ldots\ldots (4)$$

and for the 10 i.p.s. case

$$\frac{9}{10} = RC \log_e \left|\frac{2V}{v_{fs}}\right| \quad \ldots\ldots\ldots (5)$$

Solving (4) and (5) we get

$$\frac{V}{v_{fs}} = 4$$

and $RC = \dfrac{0.6}{\log_e 4} \doteqdot 0.433$ seconds

Substituting these values in equation (3) gives

$$\frac{9}{S} = 0.433 \log_e \left|\frac{4v_{fs}}{v}\right| \quad \ldots\ldots\ldots (6)$$

Rearranging

$$\frac{v}{v_{fs}} = 4e^{-\left(\frac{20.8}{S}\right)} \quad \ldots\ldots\ldots (7)$$

Equation (7) gives the fraction of full scale which is represented by any speed S, assuming a perfectly linear response in the vacuum tube and milliammeter circuit. In practice the circuit response is not perfectly linear. This causes errors. Deviations are illustrated in the table of Fig. 4.

NEW DEVELOPMENTS IN SLEEVE CONTROL SWITCHBOARDS

*D. S. WATSON, B.Sc.**

Sleeve control switchboards now installed in many places in this country were adequately described in earlier articles of the Journal (1). The associated circuits provided for two basic types of switching positions known as 'Through' and 'Terminating' positions. The through position was used for connecting together calls incoming on one trunk circuit and requiring connection to another trunk circuit while the terminating position catered for traffic between the trunk lines and the local CB subscribers. The purpose of the terminating position was to eliminate the need for connecting the CB subscribers to the trunk lines via the local A position telephonist. Where the local exchange was automatic, terminating positions were not required. On the basis that most incoming traffic could be classified as terminating, all incoming trunk calls in CB areas were answered on a terminating position and their transfer to a through position effected when necessary. Several disadvantages in this system soon become apparent.

(a) Because of the time taken to reach the through telephonist (the answer time of two telephonists) the efficiency of the trunk circuits was seriously affected especially where the proportion of the through traffic to total traffic was higher than normal.

(b) In periods of very light traffic when only one telephonist was required there existed the operating difficulty of handling calls on two positions.

Early Composite Positions

By arranging for some positions to be equipped with terminating and through cord circuits operation during periods of

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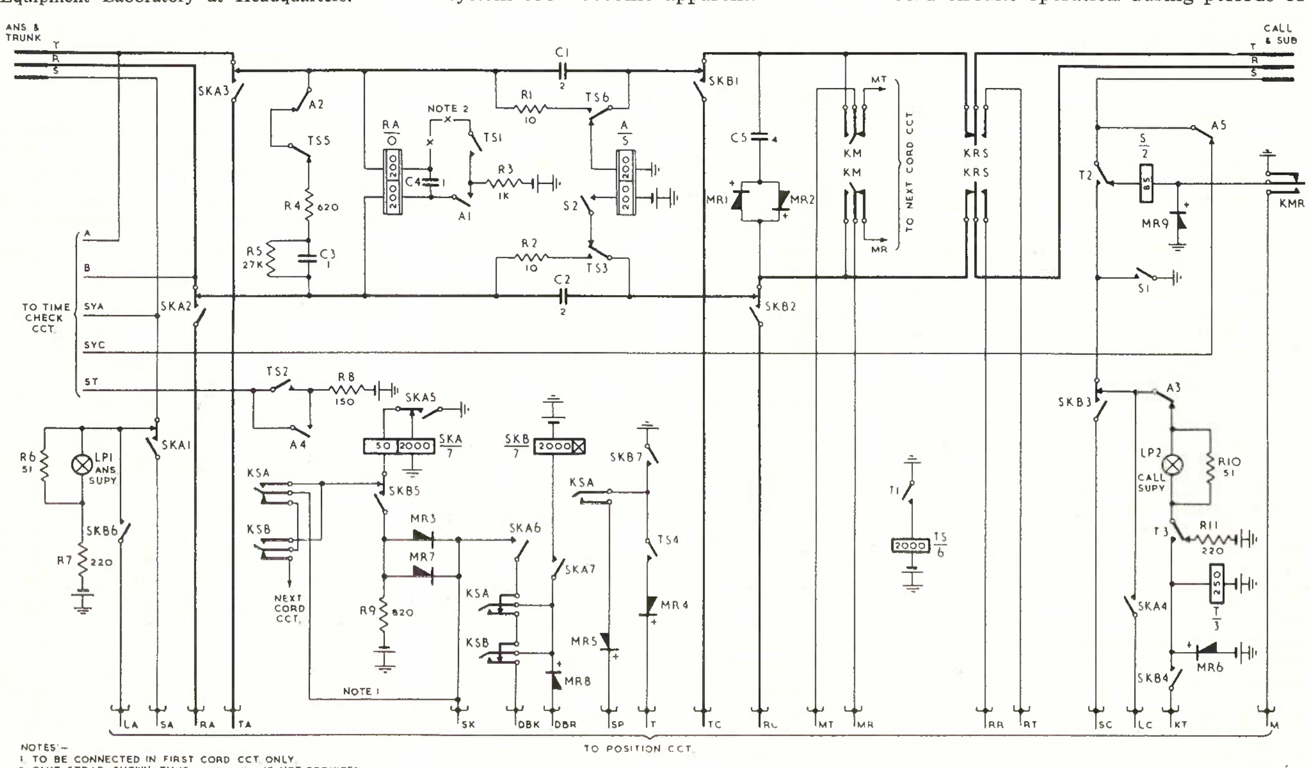
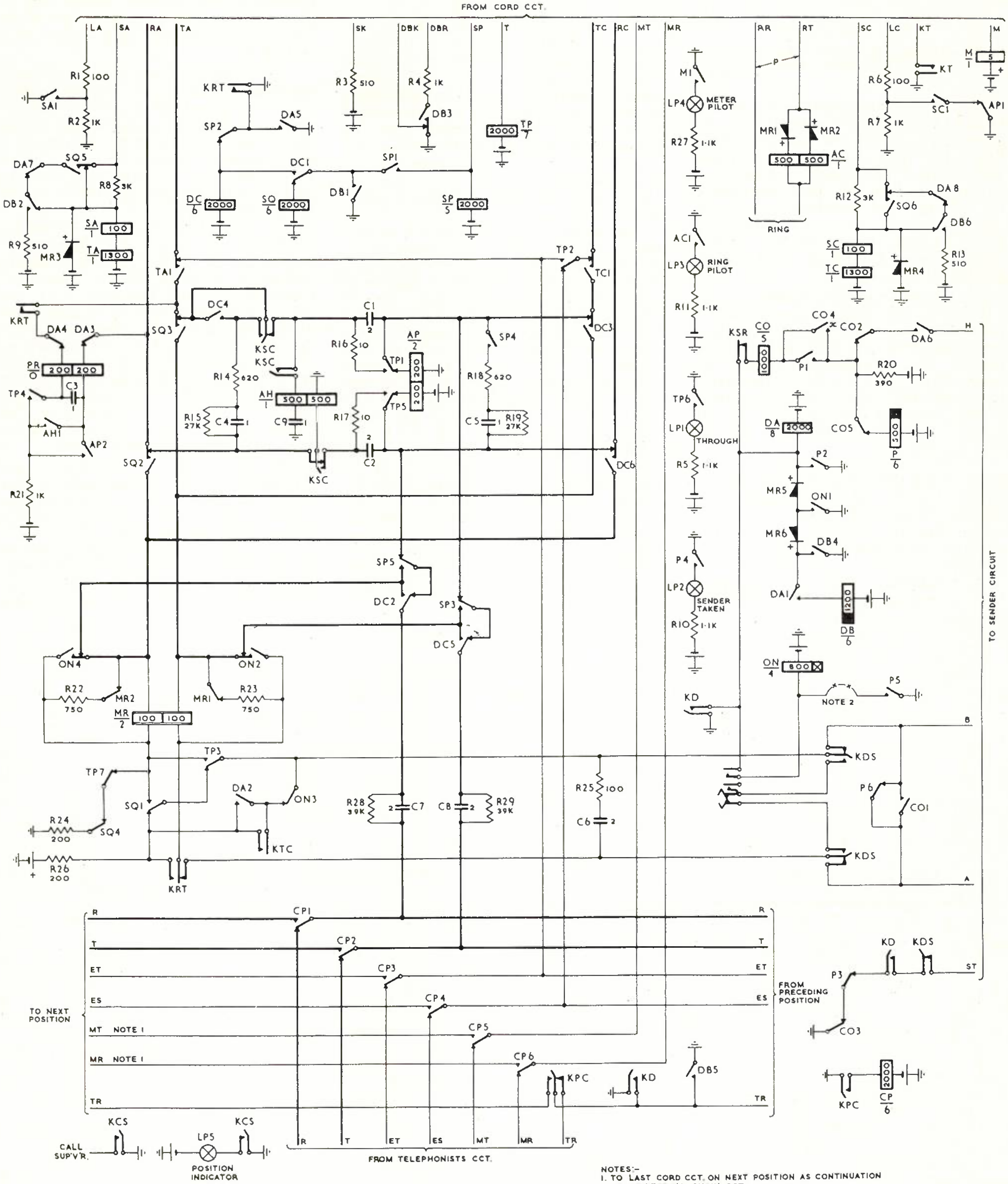


Fig. 1.—Composite Cord Circuit.

light traffic was simplified. These positions which became known as composite positions, have since been used on a much wider basis. Many exchanges use exclusively positions of this type. This was inevitable as demand working and caller-in-circuit facilities were introduced and the delays introduced with transfer working could no longer be tolerated. The composite position as such was the first step in the integration of the 'through' and 'terminating' positions.

While the use of composite position circuits overcame the difficulties already outlined, one further disadvantage now appeared. The provision of cord circuits on these positions was normally six terminating cord circuits and two through cord circuits. On some occasions when all cord circuits of one particular type were in use the telephonist was unable to



NOTES:–
1. TO LAST CORD CCT. ON NEXT POSITION AS CONTINUATION OF MONITORING CHAIN CCT.
2. OMIT STRAP WHEN 'ON' RELAY CONTROLLED DIRECTLY BY KEYSENDER.

Fig. 2.—Composite Position Circuit.

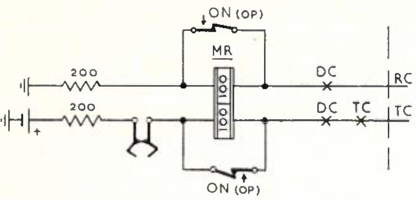


Fig. 3.—Dialling Conditions when Dialling on the Subscribers' Cord.

complete a call on demand, but still had vacant cord circuits. Clearly the requirement was a cord circuit capable of handling either type of call or a composite cord circuit. The design of such a cord circuit would complete the integration of the 'through' and 'terminating' positions; the requirements of such a cord circuit being basically those of the existing terminating and through cord circuits combined.

New Composite Position

Early in the design stages it became evident that considerable economies would result if a complete new design for all the switchboard circuits was undertaken. This was due to the savings to be effected by a reduction in relays in the individual cord circuits with only a small increase in number in the position circuit.

The new circuits are the Composite Cord circuit (Fig. 1), Composite Position circuit (Fig. 2) and the associated Telephonist circuit (Fig. 4) and Time Check circuit (Fig. 5). They are not compatible with the switchboard circuits of earlier design.

Although the circuits are designed to be operated exclusively with each other no circuit alterations are required to any of the standard trunk line circuits at present in use. Complete positions of the new sleeve control boards may therefore work side by side with positions fitted with relay sets wired to earlier circuits.

Cord Circuit

Referring to Fig. 1 it will be seen that the cord circuit is normally in the terminating condition. To connect two trunk line circuits together the cord circuit must be converted into a 'through' condition. This is achieved by operating relays T and TS in the cord circuit when the battery feed relay is disconnected and the capacitors in the transmission bridge short-circuited. At the same time the sleeve circuit is changed to that required for a trunk cord.

The design of the cord circuit is such that when the cord circuit is operated the tip, ring, sleeve and lamp circuits of both answering and calling cords are transferred to the position circuit. This is effected by the operation of relays SKA and SKB. Relay SKA operates via a chain circuit built up of contacts on each speak key. This ensures that only one relay is operated in the event of two keys being operated simultaneously. Once switching to one cord circuit has taken place switching to other circuits is prevented by the reduction of battery potential on the SK lead brought about by the low resistance winding of relay SKA. No further action takes place in the cord circuit unless the call requires a through connection when relays T and TS are operated. The setting up of the call is now controlled from the position circuit.

To keep a uniform operating procedure with switchboards of the earlier design it was decided to retain the speak answer—speak both positions on the cord circuit key, with the speak call key in the position circuit. If it is desired the cord circuit can be provided with a speak key only and the necessary splitting functions for speak answer and speak call effected in the position circuit. In all cases the operation of a speak key in the cord circuit operates both relays SKA and SKB.

In withdrawing from a call established between a trunk circuit and a subscriber relays SKB and SKA release in this order. A smooth transfer back to the cord circuit is achieved by the release in this sequence. During the release of the cord circuit relays a full earth is placed on the SK lead from the DBK lead and SKA6 operated to prevent any other cord circuit relays from operating. Coupling between cord circuits for momentary periods when withdrawing and entering circuits is therefore entirely eliminated. Capacitor C5 and rectifiers MR1 and MR2 act as an acoustic shock suppressor to the switching clicks which occur when the telephonist enters or withdraws from the cord circuit. The operation of relay A when the called subscriber answers controls the supervisory lamp, the time check circuit, the answer signal for 2VF circuits and the removal of the termination from across the cord circuit.

For calls between a CB subscriber and a trunk line circuit the operation is basically the same. To reduce operating costs on short distance trunk calls manual repeat metering has been provided. The metering takes places in a similar manner to that on 'A' positions, rectifier MR8 being required to hold the sleeve circuit during the changeover period of KMR.

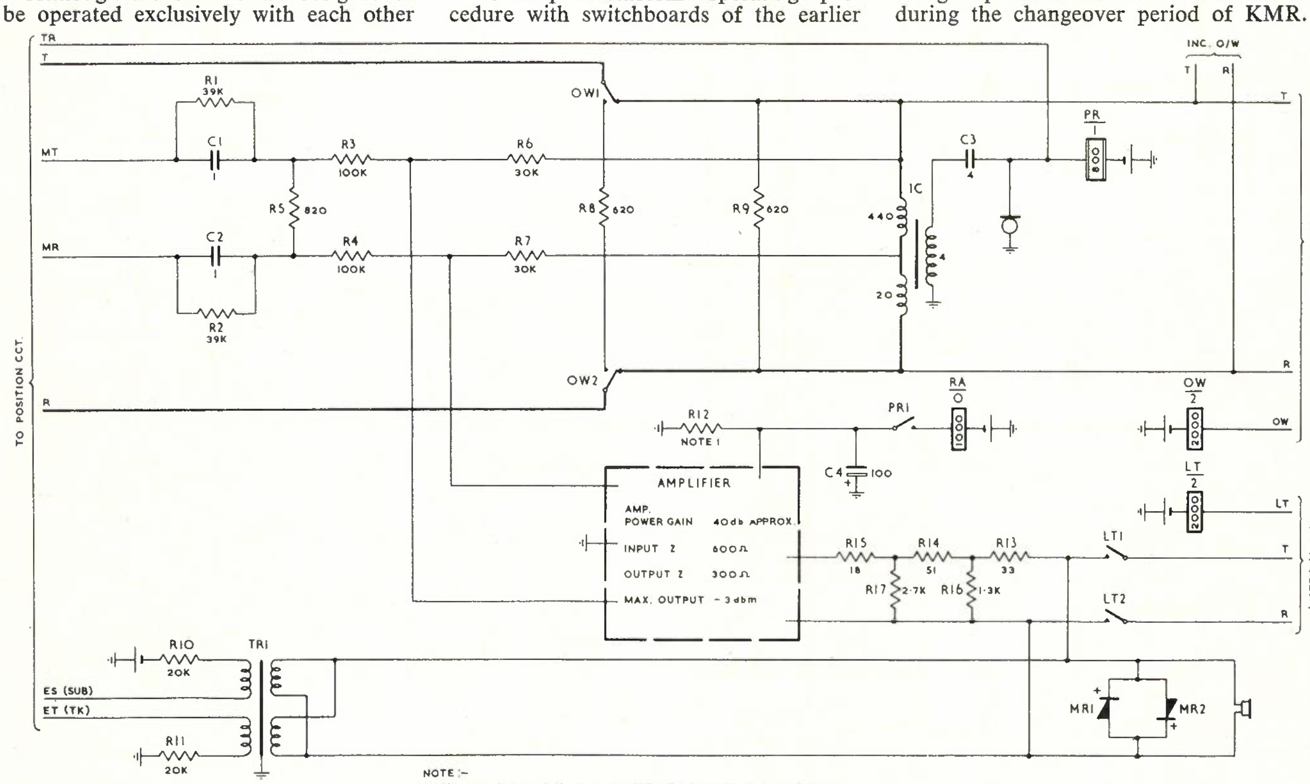


Fig. 4.—Telephonist Circuit.

For through calls, relay T is operated over the KT lead from the position circuit. The sequence of relays SKA and SKB ensures that the circuit of relay T is maintained at all times when the telephonist enters or withdraws from the circuit relay T being held either to the LC lead or the sleeve of the call cord. Where it is desired to connect 4 wire circuits together without using net cords it is necessary to provide negative battery on the tip conductor to operate the pad switching relays in the 4 wire circuit. When the strap to TS1 is inserted this battery is provided.

An overlapping facility similar to that given on some existing circuits takes place when the telephonist operates the monitor key. The monitoring leads from the position circuit are wired in a series chain via the cord circuit keys preventing more than one circuit at a time being coupled to the monitoring leads.

Position Circuit

The operation of the speak answer key in a cord circuit couples the cord circuit to the position circuit and operates relays TA, SP and SQ. SQ2 and 3 together with SP3 and 5 establish speech conditions on the answer cord only. The call cord is terminated by SP4. SQ1 and SQ4 prepare the loop dialling circuit required when dialling on trunk circuits.

In extending the call to a CB subscriber the telephonist first tests the condition of the called subscriber's line. The engaged test condition is passed over the TC lead to the ES lead for the click test. The called subscriber in answering operates relay AP. The calling supervisory lamp is extinguished and an answer condition passed over the TA lead for 2VF circuit operation. With the cord circuit speak key in the speak both position the telephonist may speak to both parties while the circuit is in this condition. In areas where a R.A.X. is situated within unit fee distance of the sleeve control exchange, dialling facilities on the call cord are required. With the cord circuit key in the speak both position the dial key is operated. Relays DA and DC operate and effect the switching of the dialling circuit to the calling cord. The conditions during dialling are illustrated in Fig. 3. Relay ON operates from the dial off normal contacts short circuiting relay MR in the impulsing circuit. On restoring after each digit dialled progress supervision is given to the telephonist. Relay DB removes the earth from the DBK lead and provides a 1000 ohm holding earth on the DBR lead to prevent premature release of the cord circuit relays should the speak key in the cord circuit be restored before dialling is completed. When the dial key is restored and the dial is normal relays DA, DB and DC release. The junction circuit is now held from relay AP.

For through calls the telephonist operates the through key in the position circuit which places an earth on the KT lead. The cord circuit returns an earth on the T lead operating relay TP which conditions the position circuit for through working. The 'through' lamp in the position circuit lights as an indication to the telephonist of the condition of the cord circuit. This lamp will light each time the telephonist enters a cord circuit which is in a through condition.

Signalling in the case of a generator signalling circuit is by operation of the ring trunk key (KRT) with the cord circuit key in the speak both position. Relay DC operates and feeds positive battery over the TC lead to the cord circuit, this being the required signal to effect ringing from the trunk line relay set. For dialling circuits the operation of the dial key operates relays DA and DC and this in conjunction with relay TP already operated completes the conditions for loop dialling on the call cord. Each release of relay ON re-applies positive battery behind the dialling loop. This condition is necessary in the case of 2VF signalling circuits to achieve progress supervision.

In so far as the position circuit is concerned the establishment of a trunk connection on the answering cord is the same as that already described for trunk connections on the calling cord. In this case the cord circuit key is operated to the speak answer position thereby operating relays SP and SQ in the position circuit. This effects the necessary change of signalling conditions to the answer side.

Should the telephonist desire to speak to the called party only, then with the cord circuit key in the speak both position, the speak call key is operated. This disconnects the answer cord from the speech conductors to the telephonist circuit, and applies a VF termination to the RA and TA leads. When in the through condition, relay AH is operated by the answer signal passed back from the line circuit when the called party has answered. The answer signal on the answer cord is therefore maintained while the circuit is split.

Telephonist Circuit

This circuit forms part of the position circuit, being separated from it only for convenience. Incoming speech on the

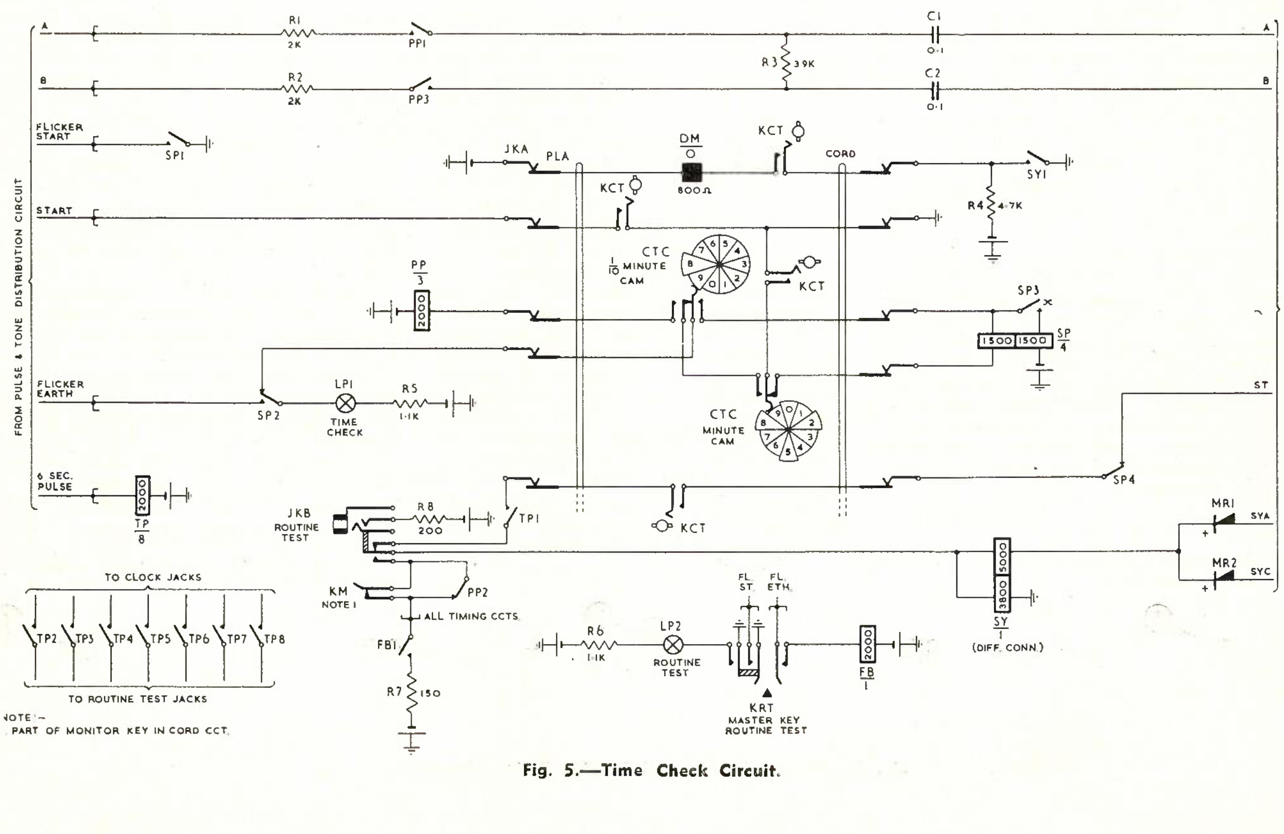


Fig. 5.—Time Check Circuit.

T and R leads is attenuated by resistors R6 and R7 before input to the amplifier unit. The input impedance of the amplifier must be approximately 600 ohms at 800 cycles when the incoming signal will be attenuated 40 db. As the amplifier gain is 40 db the signal is restored to its original level at the output terminals. The impedance of the receiver varies considerably over the VF range and a pad has been inserted between the amplifier out and the receiver to give a better impedance match.

When a monitoring key is operated in the cord circuit the MT and MR leads are connected directly across the cord circuit. The signal is attenuated by resistors R3 and R4 to a level approximately 10 db below the signal incoming on the T and R leads. The total attenuation between the monitoring and speech circuits is therefore 90 db. This ensures adequate decoupling between these circuits when parties are connected to them. It is intended that the amplifier be any transistorised unit with the following characteristics:

Amplifier gain	40 db
Input impedance	600 ohms
Output impedance	300 ohms
Maximum output	–3 dbm

A balanced input is required as an unbalance will give rise to noise when connected to some line circuits.

Time Check Circuit

Timing of trunk calls must be under the control of the calling (paying) subscriber. This means that in the case of calls established on a terminating basis it is necessary to control the time check from either cord as the calling subscriber may be on either cord depending on whether the call is incoming or outgoing. For through calls; in most cases the calling subscriber will be on the answer cord, but where calls have been reverted it may happen that the calling subscriber is connected to the call cord. For these reasons the time check circuit is controlled from both the answering and calling cords over the SYA and SYC leads. With this arrangement overcharging of the calling subscriber cannot occur.

A start signal from the cord circuit is effective in operating the differentially connected relay SY provided both SYA and SYC leads indicate an off-hook condition. Relay TP driven by the 6 sec. pulses from the exchange clock, controls the pulsing of relay SY while the start condition and off-hook conditions are maintained. At the 2.8, 5.8 and 8.8 minute time elapsed periods relay PP is operated and connects the pip-pip tone to the cord circuit. At the end of 9 minutes relay SP operates causing the time check lamp to flash, as an indication to the telephonist to restore the clock.

In the event of either party or both parties clearing the low resistance earth applied on the SYA and/or SYC leads prevents relay SY from operating when relay TP pulses.

Conclusion

After extensive laboratory testing and the success of a trial installation employing almost identical circuits, the introduction of sleeve control positions using these circuits can be looked to with confidence. In addition to the improvement from an operating and traffic point of view the opportunity was taken to improve some technical aspects of the earlier circuits to give increased reliability of operation.

Acknowledgment

The author gratefully acknowledges the assistance given by colleagues during the development of the circuit, in particular to Mr. G. Hyde.

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THE EPOXIDE RESINS

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INTRODUCTION

Prior to 1920 there were few resinous compounds sold commercially that were not of natural origin. Such materials were shellac, linseed oil, tars and resins. Since that time a large number of synthetic resins have been developed whose wide variety of properties make it possible to select a resin with the appropriate properties for almost any application.

The epoxide synthetic resins, because of their unusual resistance to chemical and corrosive attack, their improved physical properties and ready modification with certain other synthetic resins have become well established in industry in fields of application such as castings, surface coatings, high-strength adhesives, durable laminates, cold solders, lightweight foams, and potting compounds for all varieties of electrical and electronic apparatus.

HISTORICAL

The epoxide resins were first developed more or less simultaneously in the late 1930's by the Ciba Co. in Switzerland, and Devoe and Reynolds in America, but it was not until 1950 that production on anything approaching a commercial scale was undertaken. This was made possible as a result of the availability in bulk of epichlorhydrin, one of the intermediates in the process developed by the Shell Co. for the manufacture of glycerine by the hot chlorination of propylene. The availability of this material from the petroleum chemical industry has resulted in epoxide resins also being developed by that industry. Since their introduction the very great potentialities of epoxide resins have been increasingly realised and demand has risen to such an extent that the average estimated consumption by 1960 is of the order of 45,000 tons.

STRUCTURE

These resins are characterised by the presence of an epoxide (oxirane) ring >C — C< (bridged by O) in the molecule from whence they derive their name. Generally the products developed for commercial purposes are polymers or epichlorhydrin and bisphenol A. These two components are stirred together under controlled temperature conditions in the presence of aqueous caustic soda. When the reaction is complete, the aqueous portion is run off and the resin obtained is thoroughly washed in the molten state with hot water to give an electrolyte-free product of general composition shown in Fig. 1.

The polymer can be manufactured in a wide variety of molecular weights with corresponding variations in the number of active groups, marked (1) and (2) Fig. 1, by varying such factors as the time of condensation and the ratio of reactants. The simplest compound of this general formula, when n = O, is a low viscosity liquid resin. As the value of n increases the viscosity increases until when n = 10 the resin is at high melting point solid.

CURING AGENTS

The nature of the epoxide resins are such that without addition of some auxil-

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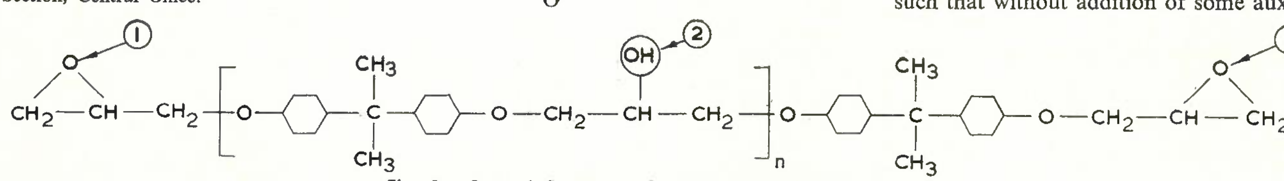

Fig. 1.—General Structure of Epoxide Resin Polymers.

iary substance they display little or no tendency to cure, even at high temperature. They are solvent soluble thermoplastic resins and in this form become intermediate material for further reaction, to give, as the final product in all cases a solvent insoluble material which is a cross-linked (three dimensional) thermoset resin. The types of substance that harden epoxide resins within a reasonable period and under normal working conditions may be classified as follows:—

(a) thermo-setting resins containing methylol groups.
(b) organic acids.
(c) acid anhydrides
(d) organic nitrogen compounds.

The first category, which includes the urea formaldehyde resins and certain of the phenol and melamine formaldehyde resins, is particularly valuable in the fields of surface coatings and laminates as the reaction that takes place above 150°C results in a film with outstanding chemical stability. With the correct type of phenolic resin the epoxide/phenolic mixture can be used on conventional laminating apparatus to give a dry impregnated material which may be safely stored for several weeks before subsequent cure.

Organic acids may be used to harden epoxide resins, but they have found very little application as complete reaction of the epoxide group involves the elimination of water. This formation of water is successfully overcome by the use of acid anhydrides, particularly those of phthalic, succinic and maleic which, although they cure without production of by-products, suffer from the disadvantages of insolubility in the liquid resin at room temperature, a long curing cycle of approximately 8 hours at 120°C and a marked tendency for the hardener to vaporise during cure.

Numerous organic nitrogen compounds have been examined as possible curing agents; these include amines, amides, imides, nitriles, urea and melamine derivatives and isocyanates. As a group the amines are the most versatile hardeners for epoxide resins, their special feature being that fully cured resins can be obtained without heating. The most commonly used ones are the aliphatic polyamines such as diethylene triamine, triethylene tetramine, and their adducts, etc., though newer products include dimerised fatty oil acid amino-polyamides. In all cases, the reactions are simple chemical ones so that the curing agent is added in stoichiometric proportions. In this respect, the "curing agent" for the epoxide resin system differs from the "catalysts" used to initiate curing with polyester and urea formaldehyde resin systems.

Skeist (5) gives detailed information on the mechanism of cure.

MODIFYING AGENTS

The properties of cured epoxide resins may be varied over a wide range by the selection of curing agent and cure cycles. They may be varied over an even wider range by incorporating into the uncured system liquid diluents, organic and inorganic fillers and other synthetic resins as described below.

(a) **Viscosity Reducers.** Despite the wide range in viscosity of the epoxide resin syrups, 64-1000 poises, it is often required to reduce the viscosity of a particular grade further by the addition of unreactive and/or reactive diluents so that better penetration in casting and better wetting ability in laminate and adhesive formulations may be achieved. Unreactive solvents such as toluol and xylol or compatible plasticisers such as dibutyl phthalate and tricresyl phosphate may be used but as these materials do not take any part in the resin cure their presence in the cured resin is undesirable for many applications (discussed below in reference to flexibility).

Reactive diluents such as epichlorrhydrin, allyl and phenyl glycidyl ethers, etc. considerably reduce the resin viscosity and take part in the polymerisation either by copolymerising with the epoxide resin or by self polymerisation. Unfortunately, most of the reactive diluents display solvent action on wire enamels, etc., and all are extremely active, often very toxic and have low flash points.

(b) **Flexibilisers.** Liquid epoxide resins, although displaying lower volume shrinkage and strain on setting than the conventional polyester resins, could be still further improved if the elastic properties could be bettered, i.e. in respect to cycling temperatures, lower shrinkage, less residual stress, higher impact resistance, improved adhesion in bend, greater resistance to deformation under load at high temperature and maintenance of physical properties at temperatures exceeding 180°F.

Attempts to make the cured resins more flexible by the use of non-reactive plasticisers such as dibutyl phthalate were not successful owing to the initial flexibility being rapidly destroyed through loss by migration, extraction, or bleeding of the plasticiser. In contrast, flexibility conferred by coreaction with polysulphide liquid polymers ("Thiokol" L.P. grades) in the presence of a suitable hardening agent, is permanent and improves the resins in all the properties in the previous paragraph except resistance to deformation and maintenance of physical properties at elevated temperatures. Worthy of note is the fact that whilst modifying for flexibility with thiokol, the viscosity of the resin may be altered in the desired direction by correct choice of the thiokol grade.

Polysulphide epoxide copolymers offer their most important advantages in the casting field when the compounds have reached their maximum cure. The final properties of such compounds may be controlled by proper selection of polysulphide liquid polymer/epoxide resin ratio. the grade of polysulphide polymer, type of amine curing agent, the temperature, and time for curing. The form of control has to be carefully considered as a compound designed for high tensile strength does not necessarily give the best impact and thermal shock properties.

Table 1 indicates the vastly different properties obtained with "thiokol" containing compounds cured with primary and tertiary amines.

Flexibility may also be imparted to epoxide resins by the use of the amino-polyamides (Versamid, "Laramin" etc.) or a modified amine ("Lancast" A). In both instances the ratio of reactants, amine polyamide or "Lancast" A to epoxide, is not critical as they both serve a dual function. They cure the epoxide resin at the same time provide a degree of plasticization, adhesiveness and flexibility more or less consistent with the amount present. Because the ratios may be varied, the system can be adjusted to cover a wide range of requirements in hardness and flexibility; in comparison the ratio of reactants in the amine-cured system is critical since the amine serves only as a curing agent.

(c) **Fillers and Reinforcing Agents.** There is a fairly large number of materials which may be used as fillers and reinforcing agents but they are not all equally suitable, as the percentage which the resin plus hardener will tolerate varies from 25% to as high as 350%. Among the materials which have been tested are slate powder, mica dust, glass, clays, powder, quartz meal, sand, ground porcelain, asbestos and aluminium powder. Care must be exercised in choosing a filler as materials such as mentonites and other clays are highly alkaline and can contain large amounts of combined water. This will tend to upset the hardener balance during cure and produce an inferior resin. Some metallic pigments can act as cure inhibitors while

TABLE I—VARIATIONS OBTAINABLE USING DIFFERENT COMPOSITIONS.

COMPOUND	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Composition (parts by weight)								
"Thiokol" LP3	100	100	100	100	100	100	100	100
"Epikote" 828§	100	100	200	200				
"Araldite" Casting Resin F§					100	100	100	100
Triethylene Tetramine (Primary Amine)	10		20		10		20	
Tridimethylaminomethyl phenol (D.M.P.30) (Tertiary Amine)		10		20		10		20
Working Properties								
Brookfield viscosity at 80°F poises	20	20	265	26.5	34.5	34.5	52	52
Pot life at 80°F min. 50 gram mass	40	35	20	20	27	16	14	14
Max. Temp. °F 50 mass.*	251	263	310	304	226	202	300	250
Stress-strain Properties†								
After 5 days cure at 80°F.								
Tensile, lb./sq. in.	1785	2800	4580	4800	950	2175	3425	4860
Elongation, %	30	30	5	10	60	30	5	5
Hardness, Shore D‡	41	63	60	78	42	60	70	75
After aging 70 hours at 212°F.								
Tensile, lb./sq. inch.	1800	900	5000	4200	1550	1700	5200	6000
Elongation, %	30	80	0	5	30	40	0	0
Hardness, Shore D	43	40	65	76	53	56	80	80

* Starting at 80°F. at 35% relative humidity. † A.S.T.M. D-412. ‡ A.S.T.M. 49T—Method B.

§ The epoxide resins available in this country are sold under the trade name of "Araldite", Ciba Co. Pty. Ltd., "Epikote", Shell Chemical (Aust.) Pty. Ltd., "Epophen", Casco Chemicals Pty. Ltd., and as Bakelite Epoxide Resins, agents O. H. O'Brien Pty. Ltd., and Dow Epoxy Resins,

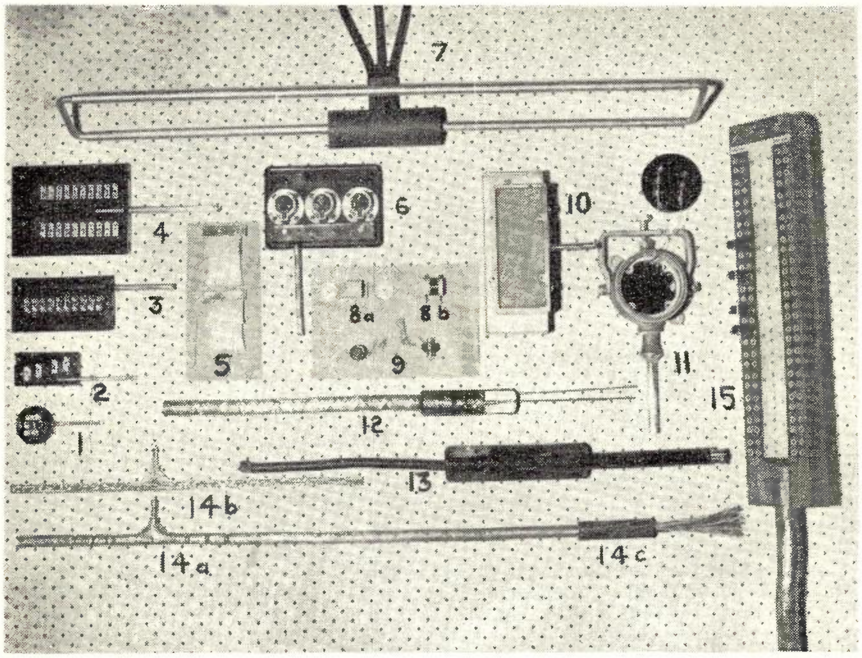

Fig. 2

Items 1, 2, 3, 4 Sealed 1, 2, 5 and 10 pair terminal boxes.
5 Two component bags suitable for sealing the above boxes.
6 Microphone plugs suitable for burial in the ground as cable outlet has been sealed against ingress of moisture.
7 Encapsulated junction of the coaxial cable to aerial on the driven element of the Yagi aerial.
8a and b No. 9 resistor components stuck with epoxide adhesive.
9 Potted delay line coils for Video Transmission Set.
10 Mica filled unit type cable terminal box.
11 Sealed gas pressure alarm terminal box with removable terminal plate.
12 Suggested termination for the Bass Strait cable.
13 Encapsulation of a Polythene insulated and sheathed/P.V.C. insulated and sheathed junction.
14a Injected P.V.C. insulated lead sheath cable.
14b Above cable sawn in half to show impregnation detail.
14c An alternative termination by encapsulation.
15 A sealed terminal unit, trunk type.

others are very active depolymerisation catalysts at elevated temperatures and can also degrade the resin.

A particle size smaller than that which passes a 120 B.S.S. mesh sieve appears to confer the best all-round properties and care must be exercised not to exceed the tolerance limit of the resin as there will be tendency to settling out during cure.

Apart from reducing the thermal expansion by bulk effect, the addition of fillers also provides a means of increasing heat conductivity, impact and abrasion resistance. Fillers may also give improved electrical characteristics and considerable reduction in cost of the resin mix as they are usually cheap materials.

When fillers are used they have the effect of raising the viscosity of the mixture and with most it is the viscosity at pouring temperature which limits the amount used. The increase in viscosity means that there is a much greater possibility of any air entrapped in the mould being unable to escape, thus causing blow holes in the final casting. In order to obviate this possibility, it is advisable to deaerate the resin and filler by warming under vacuum and then cooling to room temperature before adding the hardener.

(d) **Pigments.** Epoxide resins are generally light yellow in colour and for various applications it is desirable to pigment them to impart colour and opacity. An assortment of highly concentrated colouring pastes or solids developed for tinting both filled and unfilled epoxide resins are available.

MOULDS

A wide variety of materials may be used for manufacturing moulds suitable for use with casting resins i.e. steel, iron, light metal, cast aluminium, lead alloys, thermoplastic synthetic resins, polyvinyl chloride, plaster, wood, vulcanised rubber, etc. The design of mould will obviously be dictated by the nature of the component being processed but wherever possible sharp corners or sudden changes of section should be avoided. As epoxide resins have excellent properties of adhesion to metals, it is necessary to use a parting compound to prevent the cured resin from adhering to the mould; the use of curing temperatures in excess of 100°C rules out the use of most waxes.

The usual parting agents used are those belonging to the silicone groups such as "Pan Glase", "Releasil 7" grease or "Releasil 14" liquid. The low surface tension of silicone fluids means that they may be applied by brushing, wiping, dipping or spraying, the latter being the most economical of material. "Pan Glase" requires a baking period of 6 hours at 205°C or 1 hour at 245°C after preliminary drying at 40°C but has the advantage of sufficing for several coatings as long as the film is not destroyed or damaged. On the other hand, it is advantageous to apply a film of silicone grease or liquid everytime before using. Apart from the ease of parting obtained, the surface finish of the products is improved, moulds are kept cleaner and maintenance is made simpler, since the silicones do not decompose under moulding conditions and have low volatility which also means that there are no objectionable fumes from this source. It should be remembered, however, that paints and adhesives will not stick to a silicone-treated surface.

When a mould is new it quite often happens that, when silicone greases are used, the first two or three castings produced in it do not free themselves very easily and it is therefore suggested that before casting into a new mould, the process of applying the parting agent and curing is carried out with the mould empty. After this treatment it is usually found that separation of the mould and casting does not present any difficulty. It should be remembered, however that the fact that the resin has a higher shrinkage rate than the mould material means that if cores are used when casting, they must be removed while the casting is still hot otherwise their removal will be impossible due to the shrinkage of the resin on to the core.

If the mould is itself large, this should be heated to a temperature slightly higher than that of curing before the resin mix is poured. This delays the cooling of the resin mix thus making the removal of any air bubbles present easier owing to the decrease in viscosity of the mix. With sheet metal moulds, however, this is not necessary.

APPLICATIONS

1. **Surface Coatings.** The paint industry is and will probably remain the major outlet for epoxide resins. For several decades now synthetic resins have been established as major film-forming ingredients in paints and lacquers, but epoxide resins have a very special contribution to make in that they impart to the surface coating film a combination of adhesion, chemical resistance and toughness of an exceptionally high order. These properties enable epoxide resin finishes to be used in applications where the highest performance is called for but it is essential that every care be taken to use the best possible formulations and to employ the appropriate grades of resin and of cross-linking agent.

For stoving finishes, domestic equipment such as refrigerators, washing machines and kitchen appliances, constitutes an important outlet because of the corrosion resistant properties, hardness and chemical resistance of epoxide resin based coatings. For many purposes stoved enamels based on epoxide-phenolic blends are replacing vitreous finishes with great success because of their resistance to shattering and, in many cases, lower cost, although they are not quite as hard and will not withstand very high temperatures, as well as vitreous finishes.

Coatings and linings for drums carrying chemicals of all descriptions including, of course, petroleum products are an important application for epoxide resin finishes. Can coatings represent the largest single outlet in the U.S.A. and this is understandable when it is realised that lacquers based on these resins have such excellent adhesion, flexibility and resistance to the products packed.

Wire enamels based on epoxide resins are now competing with the polyvinyl formal types, one of their important advantages being improved high temperature performance. Technically there would appear to be a considerable future for these finishes in the automobile industry but, as yet, commercial progress has been somewhat limited because of the adverse cost factors of these premium quality resins in this highly competitive market.

Formulations, based on the process of cross-linking with amines, with qualities such as hardness and chemical resistance almost equal to that of the best stoved finishes can be obtained at little above room temperature. These have been shown to be outstanding in protective coatings for chemical plant, linings of tanks on ships and also for road and rail tank cars, and coatings for concrete floors, wood, paper, etc.

For floor varnishes and wood finishes generally, air drying epoxide-ester resins are widely used. In the purely decorative field there cannot be said to be a real call for the premium qualities afforded by epoxide finishes as a class but it seems likely, by modification in various ways which could permit more direct competition in price with conventional decorative finishes, that epoxide resins may well find a place and it is abundantly clear that only a very modest replacement of existing resins in this field could give rise to a very substantial demand for them.

2. **Electrical Industry.** This industry represents a major outlet for epoxide resins, primarily in the application known as potting or encapsulation and, to a lesser extent, in laminates and for printed circuits. Potting is a relatively new technique in which the resin is effectively replacing air, oil or bitumen as an insulating medium. Polyester resins were the first to be used in this field but for most purposes epoxides are much to be preferred on account of their better stability under conditions of temperature and humidity and the greater degree of hermetic sealing that they offer, due to their excellent adhesion to metallic leads. Other plastic materials like polystyrene and polyethylene have better dielectric properties than the epoxide resins, but there is no other class of material which provides such outstanding adhesion to materials such as metals, porcelain, mica, quartz and the like used in electrical equipment.

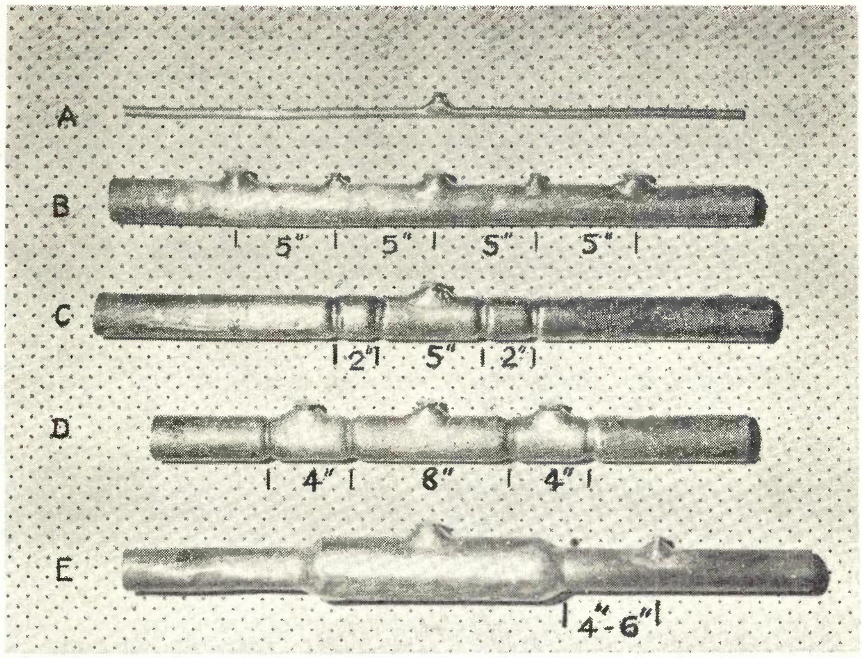

Fig. 3.—Methods of cable preparation for cable injection.
A. Straight Injection
B. Resin Block method.
C. Annular Restrictions.
D. Combination of methods B and C.
E. "Wiped-on" Sleeve.

3. **Structural Laminates.** During recent years, impregnated glass fibre laminates have come forward as a completely new structural material and have caught the public eye in such uses as car bodies and plastic boats. They have the outstanding advantage of lightness in weight, great strength and ease of production in relatively small numbers. Polyester resins which are relatively low priced, account for the major part of this development but epoxide resins which have much better adhesion to glass and chemical resistance of a much higher order are taking an increasing share of this market wherever the emphasis is on superior performance in spite of their higher cost.

In storage tanks, both static and mobile, and particularly piping where the combination of strength, low porosity and chemical resistance is required there should be a very big future indeed for epoxides. Section type storage tanks with capacities as high as 20,000 gallons have for some time now been made commercially in the U.S.A. from epoxide laminates and are being successfully used for containing brine, crude oil and hydrochloric acid.

4. **Press Tools.** Another recent development has been the manufacture of plastic tools, jigs and dies. It has been found possible to cast suitably filled resin rapidly with a high degree of precision in the form of press punches and dies at a very much lower cost than by machining from metal. Because of their strength, toughness and low shrinkage, epoxides are the preferred resins for this purpose. They are normally used with a high proportion of filler to improve compressive strength and to disperse the exotherm which is developed during the curing process; at the same time fillers reduce the cost.

Glass fibre laminates are also used as a basis for the manufacture of patterns, jigs and fixtures. Such articles are very simple in manufacture, cheap to produce, have good dimensional stability and require very little, if any, further processing.

More recently these methods of use have been adapted to foundry working where pattern plates or match plates are formed from epoxide resins reinforced with glass cloth. Once again the low shrinkage, hardness and light weight make these materials particularly suitable, and since the smooth surface of the cast resin does not tend to pick up sand, drawing is facilitated. It is said that some thousands of castings may be produced from a single such pattern without significant wear.

5. **Adhesives.** This application has been extensively developed and epoxide adhesives are available in 3 forms:

1. As pastes or putties that are cured by heat. It is also available in moulded rods for wiping of preheated joints and as dry powders.
2. As the basic form—a two-part combination cured by hardener action with or without heat.
3. As a three-part combination with control over the amount of powdered filler included.

These products are usually solvent-free and, as no volatiles are released during cure, pressure is not required during this process. Acid anhydrides or amine curing agents are used and cure can be carried out over a wide temperature range. In general, a better performance is obtained from a heat cured composition. The shear strength of joints bonded with epoxide resin is excellent but their peel strength is low. Fillers and modifying resins can be introduced to improve the latter property; the addition of fillers also improves impact strength.

Epoxide resins were primarily intended for metal to metal bonding but they will, in fact, join almost any combination of polar compounds. At the present time they are very popular in the aircraft industry.

6. **Stopping compounds and patch kits.** The properties of epoxide resins which fit them so well for laminates and press tools are again of value in filling and repairing applications. Filled resin formulations which adhere well to metal have given excellent results in the replacement of body solder in filling cavities and seams in motor car manufacture, domestic equipment and the like.

7. **Other Applications.** Certain low molecular weight resins have been recommended for imparting crease resistance and dimensional stability to cotton, rayon and wool fabrics, and the treatment of rayon fibres to increase adhesion to rubber in tyre manufacture is a possibility. Interest is also being shown in the treating of paper with epoxides with the object of increasing its wet strength.

Preparations filled to give the consistency of butter or putty and with thixotropic properties have been developed for cementing together chemically resistant tiles used in chemical plant for drainage, etc., and also for application by rendering or screeding as a lining to storage tanks.

SPECIFIC APPLICATIONS WITHIN THE DEPARTMENT

Practical use of the epoxide resins within the Department has, except in a few cases, been confined to the use of liquid resins cured without application of heat by utilising the special features of the amine group of hardeners. Modification has been made by addition of either a reactive plasticiser, a reactive diluent and/or an inert filler. The cold setting formulations gained favour because of the difficulty in applying and suitably controlling heat curing of compounds in the field.

The overall compatibility, low shrinkage and positive all-time seal was responsible for them being used in the sealing of components such as 1, 2, 5 and 10 pair terminal boxes, unit type cable boxes, gas pressure alarm terminal boxes, etc.—see items 1, 2, 3, 4, 10, 11 of Fig. 2, respectively, to ensure that the item is air and/or water-proof.

The low co-efficient of expansion of the modified resins that enables them to withstand considerable thermal shock has been utilised in the encapsulation of "Ferroxcube" coils as, for example, in the manufacture of Retard Coils.

A compound based on an epoxide resin that can be injected into a P.I.L.C. cable as a low viscosity liquid and solidifies to form a gas-tight seal at ambient temperatures without exposure to air, has been developed and is replacing the difficult and dangerous molten bitumen-wax method of blocking cable ends and sectionalising long lengths of cable for pressure maintenance purposes. In practice a seal is made by injecting into the cable by means of a screw-type gun, an amine hardened epoxide-thiokol mixture, see Fig. 4, which because of its law viscosity finds its way along the sheathing and into the interstices of the cable, forming a solid block on curing. Of the five possible ways of preparing the cable for sealing by resin injection illustrated in Fig. 3, method E, the "wiped-on" sleeve method has been adopted as it involves less skill than annular constrictions, operations may be completed the same day and a smaller number of charge sizes are required to cover the complete range of cable.

Fig. 5.—Epoxide Resin Pulling Termination for Coaxial Cable.

Method C, Fig. 3, may also be used to form a resin seal in the P.V.C. insulated lead sheath cable installed between pot-head and main frame in telephone exchanges, see items 14a and 14b, figure 2. The P.V.C. insulated cable is not subject to humidity troubles as were common with the enamel insulated textile lapped and waxed cable employed formerly and the resin seal prevents breathing of moisture back into the paper cable along the comparatively open P.V.C. insulated cable core. An alternative method is to encapsulate the P.V.C. insulated conductors in epoxide resin at the termination of the lead sheath as shown in item 14c, Fig. 2—this latter method is now common practice.

The excellent adhesion to metals exhibited by the epoxides was the reason for their initial success, but in fact they have been used to join almost any combination of compounds such as china, glass, wood, porcelain, etc., the exceptions being thermoplastic resins. Item 8a and b, Fig. 2, illustrates the adhesive qualities of an epoxide resin on porcelain components of a No. 9 Resistor.

In spite of the epoxide resins non-adherence to thermoplastic materials, airtight joints on plastic cable have been made by taking advantage of the small but effective volume shrinkage on curing, of approx. 2%. Item 13, Fig. 2, illustrates an epoxide resin encapsulated joint made between P.V.C. and polythene insulated and sheathed cables.

Fig. 4.—Illustrates materials required and method of injection into a "wiped-on" sleeve.

Jointing of plastic insulated and sheathed cables to P.I.L.C. cables is being successfully carried out by installing a squat metal funnel at the end of the stripped back sheath of the plastic cable and filling the funnel with resin. Conductor jointing is carried out in the normal manner and the joints protected by wiping on a lead sleeve to the filled funnel and adjacent lead sheath.

The encapsulation method has also been suggested for the land terminations of para-gutta insulated cable of the Bass Strait type as a means of protecting the para-gutta from air oxidation. All the armouring and wrapping is removed to expose the lead sheath, which in turn is cut back approximately 2″ to permit the soldering of the return conductor tapes to a copper terminal wire. The end is then encapsulated in epoxide resin, air tight seals being brought about in this case by excellent adhesion to the lead sheath and copper wires, see Item 12, Fig. 2.

A pulling termination for coaxial cable in which all the cable components are bonded together and to a pulling-eye inserted in the cable end, by filling the air space with an epoxide compound for a distance of 4″ to 6″, see Fig. 5, has been developed because of the inadequacy of the stranded steel wire cable grip on this type of cable. The resin termination which is stronger than the cable itself permits drawing into ducts longer lengths of coaxial cable than is customary for P.I.L.C. cables, thereby reducing the number of man holes and jointing operations necessary in the field.

Other miscellaneous applications in which epoxides have been used is the encapsulation of aerials and coaxial connectors as protection against atmospheric disturbances, and as reinforcing material at the junction of coaxial cable to aerial, see item 7, Fig. 2. They have also been used to impregnate and embed very fine windings, see item 9, Fig. 2, and as trial coatings to protect mild steel poles against corrosion.

TOXICITY

The liquid grades of epoxide resins, amine curing agents, and formulated resin compositions incorporating curing agents or reactive diluents are primary skin irritants. When in contact with the skin for a sufficient period of time, these materials are capable of producing contact dermatitis in most individuals. In addition, these liquid products also have been observed to produce a superimposed allergic type dermatitis in a relatively few hypersensitive workers.

This dermatitic effect is not confined to the use of epoxides as it may be caused by contact with such diverse materials as vegetation, petroleum products, chemicals, plastics, food, metals, cement, dyes, etc., and is therefore encountered in all industries and occupations. The likelihood of an individual being attacked by a particular substance depends not only on the extent of contact but on the susceptibility of the individual. Thus, one worker may find no discomfort in working closely with a particular substance, whereas another may be badly affected by extremely small concentrations in the atmosphere.

Where epoxide resins are used commercially, precautions which permit only intermittent skin contacts with these materials are effective in preventing the occurrence of dermatitis among normal workers for a protracted period of time. However, under these circumstances, a small number of hypersensitive workers have been observed to develop a sufficient degree of sensitivity to be affected adversely by the resin products in a relatively short period of time. Unfortunately, such hypersensitive individuals cannot be identified in any group of workers until recurrent dermatitis is displayed. Because of this combination of circumstances, it is obviously necessary for all workers to use protective measures to prevent contact of the skin with liquid epoxide resins, curing agents and reactive diluents—the importance of observing the protective measures increases proportionally with elevation of temperature of both the formulated materials and the adjacent atmosphere.

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REDUCTION OF NOISE GENERATED BY ENGINES INSTALLED IN TELEPHONE EXCHANGES — PART 1

*J. F. M. BRYANT, B.E., B.A., A.M.I.E.E.**

INTRODUCTION

The installation of standby power equipment incorporating diesel prime movers is at present an integral feature of exchange power plant design (1) in order that continuity of operation is ensured in the event of interruption of the commercial supply. Furthermore, if battery capacity is limited, the standby plant must be of sufficient capacity to carry the full exchange load. The operation of diesel engines within or in the vicinity of exchange buildings raises certain problems among which that of noise is of great importance in its effects.

The purpose of this exposition, is to make available to engineers and architects responsible for the planning and design of exchange buildings and equipment, a systematic procedure which will ensure that the noise control measures adopted are adequate but at the same time will avoid the overdesigning which is of common occurrence in acoustical practice and which stems from lack of quantitative data on many of the factors involved.

In this part, the first of a series, general consideration will be given to the effect of noise and how it may be reduced. Later parts will be occupied with the design of ventilating ducts, acoustical measurements and annoyance criteria.

The noise generated by the standby plant is likely to affect three separate classes of people. These are the engine operating staff, the exchange operating staff and the neighbourhood population distributed around the exchange.

THE EFFECTS OF NOISE

Effect of Noise on Engine Room Staff

The effects of high level noise may be considered as that leading to temporary or permanent impairment of hearing and that causing loss of intelligibility.

Deafness Risk: The main effect of excessive noise on engine room staff is likely to be temporary or permanent impairment of hearing of personnel exposed to the noise. The criterion to be observed is that of determining the intensity of roughly pure tones of maximum noise intensity in any critical bandwidth of the noise. (For definitions of technical terms see glossary.) Although the study of deafness due to acoustic injury is far from complete, tentative standards have been formulated. It has been established that if partial but permanent deafness is to be avoided as the result of repeated exposure over an extended period (not less than a year) to noise, the maximum level in any critical band should not exceed 85 db above threshold. For intermittent exposure of short duration (not more than one year) at infrequent intervals it is probable that a critical band level of 100 db could be borne without permanent damage although some temporary hearing loss may be apparent. Below a frequency of 300 c/s the ear becomes increasingly immune to damage from acoustic trauma.

Since sound level meters or noise meters are commonly used to measure noise levels it is worth noting that such measurements do not necessarily indicate deafening effect of noise. For a "flat" noise, the sound level meter may read 30 db higher than the spectrum level of the noise but less than this amount when the spectrum is not uniform, the usual case in industrial noise.

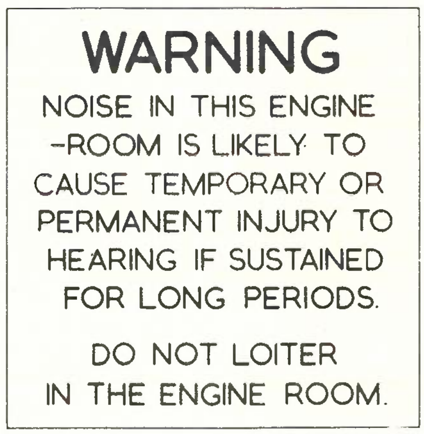

Fig. 1.—Warning Notice Suitable for Display in Engine Rooms.

Where there is doubt that the noise generated by an engine is within safe limits it is very desirable that a spectrum analysis be made. This may be done conveniently with the aid of half or third octave filters, the damage risk criterion being 91 db in the former and 90 db in the latter case. It is recommended that a warning notice be displayed in engine rooms if the noise level is likely to exceed the damage risk criterion (Fig. 1). Engine operators should wear ear muffs if exposed to noise for extended periods.

Intelligibility of Speech: It is often found that speech communication in engine rooms is very difficult and telephone communication impossible unless steps are taken to mitigate the noise in the vicinity of the telephone. In large engine rooms which the operating staff is likely to occupy for considerable periods and in which a telephone is installed, it is desirable to improve the sound absorption of the walls and ceiling. The noise level, which is the controlling factor in speech intelligibility, can be determined accurately by means of octave band measurements and more approximately by simple sound level measurements. The following table gives permissible speech interference levels and approximate sound levels for satisfactory communication under the conditions stated.

Table 1.

Condition	Speech interference level (db)	Sound level (db)
Telephone	60	66
Speech at		
1 ft	65	70
2 ft.	59	65
3 ft.	55	60

By raising the voice, conversation can be maintained without difficulty under conditions 6 db worse than those stated in Table 1.

Effect of Noise in the Equipment Room.

The noise level prevailing in equipment rooms is largely that due to the operation of the switching apparatus and is not easily influenced by the usual methods adopted in the acoustical control of noise. In the absence of any large survey of noise levels in exchanges it may be appropriate to adopt the figure 60 db for the present purpose. It is possible that with other types of switching apparatus, lower noise levels may be obtained. The main benefit of a lower noise level would be in improved telephonic speech conditions at test points in the exchange and this improvement could possibly be achieved in other ways, e.g., by the incorporation of an antisidetone feature in the handset No. 3 (Buttinski).

The position with respect to test desks is rather different. Although under normal conditions satisfactory communication can be maintained in a noise environment of 60 db, the testing officer is often called upon in circumstances in which the received level is low. Furthermore, present test methods include listening tests over lines in which pads having 20 db or 40 db of attenuation have been inserted. Judgments of speech intelligibility under such conditions are obviously greatly influenced by the ambient noise and the degree of sidetone suppression. It is desirable that more objective methods should be devised and used wherever possible in the testing of subscribers' circuits, but since the test desk is used for other purposes it is equally desirable that it be always placed in a low noise environment of not more than 45 db sound level (American sound level meter).

Effect of Noise Outside the Exchange.

The effect of noise generated by an internal combustion engine in an exchange on the neighbouring community is related to the sensitivity of the community. The factors determining this sensitivity have not been fully explored, but it appears that among them are:—

(a) the nature of the disturbing noise (whether continuous or impulsive)

(b) the frequency of repetition of the noise (whether occurring once or many times each day, week or month, etc.)

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(c) time of day (whether day or night),
(d) the existing noise environment (whether quiet suburban or noisy industrial area, traffic noise, etc.),
(e) local ordinances against noise.

In practice, there are two reasons why standby plant is likely to be operating in an exchange—either for maintenance purposes or as the result of power failure. It is necessary therefore, to consider the effect of noise under both conditions.

When an internal combustion engine is operated for maintenance purposes only, the time of day at which the procedure is carried out can be chosen with much freedom. Where noise is likely to be objectionable, the views of residents in the vicinity as to the least inconvenient time of day could be ascertained.

In the event of power failure the stand by plant would be required to operate continuously in the interregnum. The records of the supply authority might be examined in order to establish the probabilities of incidence and duration of power failure as a basis for determining the annoyance value of noise due to standby plant operation (factor b).

The most recently developed criteria for the annoyance value of noise is that due to Rosenblith and Stevens which will be discussed in the next part of this series.

Anti-Noise Ordinances

In addition to the relief which a person may seek at law from the nuisance and discomfort caused by noise, it is becoming common in many countries to provide for the control of noise by governmental or municipal regulation. Control in this manner is sought over two different classes of noise, one in which the noise is local and more or less permanent, such as that associated with certain sorts of trade or business, the other being noise of a general and usually transitory nature, such as the noise of automobile engines and exhausts, public-address systems, street hawkers and low-flying aeroplanes.

Ordinances in Other Countries: In Britain under the Local Government Acts, councils may make bylaws concerning noisy animals, instruments, loudspeakers, etc., and under the Public Health Act, control is exerted over noise falling into the first category mentioned above, even to the extent of regulating the materials to be used in the construction of buildings. In general, however, a body acting under statutory powers, e.g., a railway company, is exempted from the provisions of such ordinances.

In America, many municipal councils have adopted comprehensive bylaws for the control of potential sources of noise both local and general. For local noise, industrial zoning is adopted as the chief regulatory measure and for general noise, reduction of the annoyance caused by vehicles is the main target. In Milwaukee, Wisconsin, for example, sound exceeding 95 db at a distance of 20 ft. is described as excessive in the city ordinance dealing with motor vehicle noises.

Local Ordinances. — The following comments refer only to the State of Victoria for which the relevant Acts, etc. were readily available. It is presumed that the legislature in other states will follow a similar course of action to that of Victoria. For further information recourse should be made to local sources.

The Public Health Act of Victoria makes specific provision for the control by regulation of a number of nuisances which are described and of nuisances defined as "any condition whatever which is a nuisance or dangerous to health or offensive". It is not apparent that the intention of the Act with regard to nuisances includes also noise except that "steam whistles or like appliances" are specified. Hence, it remains to be determined whether action under this legislation, which may be taken by any person (Section 45 (1)), with regard to noise would be successful.

The Local Government Act of Victoria (5203) was amended (6151) in December, 1957, to provide for the suppression by municipal council bylaw of nuisances "including controlling and regulating the use of premises with a view to preventing objectionable noises at unreasonable times". This act also provides indirectly for some control over noise in privately owned buildings through the Building Regulations.

Although attempts have been made by some municipal councils to draft ordinances concerning noise, at the time of writing, none has been gazetted owing to the difficulties envisaged in their application.

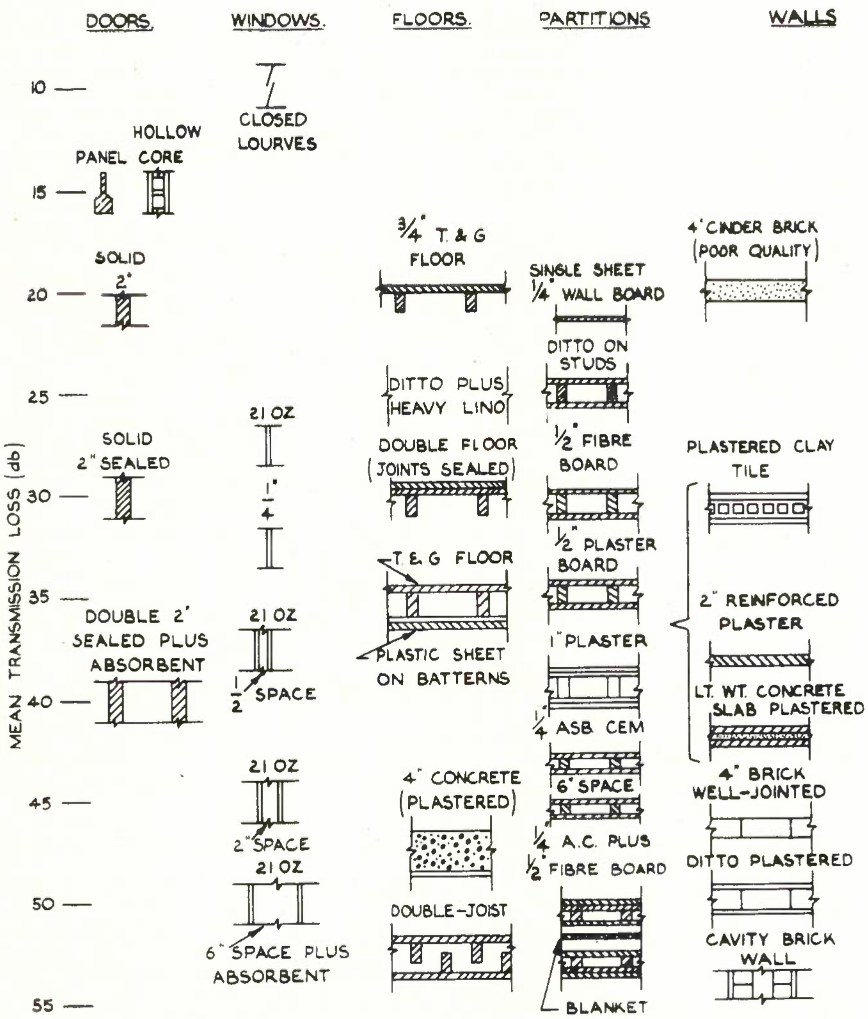

Fig. 2.—Transmission Loss of Typical Structures.

The Effect of Noise Suppression on Telephone Transmission.

Although the pathological effect of noise on humans has occupied the attention of many research workers and noise abatement associations, commissions, etc. for more than half a century, and intensively since World War II, it is only recently that the part played by noise in the limitation of intelligibility of speech has received attention. The difficulty of hearing a message through intense noise was a major problem in military aircraft during the second world war and, since the introduction of public-address systems in passenger cabins, remains so in civil aircraft.

The effect which noise has on intelligibility is a complicated one. Fletcher (2) has devised a method of estimating the articulation index, A, of a telephone system where A expresses the articulation of the system relative to that of an optimum "flat" system (A = 1). Similar work has been carried out in the British Post Office.

However, by means of articulation tests it has been possible to reach the simple conclusion that, within limits, an increase (or decrease) in noise may be treated as an equivalent impairment (or improvement) in circuit attenuation.

It will be apparent that a reduction in the mean noise level at subscribers' telephone locations will be reflected as an improvement in intelligibility of telephone conversations. In the planning of telephone systems allowance is made for noise greater than the mean level. This allowance is proportional to the standard deviation or scatter of noise levels about their mean. Thus a reduction in the standard deviation of the noise level distributions would permit a reduction in the allowance made. Determinations of room noise distributions have been made in both U.S.A. and U.K. In America, Seacord found the average sound levels and standard deviations to be as follows (Table 2).

Table 2—Sound Levels of Room Noise (db above threshold)

Types of Location	Average	Standard Deviation
Residence		
without radio	43	5.5
with radio	50	8.0
Small store	53.5	7.5
Large store	61	6.0
Small office	53.5	6.5
Medium office	58	6.5
Large office	64.5	4.5
Factory office	61.5	9.5
Misc. business	56	7.5
Factory	77	18.0

Corresponding measurements in the U.K. are not given in detail. The most frequent noise level is stated to be 50 phons with a standard deviation of 11 phons. At this loudness level the American sound level meter reads lower than the equivalent measure in phons. The U.K. measurements probably refer to noise levels in residences, without regard to the presence of absence of radios, etc.

REDUCTION OF NOISE

In general, three methods of approach are available to the noise-control engineer, redirection of the radiated sound energy, absorption of the energy by suitable materials, and confinement of the energy within a restricted volume. Application of these three methods have been made.

Treatment of the Prime Mover

Confinement of sound energy close to its source has obvious advantages; a minimum of sound insulation is required, it is designed to suit the machine and becomes an integral part of it so that removal to another site does not involve treatment afresh. However, the accompanying disadvantages are severe enough to make alternative methods preferable. These disadvantages are the increased difficulty of maintenance and the unsuitability of most machines for this type of treatment. On the other hand, manufacturers should be encouraged to design machines of which sound insulation may be made an integral part.

An excellent description of treatment applied to a modern stationary diesel engine is given in Ref. (3). The treatment consisted of a set of sheet metal covers, lined internally with acoustic absorbing material, which were mounted directly over noisy areas of the engine by means of built-in vibration insulators. Noise reductions for the direct sound were at least 8 to 12 db observed at a distance of one foot from the engine. The total loudness of the engine noise at six feet was reduced from 320 to 220 sones. This represented a substantial improvement with regard to voice communication in the immediate vicinity of the engine. The speech interference level of the engine noise at six feet was reduced from 87 to 82 db.

In suitable cases such as with large permanent installations, noise suppression by treatment of the prime mover is to be preferred to the use of sound absorbing material since the degree of suppression is likely to be greater and its cost less.

An attempt to suppress the noise of an air-cooled diesel engine (Deutz) at Five Dock (Sydney, N.S.W.) by partial covers was unsuccessful owing to the escape of sound energy through numerous openings. The principles to be observed in the design of covers are essentially the same as are observed in sound insulation generally, i.e., the insulating structure must have adequate transmission loss and all openings must be sealed. The latter requirement will usually mean that ventilation through sound-attenuating ducts is required.

Use of Sound-Absorption

Acoustical sound absorbing material is widely used in the treatment of rooms, halls, etc. By its use, the reverberation time may be reduced, the overall noise level decreased and the annoyance caused by sporadic noise inside the enclosure lessened considerably.

However, when used specifically for the reduction of noise in engine rooms other advantages are usually of little account. The room volume is usually small and the direct sound pressure high. Absorbent must be used in large quantities to achieve worthwhile reduction in sound intensity and in considerable thickness to obtain the desired effect at low frequencies.

Diffuse and Direct Sound Pressure: When a sound source is operating in a room, a condition of equilibrium is rapidly reached at which the energy absorbed by the air, the surfaces of the room, and the objects contained in it is equal to the energy supplied by the source.

The sound field at any point in the room may be considered as divided into two parts, the direct sound field and the diffuse or reverberent sound field. The former comprises all waves arriving at the point without reflection from a surface, the latter those waves which have been reflected one or more times.

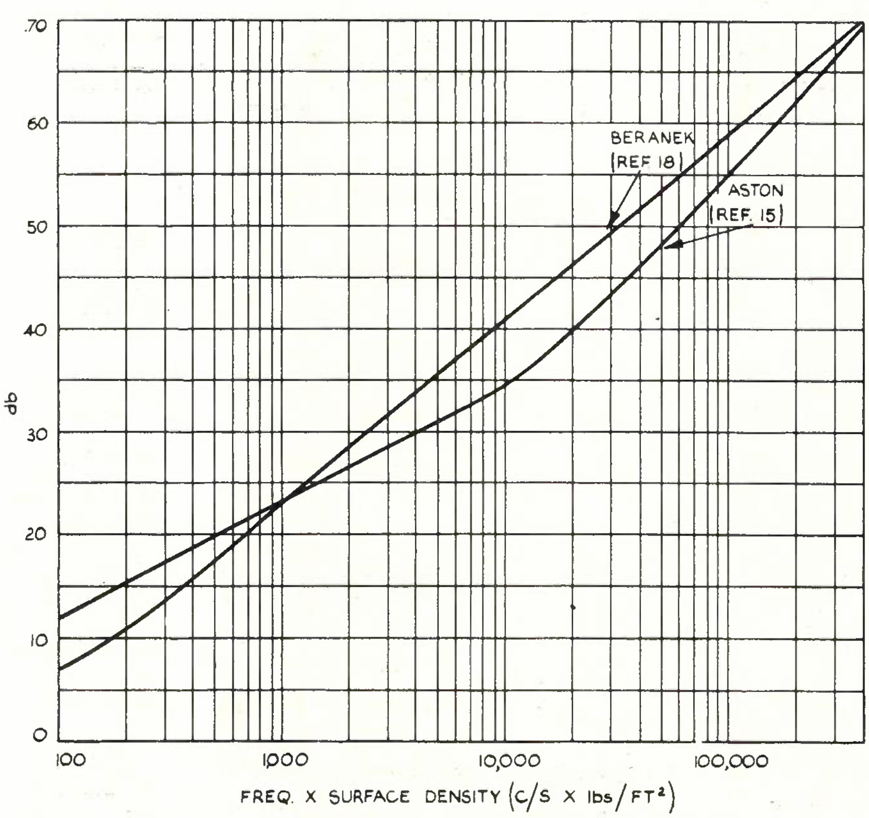

Fig. 3.—Transmission Loss of Single Homogeneous Walls.

In general, near a small source of sound the intensity is greater than at a distance. At increasing distance from the source the direct sound field decreases in intensity and eventually the diffuse sound field predominates. Considering the direct sound first, the sound pressure at a point distant from an isotropic (spherical) source of strength W is given by:

$$\frac{|p_r|^2}{\rho_0 c^2} = \frac{W}{4\pi r^2 c},$$

where ρ_0 is the density of the air and c the speed of sound.

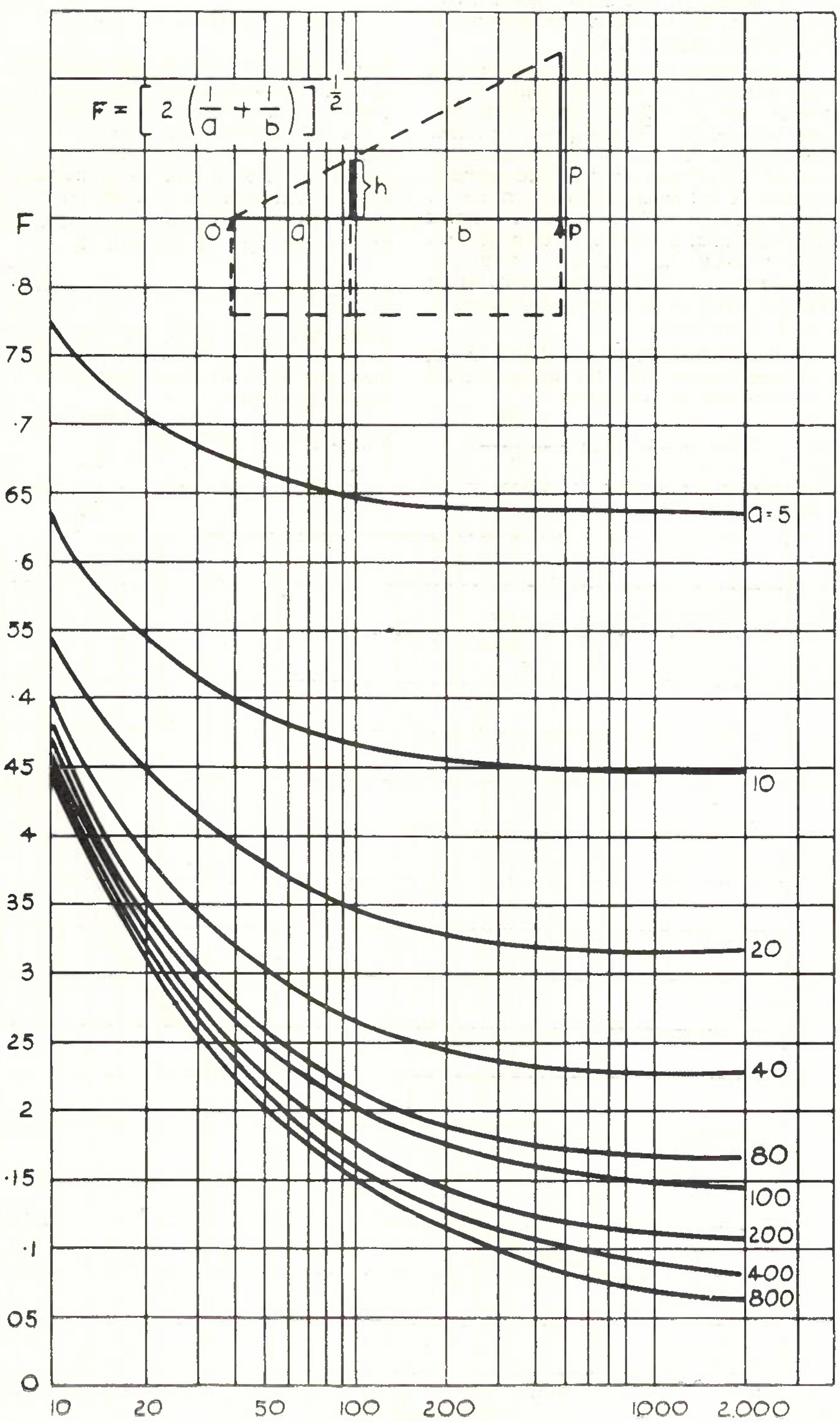

Fig. 4.—Screening Effect of a Wall—The function F.

To determine the sound pressure (averaged over space and time) of the diffuse field it is necesssary to consider the mean-free-path, R, of any wave radiated from its source. This is dependent on the shape of the enclosure but a good value of R is

$$R = \frac{4V}{S},$$

where S is the surface area and V the volume of the room.

The number of reflections of a wave in one second is therefore

$$N = \frac{cS}{4V}.$$

The sound source radiates a power W into the room. Of this power, a fraction, W_1, will be absorbed by the room surface at the initial reflection and the remainder, W_R, at all subsequent reflections (neglecting air absorption). If the room surface has an average absorption coefficient $\bar{\alpha}$ the power W_1 absorbed initially is

$$W_1 = W\bar{\alpha}$$

and the power reflected, i.e., the power in the diffuse sound fields, is

$$W_R = W(1 - \bar{\alpha}).$$

Suppose, under conditions of equilibrium, the reverberant energy density is D. Then the reverberant energy removed from the room each second is

$$DV\bar{\alpha}N = W_R$$

$$\text{i.e.}\quad DV\bar{\alpha}\frac{cS}{4V} = W(1 - \bar{\alpha}),$$

$$\text{whence}\quad D = \frac{4W}{cS}\cdot\frac{1 - \bar{\alpha}}{\bar{\alpha}}.$$

The mean sound pressure is therefore

$$|\bar{p}| = \sqrt{\rho_0 c^2 D} = \left[\frac{4\rho_0 cW}{R}\right]^{\frac{1}{2}},$$

where $R = \frac{S\bar{\alpha}}{1 - \bar{\alpha}}$, is known as the room constant. If change in sound pressure is measured in decibels we may write

$$20 \log |\bar{p}| = 10 \log \frac{4\rho_0 cW}{R}.$$

Calculation of Reduction in Diffuse Sound Pressure: For constant power from the source, any change in sound pressure is due to variation in the room constant R and is expressible as 10 log R decibels. For values of $\bar{\alpha} < 0.1$, it is adequate to use the approximation $R \doteqdot S\bar{\alpha} = a$, where a is the total room absorption (sabins). However, in rooms in which there is extensive sound absorption the approximation is not valid. The majority of text books on acoustics state that the diffuse sound pressure is proportional to the room absorption; it will be seen that this is not strictly correct and is in fact true only of fairly reverberant rooms.

Example: An engine room has a floor area 10' x 14' 6" and height 9'. The walls are of brick, the floor and ceiling concrete. The absorption in the room is determined as follows (Table 3).

Table 3

Surface	Area sq. ft.	Abs. Co-eff.	Absorption (sabins)
Walls	400	0.035	14.0
Ceiling, floor	290	0.015	4.4
Doors	50	0.09	4.5
Total	740	$\bar{\alpha} = 0.031$	22.9

Suppose now we cover the ceiling and walls (excluding the doors) with absorbent using a fibre-glass or rock wool blanket of 3" thickness and density 6 lb. per cu.ft. The absorption is as shown in Table 4.

Table 4

Surface	Area sq ft.	Abs. Co-eff.	Absorption (sabins)
Walls	400	0.90	360
Ceiling	145	0.90	130.5
Floor	145	0.015	2.2
Doors	50	0.09	4.5
Total	740	$\bar{\alpha} = 0.67$	495.2

The reduction in diffuse sound pressure is given by

$$10 \log \frac{R_2}{R_1} = 10 \log \frac{0.67}{0.33}\,\frac{0.97}{0.03} = 18 \text{ db.}$$

Using the more common (and inaccurate) formula, the reduction is

$$10 \log \frac{S_2}{S_1} = 10 \log \frac{495.2}{22.9} = 13.3 \text{ db.}$$

i.e. an error of nearly 5 db.

Sound Insulation of the Engine Room

Sound energy from the engine room escapes to the outside via the walls, doors, windows, and various cracks and apertures, conduits and pipes. The designer must ensure that the attenuation of sound over all these paths is adequate; a neglected path may well short circuit the attenuation imposed by the remainder of the structure.

Transmission Loss: The transmission loss of a structure is defined as the ratio of the acoustic energy transmitted through it to the energy incident upon it. Note that the definition covers not merely normal transmission through, say, a wall, but also the sound energy radiated from a surface any distance from the receiving surface but connected to it. (This covers transmission between rooms which do not share a common wall). The transmission loss is expressed in decibels as

$$TL = 10 \log \frac{W_1}{W_2} = 10 \log \frac{1}{\tau} \text{ db,}$$

where W_1, is the incident acoustic power on the surface of area S_W (perfectly absorbing) W_2 is the acoustic power radiated from an equal area S_W into a perfectly absorbing space, and τ is defined as the transmission coefficient. The transmission loss of a variety of structures has been determined in several countries. Most of the standard text books on acoustics contain summaries of this work and several special publications have also been issued (4), (5), (6). A representation of the transmission losses of the more common constructions met with in Australian practice is given in Fig. 2. It has been found that the transmission loss of a single wall of homogeneous construction is dependent only upon the weight per unit area (surface density) and the frequency at which the loss is determined, i.e., the nature of the material of the wall is unimportant.

It is possible therefore to represent the transmission loss of such walls by a single curve as in Fig. 3, where data from two sources (4), (7) are given. Beranek recommends the use of the transmission loss at 500 c/s per second as an approximation of the mean transmission loss in the band 100-4000 c/s and a similar approximation is obtainable from Aston's data by taking the ordinate at 1000 c/s. However, as will be demonstrated later, precise calculations necessitate the use of the full spectrum.

Noise Reduction: It was shown in the previous section that the diffuse sound pressure may be written as

$$20 \log |\bar{p}| = 10 \log \frac{4\rho_0 c W}{R}$$

relative to an arbitrarily chosen reference, i.e.,

$$20 \log |\bar{p}| = 10 \log W + 10 \log_{\rho_0} c + 10 \log \frac{4}{R}.$$

For a source of constant power and with unvarying atmospheric conditions, the final factor on the right hand side of this equation is the only one which can be changed. The equation may be expressed as

$$SPL = PWL + 10 \log \frac{4}{R},$$

where SPL and PWL are the sound pressure and power levels of the source relative to suitably chosen reference levels.

Let us suppose that the source is located in an enclosure and energy is passed through a wall of transmission loss TL and area S_W to a second enclosure. Then it can be shown that the transmission loss of the wall is

$$TL = SPL_1 - SPL_2 + 10 \log \left(\tfrac{1}{4} + \frac{S_W}{R_2}\right)$$

where SPL_1 and SPL_2 are the relative sound pressure levels in the two enclosures and R_2 is the room constant of the second enclosure.

The noise reduction is defined by

$$NR = SPL_1 - SPL_2 \text{ (db)}$$

$$= TL - 10 \log \left(\tfrac{1}{4} + \frac{S_W}{R_2}\right), \text{ (db).}$$

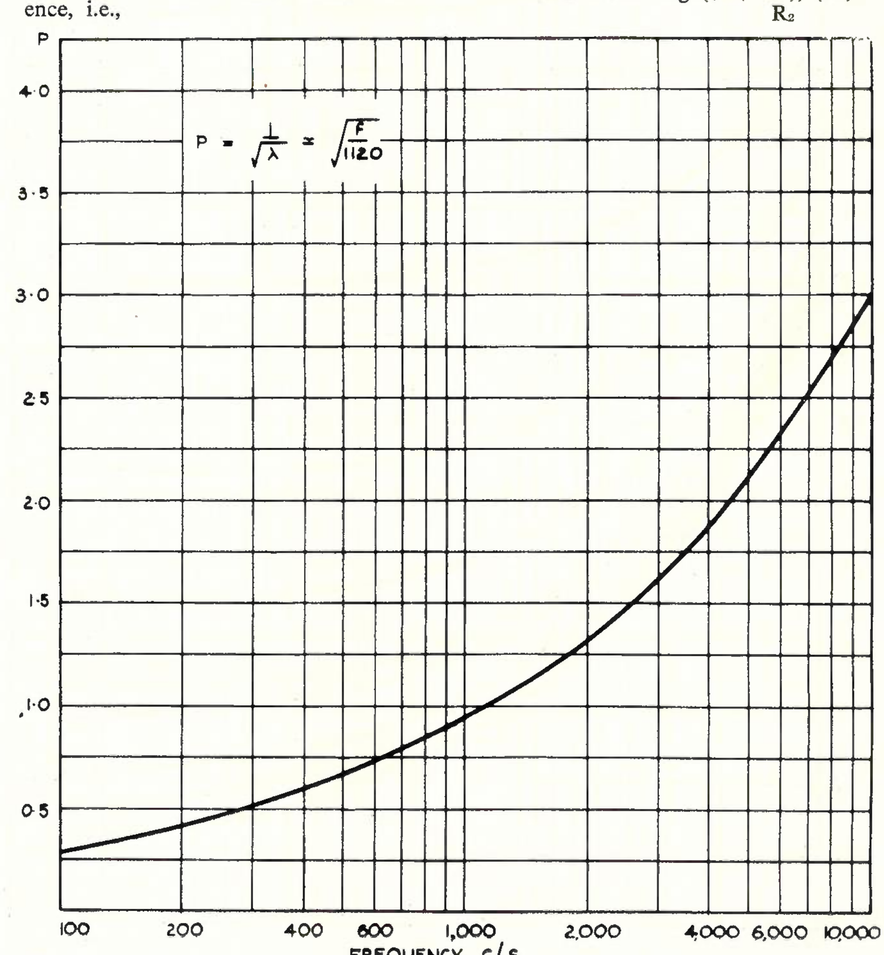

Fig. 5.—Screening Effect of a Wall—The function P.

Two important conclusions may be derived from this result. First, if the second enclosure is highly absorbent or opens onto the out-of-doors the noise reduction is simply

$$NR = TL + 6 \text{ db}.$$

Second, at a point sufficiently distant from the partition (i.e., at a distance roughly equal to its largest dimension) the sound pressure level in the enclosure is

$$SPL_2 = SPL_1 - TL + 10 \log \frac{S_W}{R_2}.$$

Effective Transmission Loss: The values of transmission loss (TL) and surface area (S_W) appearing in the equations of the last section must be considered as the effective values in the case in which the transmitting structure is a compound one. Each element of the structure, e.g., doors, windows, ventilating and other openings, must be considered separately and combined to give an effective transmission loss by the equation

$$TL = 10 \log \frac{\Sigma S}{S_1\tau_1 + S_2\tau_2 + }, \text{ db},$$

where $\Sigma S = S$; S_1, S_2, etc. are the areas of the separate elements having transmission coefficients τ_1, τ_2, etc., respectively, found from the equation

$$\tau_n = \frac{1}{\text{antilog } (TL_n/10)},$$

TL_n being the previously determined transmission loss corresponding to the element S_n.

Example: Determine the total effective transmission loss of a single brick partition wall of area 200 sq.ft. containing a single glazed window of area 20 sq. ft. and a hollow-core door of similar area. The calculations should be carried out as follows (Table 5).

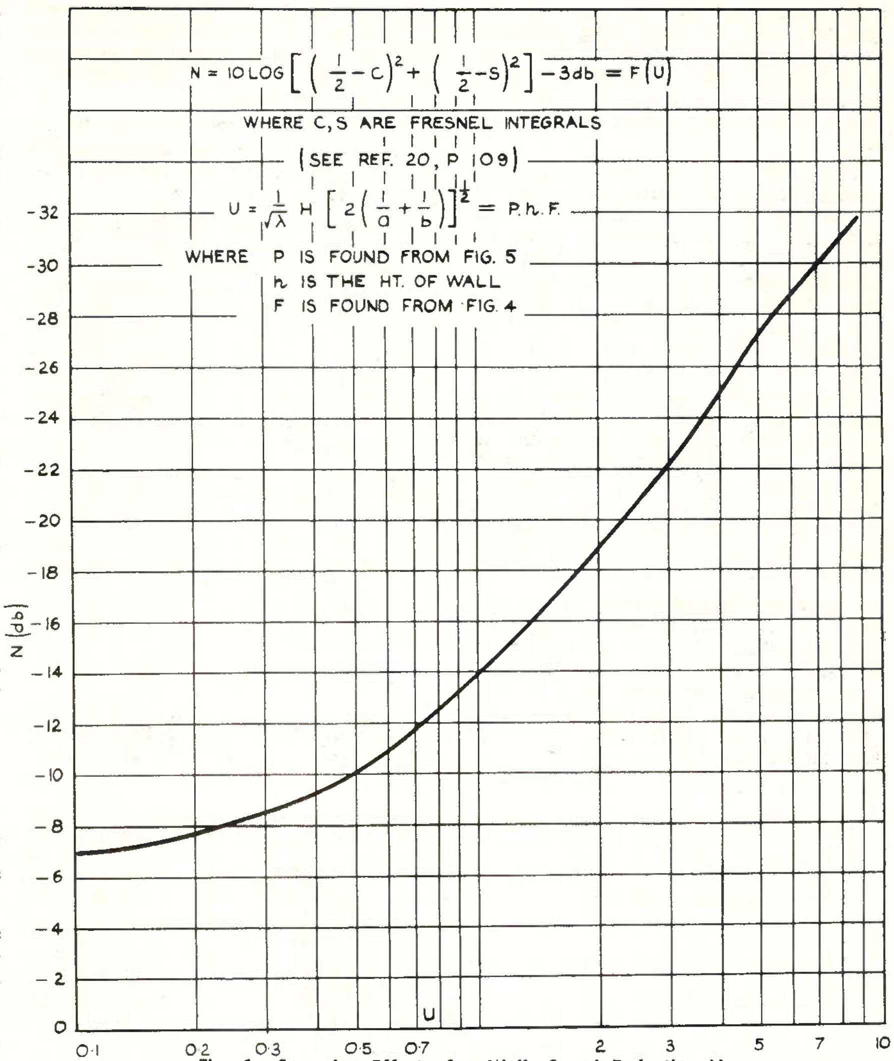

Fig. 6.—Screening Effect of a Wall—Sound Reduction N.

Table 5

Surface	TL (db)	τ ($\times 10^{-2}$)	Area sq. ft.	$S\tau$	Remarks
Brick	48	0.00158	160	0.00253	Homogeneous wall of density 11 lb. per sq. ft.
Window	28	0.158	20	0.03162	32 oz. glass well fitted frame.
Door	15	3.162	20	0.6324	Flush ⅛" plywood panels on hollow core, well fitting.
Total	25	0.3333	200	0.6666	

It is seen the door is the only important factor in this structure as it stands and that improvement of the insulation of the door to provide a transmission loss greater than that of the window would not be warranted. The value of $S\tau$ for the door shows also that the fit of the door is quite unimportant; a gap of ⅛" around the door would have a transmittance, $S\tau$, of 0.17, increasing the total effective transmittance to 0.84. i.e., a TL of 24 db instead of 25 db.

Flanking Transmission: Acoustical energy is transmitted through solid structures by setting them into vibration. The attenuation of the energy inside the structure is comparatively slight, as low as 0.3 db per 100 ft. for steel and up to 10 db for wood with brick and concrete at intermediate values.

Flanking transmission may arise from airborne energy at the source or from impact noise. In the former case, the energy radiated from any part of the structure may be determined as if each part of it formed a direct transmission path with its appropriate transmission coefficient, providing the structure is massive, homogeneous and continuous. It is good practice, in building construction, to interrupt flanking transmission paths by highly attenuating discontinuities. Attention should also be given to pipes, ducts, etc., which may form flanking transmission paths of low insertion loss.

Sound Reduction Outside the Exchange

Disturbance due to noise in the neighbourhood of an exchange may often be lessened by taking advantage of certain propensities which may be inherent in the site. The most important of these are the directionality of the noise sources (regarded from outside the exchange), the use of boundary walls or fences to throw a noise "shadow" or screen the noise source, and the sound absorptive properties of the atmosphere, buildings, trees and shrubs.

Directionality of the Noise Source: Noise sources in exchange buildings are likely to be of two types. In one, the noise originates from a small source, the engine exhaust pipe, which may be situated above the building or on an external wall. In the other, the noise is radiated from an aperture in an external wall, such as a window, duct termination or ventilator.

An exhaust pipe situated above a roof will radiate uniformly in the horizontal plane unless the field is disturbed by obstacles such as neighbouring buildings. The sound pressure in the undisturbed field varies inversely with distance from the source, i.e., there is a 6 db drop in sound pressure for each doubling of the distance.

The sound radiated from a pipe projecting from or suspended on brackets on the exterior of a wall will be increased in intensity in the horizontal plane by reflection from the wall. At high frequencies there is appreciable beaming along the axis of the pipe. It is therefore, generally preferable to take exhausts well above roof level and radiate the sound vertically.

When sound is radiated from a large aperture in a wall, the situation corresponds with that of a piston in an infinite baffle. The source will be highly directive at quite low frequencies, depending on the size of the aperture. It is desirable that a similar procedure to that in the case of exhaust pipes should be adopted.

Screening Effect of a Wall: The screening effect of a wall or fence is apparent only when the wall interrupts the line of sight between the source and the observer and even then is not large unless the wall is relatively high. Since the phenomenon depends on the diffraction of energy around the edge of the wall the lower frequency spectrum of acoustic waves renders them more susceptible to diffraction. For the same reason the screening due to the wall decreases with frequency in the audible range.

The sound level reduction due to the diffraction over a wall has been discussed by Rettinger (8) and the method to be given is based on his.

It should be noted that the procedure described by Beranek (7) appears to be erroneous. The measured data quoted by Beranek is in as good agreement with the predicted performance determined by Rettinger's method as that determined by Beranek. However, this may serve to emphasise the fact that the theoretical value of screening at any frequency will not be realised under normal conditions for reasons discussed below.

The sound pressure reduction achieved by the wall is given by

$$N = -3 + 10 \log([\tfrac{1}{2} - C(u)]^2 + [\tfrac{1}{2} - S(u)]^2), \text{ db},$$

in which C(u), S(u) are Fresnel's integrals,

$$C(u) = \int_0^u \cos \frac{\pi x^2}{2} dx,$$

$$S(u) = \int_0^u \sin \frac{\pi x^2}{2} dx.$$

These functions have been tabulated, e.g., in Ref. (9), p. 109. We determine u from the formula,

$$u = p \left[\frac{2a}{\lambda b(a+b)} \right]^{\frac{1}{2}}$$ where λ is the wavelength and p, a, and b are as shown in Fig. 4, i.e., p. is the "shadow" cast by that part of the wall standing above the line O,P joining the source and the observer. The points O,P may be at ground level or above it.

For p write h(a + b)/a. Then,

$$u = \frac{1}{\sqrt{\lambda}} \left[2\left(\frac{1}{a} + \frac{1}{b}\right) \right]^{\frac{1}{2}},$$

$$= hP(\lambda).F(a,b).$$

The values of the functions P and F are given in Figs. 4, 5 and N can be found from the graph of Fig. 6.

Example: An engine room is ventilated to the atmosphere through windows at a mean height of 4 ft. There is a 10 ft. high boundary wall opposite the window. What is the sound level reduction due to the wall of the fundamental frequency of 150 c/s at a house 60 ft. from the wall? The effective height of the wall may be taken as 10-4, i.e., 6 ft. Then it is found that F = 0.372, P = 0.35, h = 6 whence u = 0.78 and N is approximately 12 db.

It should be noted that the reduction in sound level obtained through the screening effect of a wall is additional to the decrease in sound pressure due to distance from the source. In the example above, there is a 10 db decrease from the wall to the house in addition to the screening of the wall, giving a total of 22 db.

Sound Absorption by the Atmosphere: As has been mentioned, in an ideal, homogeneous, loss-free atmosphere the sound pressure decreases inversely with distance when the observer is in the far free-field of the source; for each doubling of distance the sound pressure level decreases by 6 db. However, under normal circumstances additional attenuation of the sound is present. The important causes of this additional loss of energy are sound absorption in the air, absorption by trees, etc., the presence of wind and temperature gradients in the atmosphere, and air turbulence.

The absorption of sound in air enclosed in a room is generally regarded as additive to the absorption afforded by the room's surfaces. The air absorption is given by

$$\alpha \text{ air} = \frac{4 \text{ mV}}{S},$$

where V and S are the volume and surface area of the enclosure (the quantity 4 V/S, is recognised as the mean free path) and m is the energy attenuation constant. Procedures for the determination of m are given in the literature (7) but a simplified graph is given in Fig. 7, which shows the absorption per thousand cubic ft. of air at 20°C at several values of relative humidity. It will be noticed from the graph that the air affords appreciable absorption only at frequencies of 1 kc/s and above.

Calculations have been made by Wiener (10) of the attenuation due to absorption in the air as a function of distance from the source. His results are reproduced in Fig. 8. The values

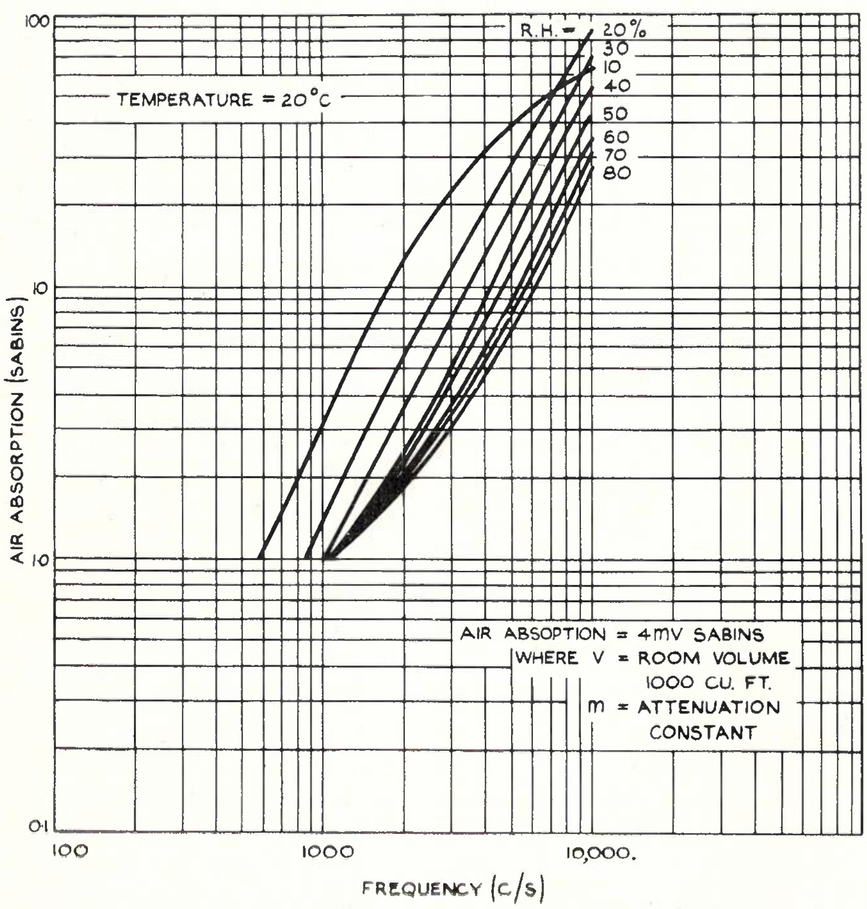

Fig. 7.—Air Absorption per 1000 cu. ft.

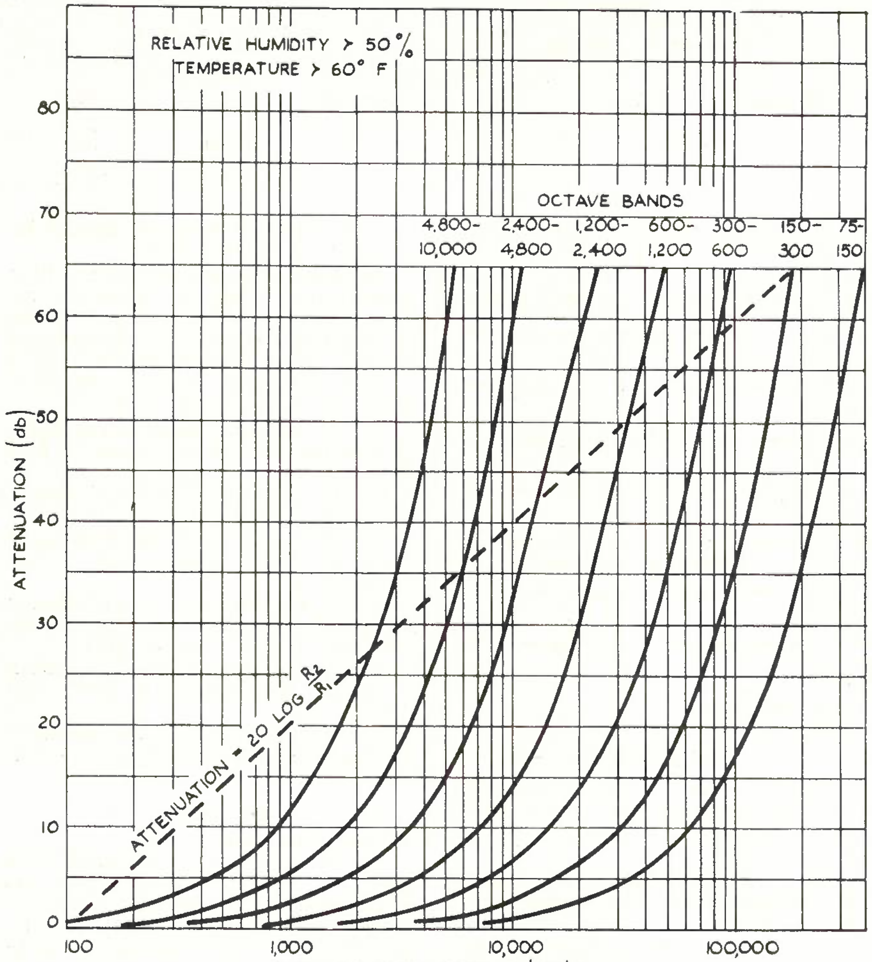

Fig. 8.—Attenuation of Sound in Air.

are stated to be conservative but indicate that at distances less than about 1000 yds. the attenuation of sound by the atmosphere in the important lower frequency bands is insignificant compared with the attenuation due to distance.

Over areas of ground comparatively free from buildings there are usually persistent wind and temperature gradients which cause the speed of sound to vary with height above ground and sound waves are therefore refracted either upward or downward. The effect of such refraction is to create "shadows" or zones of decreased intensity. It should be noted that the shielding effect of walls and buildings may also be nullified in certain conditions. The following effects may be defined. Since wind gradients are normally positive, i.e., the wind speed increases with height above ground, the sound waves are bent upwards in the upwind direction and downwards in the opposite direction. Temperature gradients may be positive (temperature inversion), usually at night, or negative (temperature lapse) which is the common daytime condition. With a positive gradient, the sound waves are refracted downwards and with a negative gradient upward refraction occurs. Sound shadows therefore only occur upwind from the source or with a temperature lapse in the atmosphere (Figs. 9,11) in certain directions from the source the effects of wind and temperature gradients will reinforce or counteract each other (critical angle).

Because of the great variation, both diurnal and seasonal, in wind and temperature gradients only average conditions can be considered in a short account such as this and then only for straight upwind ($\theta = 0$) and downwind ($\theta = 180°$) propagation. In these cases Figs. 10 and 12 provide estimates of the attenuation. For downwind propagation the attenuation is given in terms of $f_m \times r$ where f_m is the centre (geometric mean) frequency of a given octave band and r is the distance from source to receiver in feet. For upwind propagation, the attenuation is given in terms of the normalised distance from source to receiver. In any particular situation, it is best to determine the distance X_0 by sound level measurements, the sound pressure level falling rapidly below that expected by the inverse square law at that distance. The values given in the following table may be used as a guide.

It should be noted that the stability of the sound level is dependent on the nature of the atmospheric conditions. For downwind propagation, the degree of fluctuation of the sound level increases with the distance and with the frequency of the sound. For upwind propagation, the fluctuations are small (about 5 db) on a clear night with little wind, but are large (about 20 db) on a clear sunny day with strong winds.

Recent work in England has indicated that where the observer is not directly up or downwind from the source, the

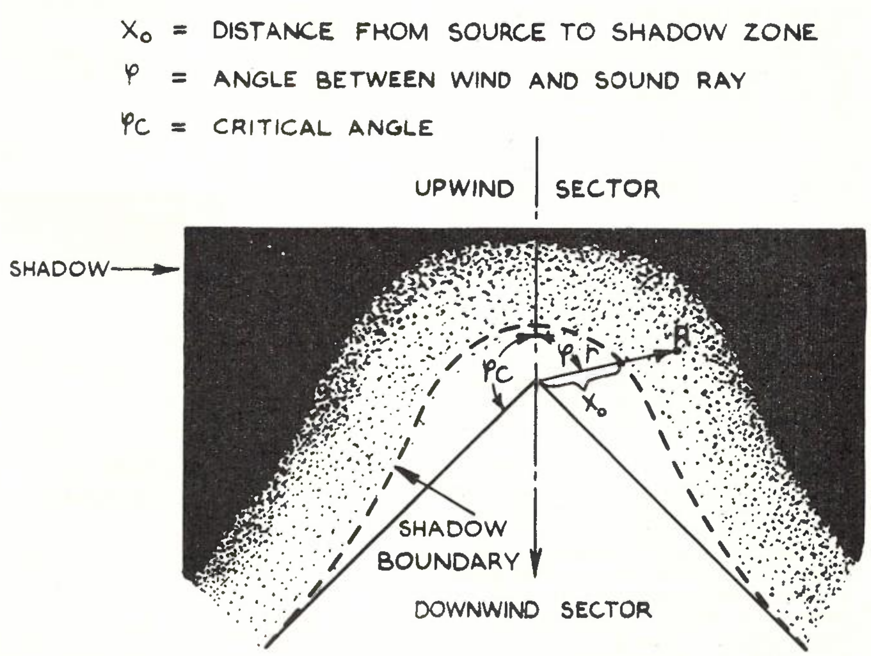

Fig. 9.—Sound Propagation (Day).

Table 6
Distance X_0 upwind

Time: Day	Time: Night	Sky: Clear	Sky: Overcast	Temp. Gradients: Large	Temp. Gradients: Nil	Temp. Gradients: Inversion	Windspeed m.p.h.	X_0 (ft.)
x		x		x			10-18	250
x			x		x		10-15	400
	x	x				x	2-4	2000

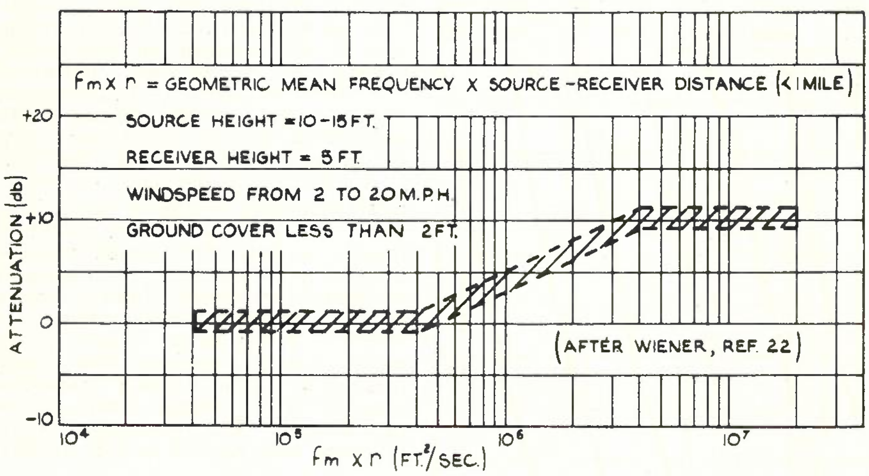

Fig. 10.—Downwind Sound Attenuation.

component of wind velocity in the line of the observer (the vector wind) should be used. It has also been observed that, measuring downwind in a vector wind of about 5 m.p.h., there was no variation of attenuation with height, but upwind there was a progressive decrease of attenuation with height of the observer above ground so that attenuation at 20 ft. above ground is likely to be some 10 db less than that at 5 ft. in the important frequency bands.

Sound Absorption by Vegetation: Little experimental work has been done on the absorption of sound energy by vegetation. Hayhurst (11) concluded from his work on the measurement of aircraft noise that the attenuation of sound is greater over grass than over concrete and that the difference increases as the frequency of the sound increases.

An extensive study of jungle acoustics during the wet season in Panama has been reported by C. F. Eyring (12). Even in relatively open terrain there is little wind and temperature gradients are small, there is therefore negligible refraction of sound. Attenuation of a 200 cps sound per 100 ft. of distance varies from 1.5 to 4db according to the nature of the terrain (from very light to very heavy vegetation). Meister (13) describes relatively dense woods as having an absorption rate for traffic noise of from 5 to 5.5 db per 100 ft.

The results of these studies indicate that, in sufficient quantity vegetation affords worthwhile attenuation of sound. To be effective it should offer a continuous barrier from the ground upwards. If the aesthetic value of trees and shrubs is taken into account the provision of hedges, etc., where ever possible on the boundaries of exchange sites is seen to be worthy of consideration.

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GLOSSARY

Critical Bandwidth:
The bandwidth of a noise which is the minimum required to mask a pure tone at the centre of the band. An increase in in bandwidth above the critical does not increase the masking owing to the selectivity of the ear.

Flat Noise:
A noise which is both white (i.e. continuous and uniform as a function of frequency) and random (i.e. having instantaneous amplitudes which occur, as a function of time, according to a normal, or Gaussian, distribution).

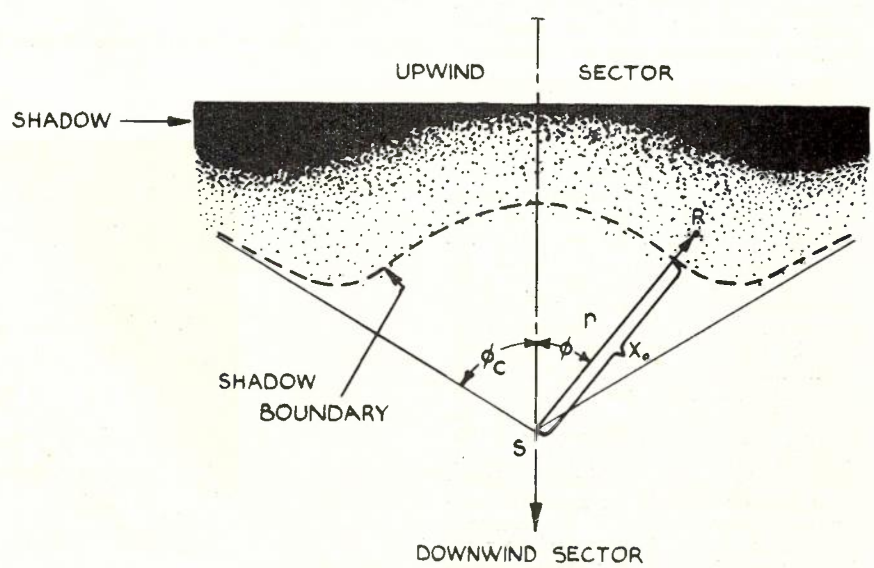

Fig. 11.—Sound Propagation (Night)

Intensity:
The average rate of sound energy transmitted in a specified direction through a unit area normal to this direction at the point considered. The MKS unit is the watt per sq. metre.

Sabin:
The measure of sound absorption of a surface. It is the equivalent of one square foot of a perfectly absorptive surface.

Sone:
The unit of loudness. By definition, a 1,000 c/s tone, 40 db above a listener's threshold, produces a loudness of one sone. The loudness of any sound that is judged by the listener to be n times that of the one-sone tone is n sones.

Sound Level:
The reading in decibels of a sound-level meter constructed and operation in accordance with a specified standard (e.g. BS.1479: 1948 or ASA Standard Z24.3—1944).

Spectrum Level:
The effective sound energy, power, or pressure level contained within a band one cycle-per-second wide centred at a specified frequency, measured in decibels relative to a stated reference. The concept has significance only for sound having a continuous distribution within the frequency range under consideration.

Speech Interference Level:
The arithmetic average of the sound pressure levels in the three bands 600-1200, 1200-2400, and 2400-4800 c/s. (An additional band of 300-600 c/s should be included if the sound pressure level in this band is greater than that of the adjacent band by 10 db or more).

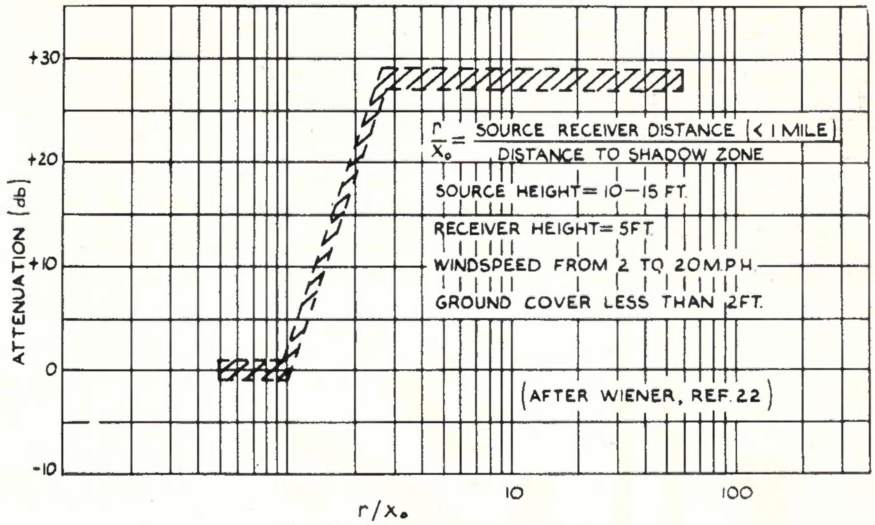

Fig. 12.—Upwind Sound Attenuation.

STAPLING MACHINES

*F. R. RAY, M.I.E.E.**

Those officers who are engaged on substation installation work will, before long, be issued with stapling machines for use in securing small-sized cables to walls or other surfaces. This will enable the work to be carried out more efficiently and more speedily. Stapling machines are somewhat similar to the ordinary commercial type of stapler but are more robust, employ a different type of staple, and are designed for one hand operation.

Before deciding whether stapling machines should be adopted for substation installation work in Australia, and which type or types would be best suited for local conditions, a number of problems had to be taken into consideration. The types of timber used in building construction vary considerably in hardness. For example, oregon pine has a hardness of approximately 1000 lbs. whilst "grey iron-bark" hardwood has a hardness of 3092 lbs., and it was, of course, desirable that the type of stapling machine selected should be suitable for use with as large a range of timbers as possible. The scale of timber hardness is related to the force required to embed a steel ball of 0.44″ diameter in timber, for a depth equal to half its diameter.

The majority of types examined were satisfactory from a purely technical point of view and were capable of doing a satisfactory job. A decision between the various types was therefore largely based upon other factors such as costs (including not only the first cost of the machine, but the recurring costs for the staples), nature of currency required for purchasing the machines, ease of maintenance, durability and the likely availability of new machines and spare parts in times of international emergency. A consideration of the above factors led to the decision to standardise on a stapling machine of Australian manufacture. Fig. 1 shows a photograph of the machine selected. This machine has a magazine capable of holding 75 staples, and a slot in the side of the magazine gives a visual indication of the contents Fig. 2 shows the component parts of the same machine.

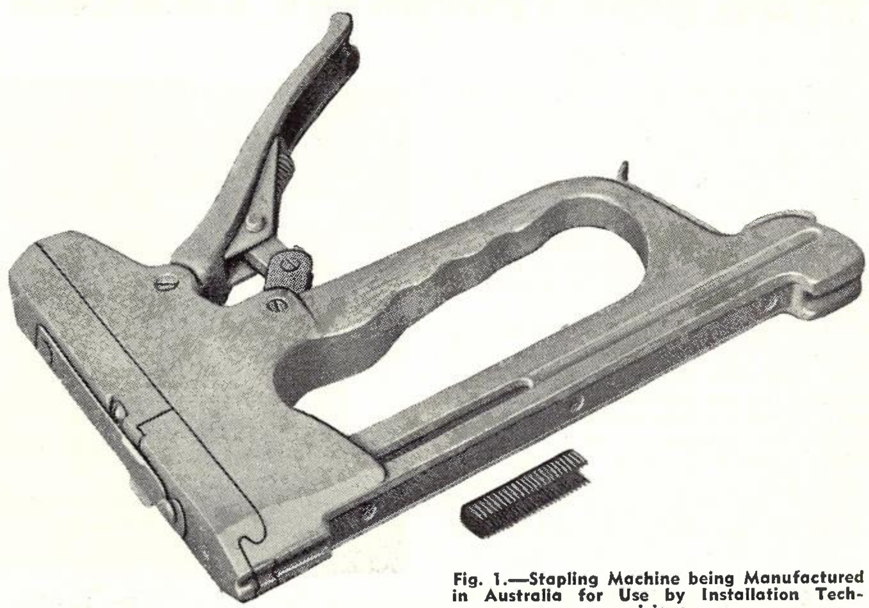
Fig. 1.—Stapling Machine being Manufactured in Australia for Use by Installation Technicians.

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Replacement of worn parts on this machine is exceptionally easy. Referring to Fig. 1 it will be observed that two cable guides are provided under the base of the machine to assist in positioning the machine on the length of cable which is being stapled.

The operation of the stapling machine is as follows:—

The hammer is drawn back against a compression spring when the trigger handle is squeezed. At a critical point the hammer is released and is driven forward by the spring. The energy of the hammer is communicated to a staple by a driving pin connected to the hammer. The staples lie in a channel and, as the hammer and driving pin are drawn back, one staple is pushed into place by a light spring in readiness to be driven forward into the wood or other material.

The weight of the machine selected is 2 lb. 2 oz., which is sufficient to prevent recoil when held firmly. The energy available for driving the staple is the energy stored in the spring when fully compressed less a small proportion due to the fact that the spring is unable to fully expand because of the end-stop. The net available energy for driving the staple in the model selected is 26.2 inch pounds weight.

The staples to be used initially will be of the "divergent points" type, manufactured from steel with a hardness value of approximately 200 V.P.H.N., and are illustrated in Fig. 3. The scale of metal hardness referred to is the "Vickers pyramidal hardness number," and typical hardness numbers are: tool steel—approximately 1000, common 2" nail—approximately 250, and soft copper—approximately 50. The size will be approximately 11/32" long x 7/32" wide (between legs). The legs of "divergent points" staples tend to twist slightly when the staples are driven into hardwood, and this assists the holding power of the staples.

It is anticipated that stapling machines will be suitable for use on all but the hardest of the timbers used in building construction, and that the completed job will not only have a much more satisfactory appearance but the resultant economies will pay for the cost of the machines within a very short time.

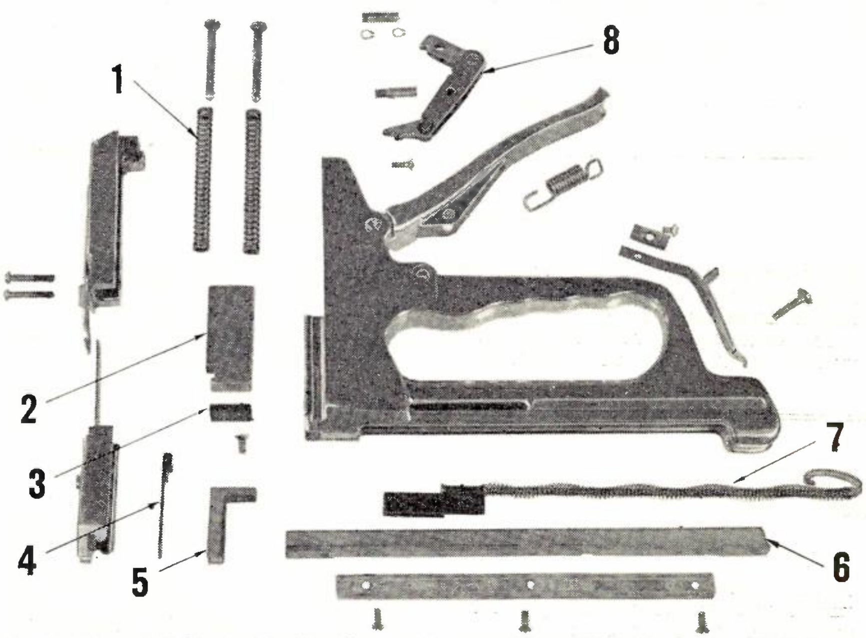


Fig. 2.—Dismantled Stapling Machine Showing Component Parts. (1) Main Spring, (2) Hammer, (3) Rubber Stop, (4) Striker, (5) Striker Guide, (6) Staple Guide, (7) Magazine Spring, (8) Trigger Assembly.

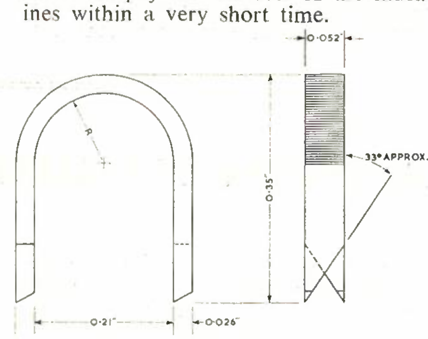


Fig. 3.—Staple with Divergent Points.

RYDALMERE TEMPORARY EXCHANGE

*M. J. POWER, A.M.I.E.Aust.**

On 6th September, 1958, two 600 number portable exchanges were established at Rydalmere in N.S.W. Extension to a capacity of 1800 numbers was made soon afterwards by the addition of a third portable exchange. Portable exchanges are now in common use within the Commonwealth, but there are certain features about Rydalmere installation which are novel and of general interest.

The site plan for the buildings is shown in Fig. 1 and it will be seen that the main front portion of the site is reserved for the permanent building. An R.A.X. hut has been used for the M.D.F. and power equipment, and this and the three portable exchange buildings have been arranged in the form of a quadrangle. The central space between the buildings has been roofed and provides

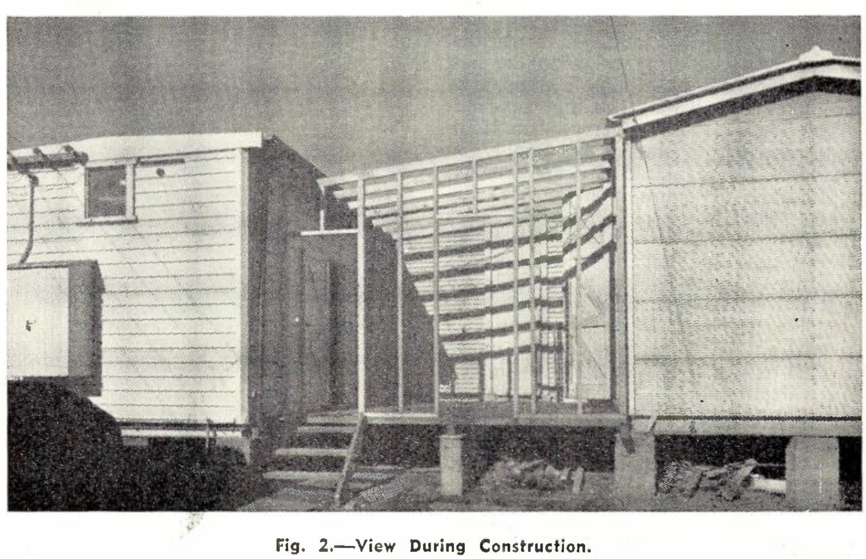


Fig. 2.—View During Construction.

*Mr. Power is Supervising Engineer, Equipment Installation, Metropolitan Branch, N.S.W.

a useful space adjunct to the huts. This can be seen in Fig. 2 which gives a view of the structure with two portables and the M.D.F. hut in position and the central awning in course of erection before the third portable exchange was positioned.

The use of the R.A.X. building as an M.D.F. hut permitted the installation of an island type M.D.F. Means of opening a line was provided by M.D.F. links, the protection equipment being already provided in the portable exchange buildings which had previously been working on other sites as complete exchange units. Although the temporary exchange capacity was 1800 numbers it was necessary to provide M.D.F. space for about 7000 external pairs and the island type M.D.F. gave this facility readily. A detailed floor layout of the equipment is shown in Fig. 3.

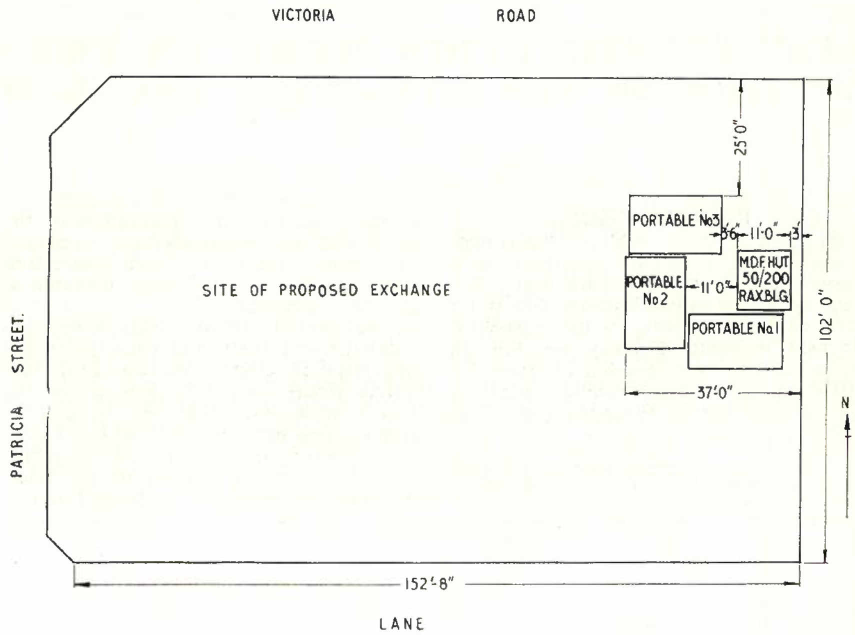


Fig. 1.—Site Plan.

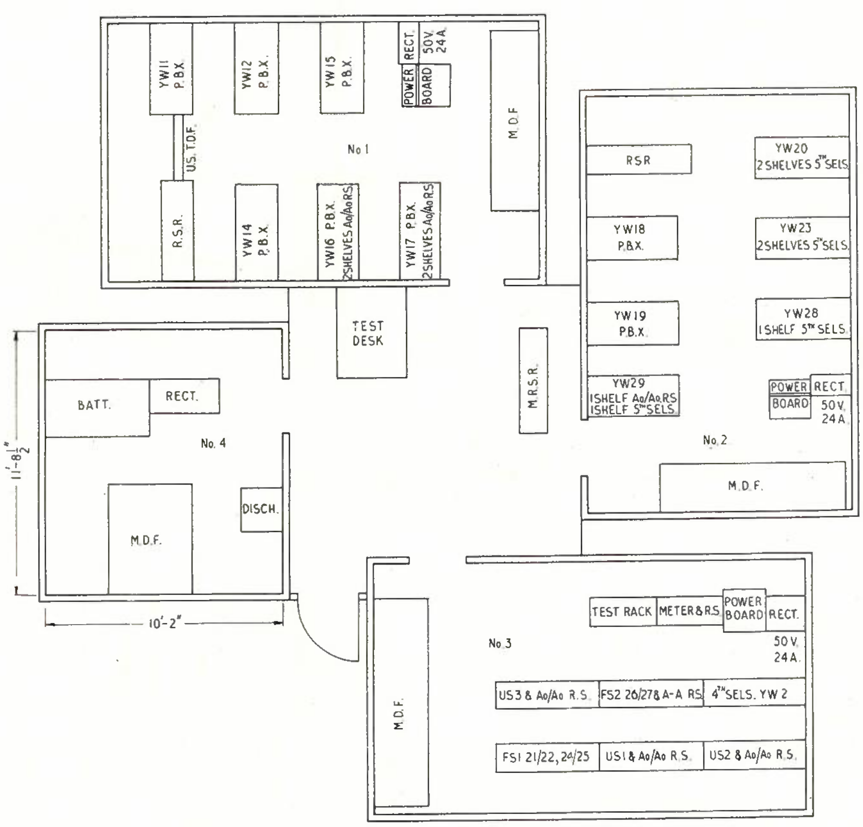


Fig. 3.—Equipment Layout—Floor Plan

LINE CONSTRUCTION WORK ON THE SOUTH AUSTRALIAN SECTION OF THE EAST-WEST TRUNK ROUTE

*D. F. BURNARD, B.E., A.M.I.E.Aust.**
*F. S. W. GUBBINS**

INTRODUCTION

Early in 1955 the P.M.G. Department was requested to provide six circuits to a point approximately 30 miles north of a railway siding called Watson, 447 miles west of Port Augusta on the East-West Trans.-Continental Railway (See Fig. 1). These circuits were needed by June 30, 1956, to give communication facilities for the first Atomic Weapons Tests. This article describes the organisation of the work and the special methods employed to complete the project and ensure that the facilities requested were available at the date specified.

The overall circuit situation between Adelaide and Perth was such that existing physical circuits on the East-West Trunk Route were fully loaded and the new requirement could best be met by running two new physical 300 lb. H.D.C. circuits over the Woomera-Watson Section of the route, a distance of 340 miles. The installation of two 3-channel carrier systems would provide the necessary 6 circuits.

Before this special requirement for Maralinga—the name given to the Atomic Weapons Testing Site—had arisen, the Department was planning for additional circuits between Adelaide and Perth to meet normal developments. This planning had reached an advanced stage and it had been determined that two new physical circuits between Port Augusta and Kalgoorlie were required. The running of two new circuits between Woomera and Watson was therefore part of

* Mr. Burnard and Mr. Gubbins are Divisional Engineers in the South Australian Administration.

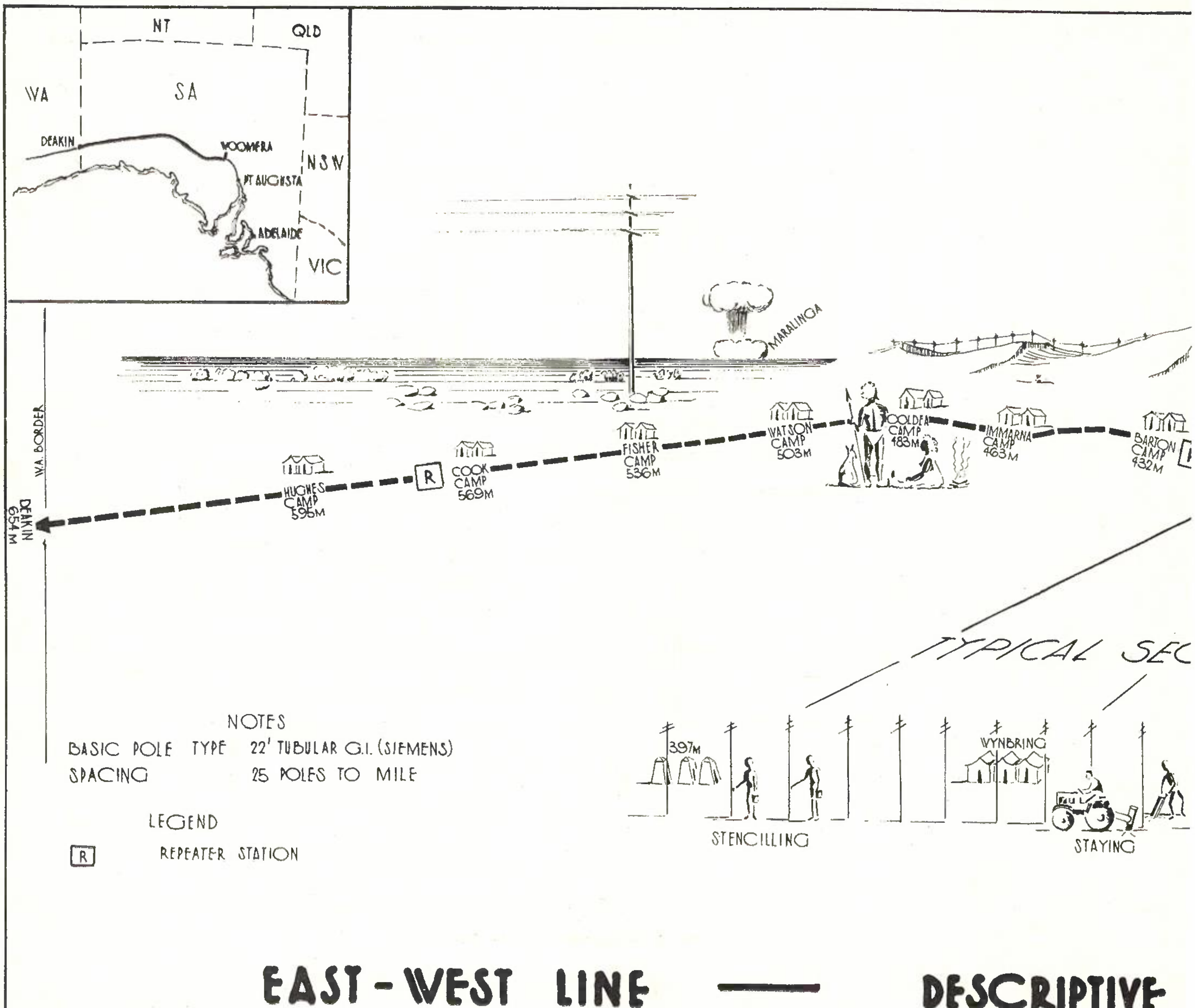


Fig. 1.

the ultimate scheme for the development of this trunk route. This fact greatly simplified the planning problems and enabled the organising of the new project to get under way almost immediately.

WORK TO BE DONE

Coupled with the work of running the extra physical circuits was a proposal to provide additional staying. The pole route traverses some very exposed country and serious breakdowns had been occurring following heavy storms. The decision had already been made that additional transverse stays should be fitted throughout the whole route on the following basis:—

(a) In exposed sections, transverse stays to be fitted on each pole.

(b) In other sections transverse stays to be fitted on every 4th pole.

Angle poles were already stayed and would be excluded from the above work. The addition of 4./300 lb. copper wires made it more imperative than ever that this additional staying should be completed as soon as possible.

The work set down to be completed in this project was therefore:—

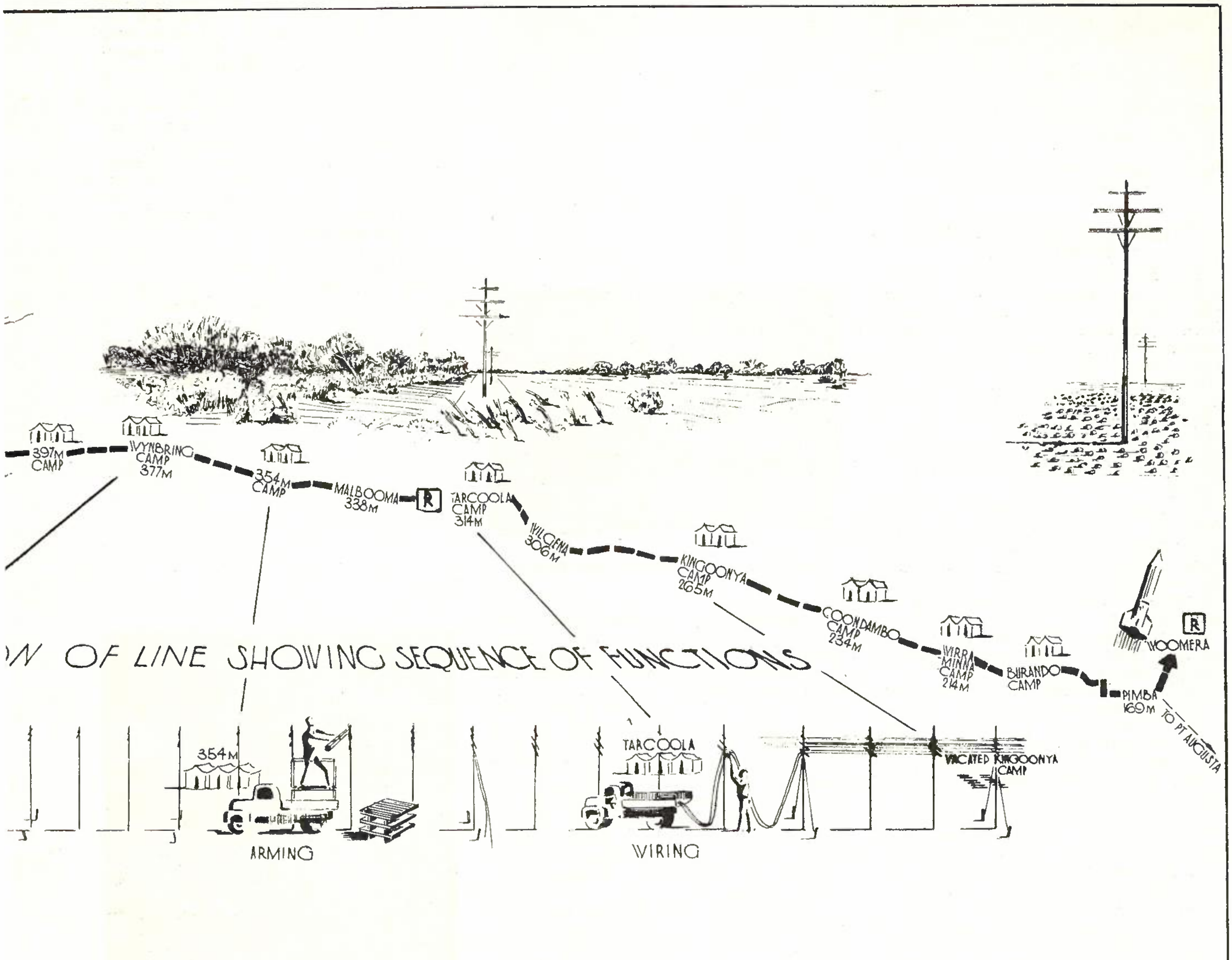
(a) Fit 108″ arm in position 5 and combine with existing arm in 3rd position on angle poles.
Run two 300 lb. H.D.C. circuits in pin positions 5 3/4 and 5 5/6 and transpose for 12 channel carrier working to Drawing CL.324.

(b) Fit transverse stays on every pole in exposed conditions and on every 4th pole in other parts.

(c) Erect a new pole route for a distance of approximately 26 miles from Watson to Maralinga. Fit 108″ arm and run 3. 200 lb. H.D.C. circuits.

There were miscellaneous extra line construction details to be attended to, such as the provision of extra poles for respacing purposes, some retransposing of existing circuits with minor alterations for road crossings, repeater stations and so on.

The pole route along the East-West line is owned by the Commonwealth Railways. Two of the existing circuits on the pole route were owned by the P.M.G. Department and the other two belonged to the Railways. The Commonwealth Railways are responsible for the maintenance of the route, but by agreement with the Commonwealth Railways, the P.M.G.'s Department may erect additional circuits. The standard pole is a 22′ tubular Siemens type, averaging 25 to the mile with every 16th pole transversely stayed. The type of construction along the East-West Line is shown in Fig. 3.



ETCH OF COUNTRY AND WORKING PARTIES

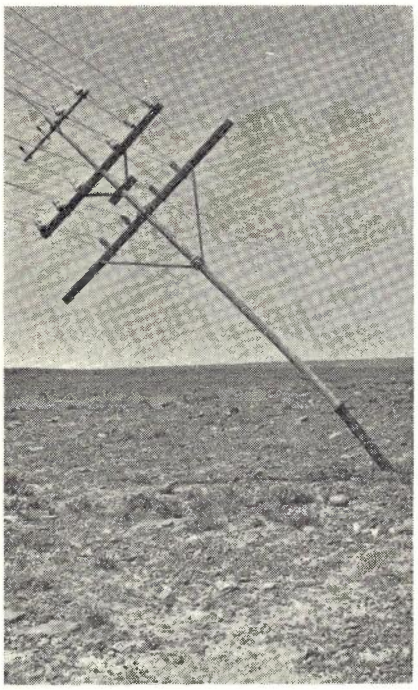


Fig. 2.—Typical Storm Damage and Showing also Gibber Plain Country.

THE COUNTRY: GENERAL CONDITIONS.

The East-West Line crosses the dry and sparsely populated country between Port Augusta (S.A.) and Kalgoorlie (W.A.). The area is one of high summer temperatures and low annual rainfall. Temperatures regularly rise to between 110° and 120°F. Soon after wire running started a worried Line Inspector rang into the office to ask what the correct weights would be for a wire temperature of 120°F. The preliminary chart given to him had only been taken to 110° F.

The average annual rainfall of 5 to 7 inches is normally recorded in a few heavy falls which usually occur under stormy conditions. During such storms the roads are impassable and work is not possible. The country soon dries out again however.

For purposes of line construction there are four types of country, each needing special consideration.

(a) Gibber Plain. See Fig. 2. This country is treeless and exposed to the weather. The soil is a heavy red clay mixed with floating rock which concentrates upon the surface, hence the name Gibber Plain. Under dry conditions motor vehicles can travel practically anywhere over this country, but after rain it is impassable.

(b) Sand Hills. See Fig. 4. Having had a number of good seasons the sand country was reasonably well covered with grass, bushes, and in parts some trees. There are two sections of rather difficult sand hills, the first one at the 416 mile camp and the other between Immarna and Ooldea. Generally speaking, however, sandy conditions existed for a route distance of nearly 100 miles. The worst hills are steep sided but by careful selection of approaches and crossings it was possible to get through with 4-wheel drive vehicles.

(c) Good Level Country. (See Fig. 5.) There were over 150 route miles of good level country with bush and tree cover—passable under practically all conditions. A sandy, shallow soil-covered limestone rock underneath.

(d) Nullarbor Plain. (See Fig. 3.) The Nullarbor Plain begins at Ooldea and extends from this point to the West Australian border. This is rocky, exposed, flat country with some grass, but no trees. The surface is rough and particularly hard on both vehicles and passengers.

West of Port Augusta living conditions are severe and special provision has to be made for water, food, and material supplies. Railway sidings occur every 20 odd miles, but these sidings consist normally of perhaps half a dozen railway cottages. Kingoonya, Tarcoola and Cook are exceptions as they are centres with a store, a school and a police station. Staffed P.M.G. Repeater Stations are located at Tarcoola and Cook. Supplies for all these places come from Port Augusta by train (the tea and sugar train as it is known locally), which travels the Commonwealth line from Port Augusta to Kalgoorlie and return, stopping at all sidings with supplies which can be ordered in advance or obtained from stocks carried.

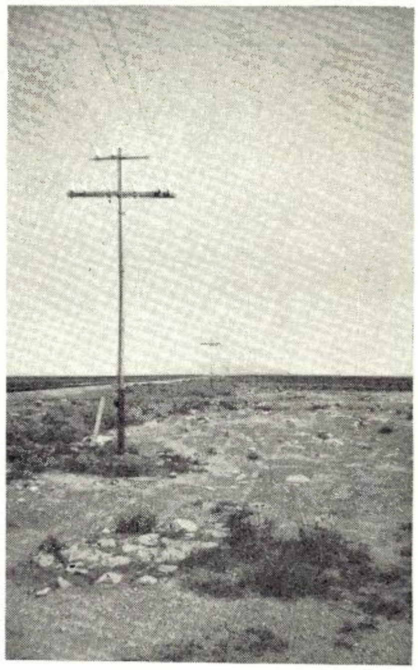


Fig. 3.—Typical Nullarbor Plain Country.

A reasonable track follows the Commonwealth Railway line as far as Malbooma, which is the first siding west of Tarcoola. It was known that tracks existed beyond this point but until an inspection trip was made the information on this score was both contradictory and vague.

ORGANISATION

The preliminary estimate of costs indicated that an expenditure of 145,000 manhours would be involved on essential external plant works. A period of four months was allowed to recruit staff, assemble material and camping gear, etc., and it was aimed to complete the line work by May, 1956, thus giving time for line testing and internal plant installations to be completed by June 30 of that year. This left a nine-month period, from August, 1955 to May, 1956, in which to complete the line work. On the basis of a 48-hour working week (6 eight hour working days) it was estimated that an average work strength of 84 men would be needed.

The working organisation was developed accordingly, with material supplies, camping gear, tools and transport arranged to keep this size construction party going at the required rate. In the case of this particular project, the Department of Supply had guaranteed the supply of motor vehicles and plans were prepared assuming that these requirements would be met without difficulty, as in fact they were. The material supply position was not easy, but it did not appear to be a controlling factor as far as the organisation was concerned.

It was decided, therefore, to organise the linemen into two geographical sections with the parties in each section working on a functional basis as follows:

(1) Staying parties.
(2) Arming parties.
(3) Wire running parties.

One Line Inspector was given the responsibility for the Woomera-Barton section and the other was in charge of parties operating between Barton and Watson. This second Inspector was also responsible for the work required between Watson and Maralinga and at the

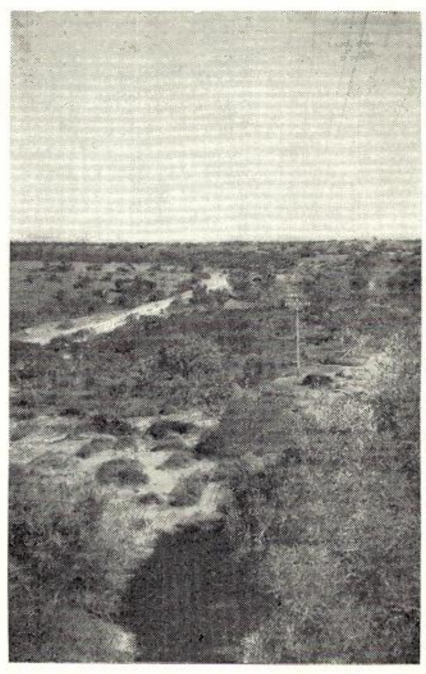


Fig. 4.—Typical Sand Plain Country in S.A. Section of East-West Route.

testing site. In addition, each Line Inspector had a party available for carrying out miscellaneous duties which included establishment of camps, handling of stores materials, designating poles, road making, clearing and collecting information for estimates. The total organisation as it affected this project within the Woomera Projects Division which had been given the responsibility for this work is shown below.

Divisional Engineer

- Grp. Eng. Woomera
- Grp. Eng. E-W. Line & Planning
  - L. Insp. A. (Woomera-Barton)
    - P/L +4 Special
    - P/L +4 Staying
    - 2P/L +13 Arming
    - P/L +11 Wiring
  - L. Insp. B. (Barton-Watson)
    - P/L +4 Special
    - P/L +4 Staying
    - 2P/L +13 Arming
    - P/L +11 Wiring

In more detail the functions of each particular party were as follows:—

Staying Party.

(a) **For the Woomera-Ooldea Section.**

(1) Mark positions for stay pegs.
(2) Bore 9" diameter holes to take rail pegs (4-5 feet long).
(3) Set the pegs.

(b) **For the Nullarbor Plain Section (Ooldea-W.A. Border).**

(1) Mark positions for stay rods.
(2) Drill 1¾" holes in rock to a depth of 2 ft.
(3) Set stay rods and cement in position.

No ladder or platform work was involved.

Arming Party.

(1) Fit additional 108" arms in arm position 5.
(2) Fit 43" braces.
(3) Fit transposition plates, spindles and insulators in pin positions 5/3 and 4, 5/5 and 6.
(4) Attach stay wires to poles and alter existing stays as necessary.
(5) Erect additional poles or move poles as required.
(6) Stencil transposition numbers on poles.

Wiring Party.

(1) Run two additional pairs of 300 lb. HDC wires.
(2) Attach stay wires to rail pegs or stay rods.

The considered optimum party sizes, and the nominal functions of individual party members are indicated in Fig. 6. The functions listed are of course basic functions only and it was necessary to re-arrange the duties of individual members for other miscellaneous work and to meet particular situations.

CAMPS

Alternative methods of providing living facilities were considered. Railway cottages were available at some sidings but not in all cases. Another possibility was to make the parties completely mobile. Each of these alternatives had serious drawbacks and difficulties and were discarded in favour of Departmentally provided camps located at 20 to 30 mile intervals along the route. In all cases, camps were established at railway sidings, which was necessary for:—

(a) The unloading and supply of line material.
(b) The supply of food and water.

In general line material was sent from Woomera by rail and at almost all sidings selected, it was possible to have railway trucks containing line material "shunted off" to be subsequently unloaded. This procedure did not always work smoothly, however, and instances of rail trucks travelling from Woomera to Kingoonya, via Kalgoorlie in Western Australia, did occur.

Food supplies coming on the tea and sugar train at any hour would be collected and paid for by the cook who also acted as camp treasurer. The camps were quite dependent on this service through the Commonwealth Railways, although there was frequently evidence in the Mess Hut that the meat supplies from Port Augusta had been supplemented by rabbit or kangaroo meat. Where possible a tap (or taps) was installed adjacent to the camp kitchen after the Commonwealth Railways had granted permission for an extension from the reticulated water system, which served the cottages at most sidings. The Railways made a water usage charge of 3/7 per man per week.

Prefabricated galvanised iron huts were supplied for cooking, eating, showering, material storage and toilet purposes, whereas tents were used as sleeping quarters, with two men per tent. A standard unit type hut was used for cooking, eating, showering and material handling—the basic size being 9 ft. x 9 ft. The sizes found necessary for the various purposes were:

(1) Cooking—single unit, 9 ft. x 9 ft.
(2) Eating—three units 27 ft. x 9 ft. (for camp strength of 15 men).
(3) Showering—double unit, 18 ft. x 9 ft.
(4) Material Storage—double unit, 18 ft. x 9 ft.

The layout of a typical camp is shown in Fig. 7. Such a camp would remain in situ and be used in turn by each functional party. On completion of work in that section camp would be dismantled and moved ahead.

The progress of each of the three functional parties was such that each Line Inspector had three simultaneous camps with a fourth set of camp gear to allow a new camp to be set up ahead of the working parties.

CAMP AMENITIES AND EQUIPMENT.

Kerosene operated refrigerators, with all necessary cooking and messing equipment were supplied to each camp. Pressurised kerosene lamps were used for lighting (Aladdin type). Portable (dry cell operated) radio sets were satisfactory despite the remoteness of the area. A set of quoits, playing cards, and darts provided the basis for relaxation. Regular mail bags were prepared, despatched through the Postmaster at Port Augusta and contact with homes was thus maintained.

Material was sent in bulk to the Divisional Store at Woomera and then forwarded by rail to sidings as required. Normally all requirements for a particular party were forwarded in one consignment, which was arranged to arrive at a siding immediately prior to the arrival of the line party. This enabled rail trucks to be quickly unloaded and released. As mentioned previously, material estimates were prepared for each camp section and each party leader was responsible for the recording of

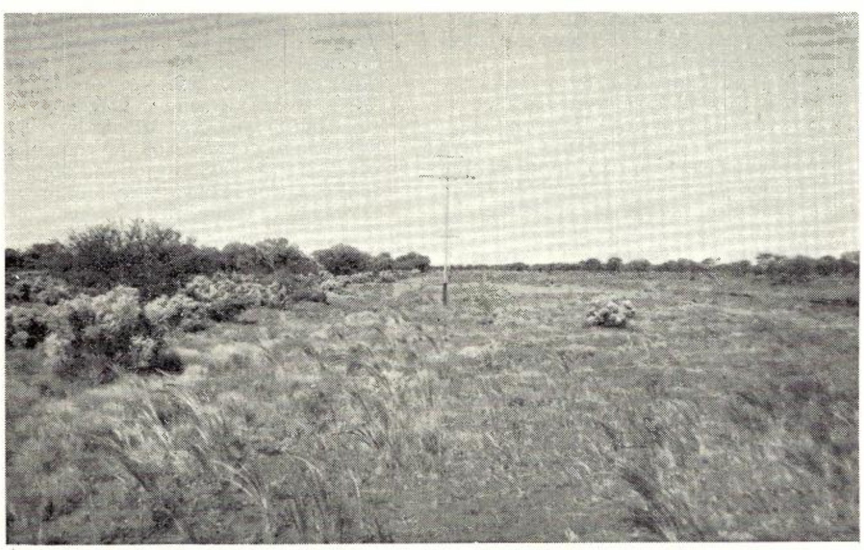


Fig. 5.—Typical Good Level Country on some Sections of East-West Route.

Party	Function	No. of men employed	Motor Vehicles	Mechanical Aids	Remarks
Staying	Pegging positions for stay holes and supervision.	1	1 Land Rover		Party Leader
	Boring holes for either:— (a) Rail pegs; or (b) Stay Rods.	2	1 Land Rover	1 Tractor Mounted Boring Unit	
	Transporting and either:— (a) Ramming rail pegs or stay rods into position, or (b) Cementing stay rods into 1¾" diameter holes.	2	1 Morris 1 ton 4 W.D. Truck		
Total per Staying Party		5	2 Land Rovers 1 Morris	1 Tractor Mounted Borer	
Arming (2 such parties per camp)	Assembling & fitting material in camp * e.g. (a) Fitting transposition spindles to transposition plates. (b) Fitting braces, back plates & either arm plates or arm seatings to poles. (c) Terminating one end of stay wires—cut to length—around thimbles by means of press-type sleeves.†	2	—	Impact Tools	1 Not available for all parties. * It was not practicable to fit transposition plates to arms until after arms were fitted to poles. The plates made the arms too heavy to handle. † Stay wires were connected to bolts connecting arm plates to back plates via thimbles.
	Delivering material to poles.	1	1 Commer 3 ton 4 W.D. Truck		
	Fitting arms and stay wires to poles.	3	1 Commer 3 ton Platform Truck	Generator & * Impact Tools	Not available for all parties.
	Supervision & miscellaneous.	1	1 Land Rover		Party Leader
	Cooking.	‡	—	—	‡ 1 cook for two parties.
Total for double arming party		15	4 Comers (2 with platforms) 2 Land Rovers	4 Generators 8 Impact Tools	Ideal arrangement.
Wiring	Running wire out along the ground and inserting crosses.	4	2 Morris 1 ton 4 W.D. Truck		
	Piking wire over cross-arms.	1	—		
	Tensioning wires.	1	1 Commer	Wire Tensioning Truck & Winch (W.T.T.)	The winch was used for pre-stressing.
	Fitting tapes, pulling wires around transposition plates and tying in.	4	2 Commer Platform Trucks		
	Supervision & miscellaneous.	1	1 Land Rover		Party Leader
	Cooking.	1			
Total for Wiring party		12	5 Commers 1 Land Rover	Wire Tensioning Truck and Winch	

Fig. 6.—Size and Function of Each Party.

voucher numbers covering transactions in his section.

STAFF

Insufficient linemen were available in South Australia for diversion to this project and so arrangements were made for the transfer of a number of men from other States. They were transferred in groups, each group containing the required number of Party Leaders, Linemen Grade 2, Mechanical Aids Operators and Drivers.

After approximately one day in Adelaide during which time the purpose of the project and proposed methods of working, etc., were explained, they travelled to Woomera where tools and camping gear were issued to them. Vehicles were allocated and the parties travelled by road to their respective camps.

The parties, both local and interstate, worked efficiently and persistently despite the rigorous climatic conditions and at times difficult terrain encountered. A high staff morale was achieved at the start and maintained throughout.

METHODS

1. **Staying.** The fixing of the stay at the ground end presented real difficulties. The standard stay rod and steel plate were not suitable in any part of the route for reasons which will be apparent. Two main types of transverse stays were finally adopted.

(a) **Rail Pegs.** Lengths of 80 lb. tramway rail 4 ft.-5 ft. long were installed at 20° to the vertical, leaning away from poles. In general the stay wire was connected to the head of the rail peg via a ⅝" x 9" eyebolt which provided a means of adjusting the stay tension. Two nuts, one for adjustment and one lock-nut were fitted to the eyebolt. In some cases strand grips without eyebolts were used. Further mention will be made of strand grips.

Stays of this type were fitted from Pimba to Ooldea and have proved satisfactory except in "gibber plain" sections near Pimba and Coondambo, where the holding power of the ground is very poor, especially after heavy rain. This ground is also very corrosive and untreated stay rods are not satisfactory. A trial installation has been made, in this section, of standard stay rods wrapped with an adhesive plastic tape.

(b) **Stay Rods Cemented into Rock.** Between Ooldea and the Western Australian border, as mentioned previously, the terrain consists of solid limestone rock with an overlay of loose stones or sand averaging 0"-6" in depth. The cost of drilling and blasting to form a hole large enough to take either a stay rod and plate or rail peg would have been prohibitive. Trials were made with a waggon drill boring 4" diameter holes, but these were not satisfactory. (see later). Therefore it was decided to drill 1½" diameter holes in the rock by means of either a pneumatic drill or a "blasting auger" attached to a Proline Borer and to cement the rods in position. Trials were made with holes bored to a depth of two feet, and at varying angles to the stay wire. A sloppy mixture of cement and quarry dust was poured around the rods. After some experimentation it was found that optimum holding power was obtained by boring holes and installing rods in line with the stay wires. Modified ⅝" Galvanised Iron

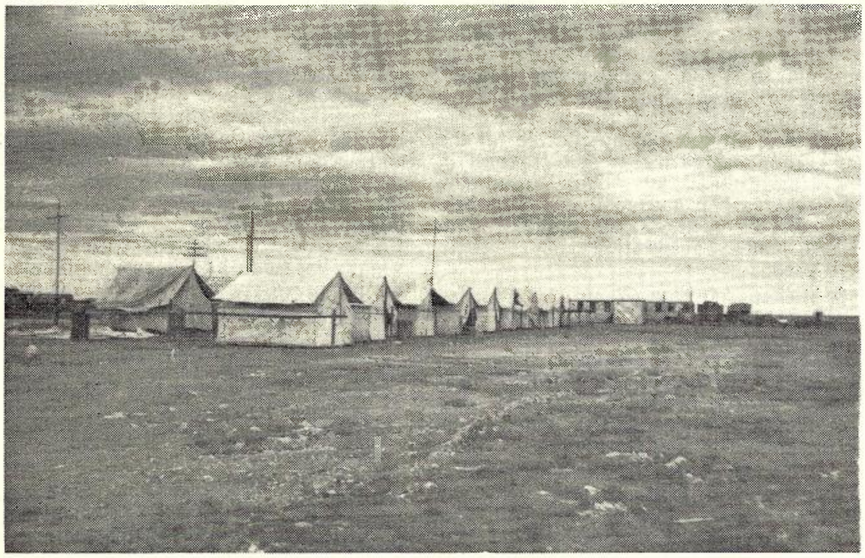


Fig. 7.—Layout of Typical Camp.

rods 5 ft. long without a bend at the lower end were provided for this purpose. Standard bow tighteners were fitted for adjusting tensions.

In addition to these methods some use was made of two other methods:—

(a) **Screw Anchors.** In sandy stretches screw-anchors were installed using the power take off drive on one of the tractors which was fitted with a modified screw anchor key.
Unfortunately it was necessary to dig a hole approximately 18″ deep before the 6′ long key could be attached to the borer shaft. After the fitting of the key the screwing-in of the anchor could be very rapidly completed.

Fig. 8.—Drilling Holes in Rock for Stays.

(b) **Pipe Pegs.** For approximately 10 miles of the Nullarbor Plain Section 3′ 6″ lengths of pipe of 3″ internal diameter were let into 4″ diameter holes which were bored in the rock by a waggon drill powered by an Atlas air compressor. (See Fig. 8). The pegs were fitted at 20° to the vertical leaning away from poles.
Stay wires were terminated on either strand grips or eyebolts fitted through ⅞″ diameter holes at the tops of pegs. This method suffered from two disadvantages. The boring of 4″ diameter holes was comparatively slow. It took 20 minutes to bore a hole to the required depth.
Waggon Drill Shafts were continually breaking and the average life of shafts was 20 holes. As shafts cost approximately £13 each, the cost of boring each hole was high.

Attachment to Poles. In most cases the stay wire was connected to the pole by means of thimbles threaded through the bolts connecting back plate to arm plate. Where extended back plates had been fitted previously, stays were connected to the thimbles of the extended back plates.

2. **Arming.** Two types of fittings were used for attaching arms to pole which as stated previously were almost exclusively of the tubular Siemens type.

(a) **Arm Plate** (Ser. 424/17) and **Back Plate** (Ser. 424/19)
(b) **Arm Seating** (Ser. 424/53) and **Back Plate** (Ser. 424/19)

The latter method has the advantage of not requiring a special crossarm boring. The arm is held with a single ⅝″ bolt centrally located rather than the 2-½″ bolts and off-set holes required with method (a).

Assembly work done at the Camp with the aid of the Impact Tools included:—
Fitting of—
(1) Back Plates, Arm Plates or Arm Seatings, and 43″ Braces to Arms;
(2) Transposition Spindles to Transposition Plates, and
(3) Stay wire was cut to length and terminated at one end around a thimble.

Trucks used by the Arming Parties were fitted with working platforms and so little ladder work was necessary. The working platforms were constructed of braced GI pipe uprights, with timber floor. Extensive bracing was necessary to prevent damage. The rough tracks with the resultant continual jolting and swaying soon revealed constructional weaknesses.

Difficulty was experienced initially in holding the heavy 108″ arm in position prior to the tightening of the nuts clamping the Back Plate to the Arm Plate or Arm Seating. To overcome this difficulty supporting cradles were constructed from 43″ braces with a "U" bend at each end. The top "U" was slipped over the existing 80″ cross arm and the bottom "U" held the new 108″ arm at an exact 28″ spacing below. Two cradles were required per pole.

3. **Wiring.**

(a) **Wire Running.** Two trucks were used simultaneously for the running of wires, one on either side of poles. Two wire barrows were positioned in the tray of each truck, and "running" proceeded with a lineman walking behind each truck and inserting crosses behind him on the ground as required at transposition poles. Each transposition inserted, of course, put a cross in the wires between the "transposition inserter" and the barrows. These crosses were removed each time a coil of wire was exhausted i.e. approximately three times per mile per barrow. One man following, piked both pairs of wires over cross arms.
The wire was run in sections of just over 1¼ miles for there were existing longitudinal stays on every 32 pole and it was found convenient to run the wire from one longitudinally stayed pole to the next.

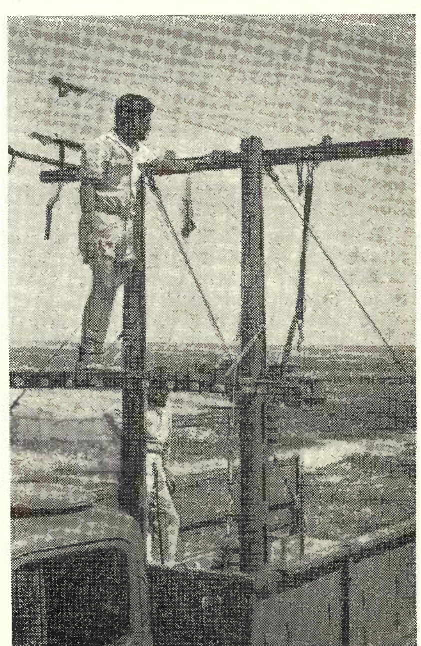


Fig. 9.—Wire Tensioning Truck.

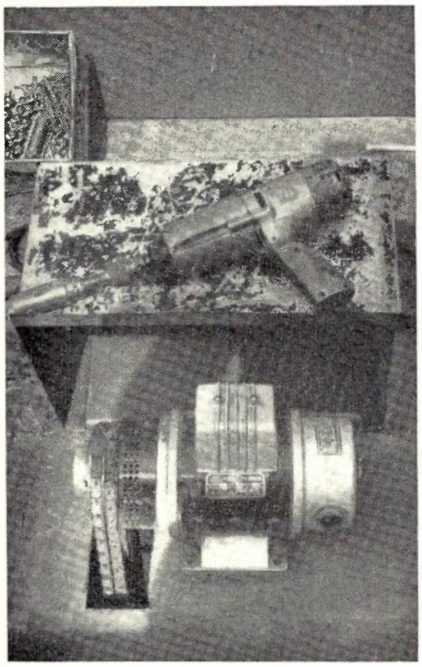


Fig. 10.—Electric Impact Tools and Generator used on Project.

(b) **Wire Tensioning Truck.** While the section of wire was being run out a Wire-Tensioning Truck was positioned behind the longitudinally-stayed pole. See Figure 9.

Each Wiring party was equipped with one such truck, which consisted of a 3-ton Commer vehicle with two parallel sectional-steel poles cut to the required length and fitted on the tray. A 108" Arm fitted across the top of the poles and a length of 8" diameter water pipe to which they were welded at the bottom braced the poles and in addition two U-bolts under which the water pipe was loosely clamped, enabled the whole assembly to be rotated down to the back of the truck in a travelling position.

When in the upright or working position the assemby was stayed with guys to the four corners of the tray. Turnbuckles in the guys permitted their tension to be regulated.

A working platform facilitated the attachment of buffalo grips to line wires. Ball bearing type pulleys, bolted to the arm, allowed the trace wires, which were attached to line wires via buffalo grips at one end and to the weight-supporting bracket at the other, to move with a minimum of friction. It was found desirable to provide a separation greater than 9" between pulleys on the arm to avoid the possibility of contact between the weights attached to adjacent wires.

(c) **Tensioning of Wires.** (1) After the 32 span section of wire had been run, most of the slack was eliminated by several linemen pulling in tandem. The remaining slack was pulled out and wires were prestressed one at a time by means of a hand winch attached to the tray of a Land Rover. (2) Weights were applied corresponding to the temperature.

(3) Two groups of two men with platform trucks commenced to arrange line wires around transposition plates and to "tie-in" commencing from the far or fixed end. The two groups "leap-frogged" between alternate poles. It was not practicable for the group nearer the weights to pull in transpositions or "tie-in" until the other group had completed its work. (4) Two methods of pulling wires around transposition plates were used:—

(a) Transposition Clamp was attached to the two insulators on the side of the plate distant from the weights and sufficient slack was pulled into the wires on the weight side by means of standard wire grips to enable the wires to be fitted around insulators.

(b) A lever-type tool originally deveoped in Tasmania was also used. Clamps were not employed. This method was quicker but it was possible to tighten the wires in the span distant from the weights with resultant overtensioning.

SPECIAL TOOLS AND LINE FITTINGS

1. **Impact Tools.**

Two line trucks were fitted with 800 watt 240 volt DC Davey Generators each of which was capable of operating two Electric Impact Tools. The Impact Tools greatly facilitated:—

(a) The tightening and loosening of nuts. (The motor is reversible).
(b) The reboring of cross-arms.

Attachments provided included:—

(a) Quick change chucks.
(b) Double depth socket spanners of various sizes fitted with adapters enabling them to be readily "snapped" into the quick change chucks.
(c) Augers (7/16", 9/16", 11/16" and 1-1/16") fitted with adapters as above.

It was found that the output of an "Arming" party fully equipped with Impact Tools was approximately twice that of a party using normal methods i.e. open-ended spanners and hand-braces. See Figure 10. These tools were effective both in assembly work in the camp and in the Arming Party. Additional equipment could have been used effectively.

2. **Strand Grips.**

Strand Grips provided a quick and simple means of terminating **7/16** stay wires. The grips are so constructed that stay wire can be readily pushed through in one direction, but is prevented from returning by sliding tapered jaws inside the strand grip body. Tension is applied to the stay wire by means of a hydraulic Stay-Tensioning Tool. Grips can be released with a special probe which forces the jaws apart and therefore permits the stay wire to be moved through them in either direction. See Figure 11.

The strand grips suffered from two disadvantages:—

(a) The price—approximately 14/- each.
(b) In some instances strand grips failed in service.

For these reasons their use was discontinued in favour of press-type sleeves.

3. **Press Type Stay Wire Sleeves.**

Press-type sleeves similar to standard line-wire sleeves were used for the termination of stay wires at the "pole-end" throughout and also at the "stay-rod or rail peg end" after the strand-grips were rejected. The sleeve is oval in section and accommodates the wire which forms the stay plus the running end, side by side. The sleeve can be fairly readily positioned at the neck of the thimble. Compression is effected with a tool slightly larger in all dimensions than the normal press-type tool. The sleeve termination is quick, neat and comparatively cheap—1/6 per sleeve.

MOTOR VEHICLES

As can be seen from Fig. 6 three types of vehicles were used:—

(a) Commer 3 ton.
(b) Morris 1 ton.
(c) Land Rover.

All vehicles had four-wheel drive and this facility proved to be a great asset particularly in the section between Malbooma and Ooldea. The usefulness of the Land Rover was clearly indicated and no doubt more use could be made of vehicles of this type on Departmental works. Most vehicles were new when supplied and this factor, coupled with the high standard of maintenance and the care exercised by drivers ensured that work was not held up through motor vehicle breakdowns.

MOTOR MAINTENANCE

The vehicles used, were hired from the Department of Supply, at a hire rate which provided for that Department to supply all petrol and oil and attend to all maintenance work. To facilitate the maintenance, the Department of Supply provided a portable workshop mounted on the tray of a "Commer" 3-ton 4 wheel drive vehicle. This truck, which was

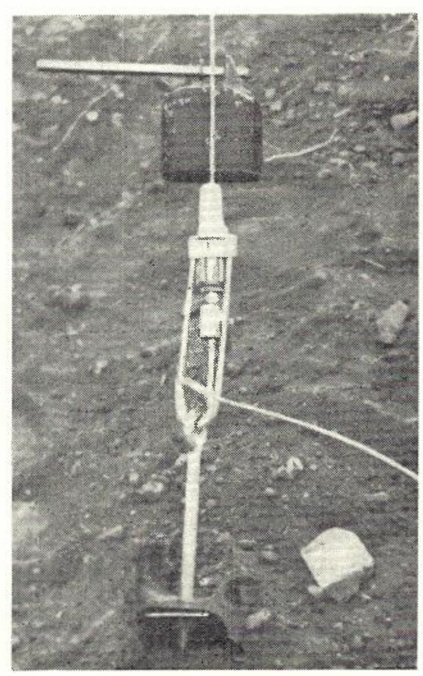


Fig. 11.—Tensioning Device used to Tension Stay when installing Strand Grip.

manned by a mechanic and assistant, moved from camp to camp and serviced vehicles as required. All routine maintenance and almost all other repairs were attended to in this manner. The fact that vehicles were promptly repaired and were never out of service for extended periods was an important contributing factor to the success of the project.

GENERAL

The first objective and the main target of all the initial planning and organisation of this work was achieved when the circuits were made available at Maralinga early in June, 1956. As discussed earlier, a number of special problems were encountered with the staying of the pole line and the completion of this work had to be delayed for a few months. As shown in Fig. 12, the staying work did not effectively commence until late October, which meant that the original plan to have the staying completed before the pole work was done had to be abandoned. As it happened this was not serious because the worst season for storms is between October and February, and the route was fully stayed by November, 1956.

The first working parties moved on to the job in August, 1955, which was approximately four months after the department was asked to undertake the work. Staff was increased in a series of steps to a maximum strength in January, 1956. The total cost was kept within the original estimate despite the unusual conditions and the fact that emphasis was on progress rather than cost.

The results achieved in this project were gratifying and justified the thorough preparation and initial detailed planning and organisation. The efficiency and effectiveness of the methods and plant used were proved so far as they were applied to the particular conditions encountered on this occasion.

This article has dealt more particularly with the urgent first phase of the total job of running two new circuits between Port Augusta in South Australia and Kalgoorlie in Western Australia. As soon as work was completed for Maralinga, Line Parties resumed on the East-West Line and continued through to the Western Australian border using the same organisation, mechanical aids and working techniques. At the Western Australian border Line Parties from Western Australia took over the work, also much of the plant and some of the staff, and the whole project, Port Augusta to Kalgoorlie, was completed in September, 1958.

During the planning and organising stages of the project, the authors of this article received much assistance and encouragement from Engineers in the Lines Section of the Engineer-in-Chief's office, particularly with regard to the provision of mechanical aids. Material and plant, as required, were ordered and supplied without any delay or hesitation. Many suggestions were received and as may be expected it was sometimes necessary to discard ideas which, because of the remoteness of the job and the very short completion time limitations, would have introduced risks which we were not prepared to take. The first responsibility was to complete the work and this was fully appreciated in all these preliminary discussions.

The final report on the Woomera to Watson project, which appeared as External Plant Information Bulletin No. 7 in November, 1957, has formed the basis of this article. The photos used have been selected from those taken by different departmental officers during the course of their visits and inspections on the job. The Supervising Draftsmen in the Adelaide Office and his staff have prepared the several sketches and diagrams, and during the work itself gave valuable assistance and always immediate service when their help was required.

METHODS OF NUMERICAL FILTER DESIGN – PART II

*E. RUMPELT, Dr.Ing.**

5. DETERMINATION OF IMAGE IMPEDANCES AND IMAGE ATTENUATION FROM INSERTION LOSS SPECIFICATIONS

The insertion loss specifications of a filter usually consist of a specified frequency range for the pass-band (or pass-bands) with maximum tolerable variations of insertion loss or a permissible minimum value of return loss, and a specified frequency range for the stop-band (or stop-bands) within which the insertion loss must remain above a certain minimum limit which may be a constant value or some function of the frequency. Between a pass-band and a stop-band there must always be a transition band for which usually no insertion loss is specified. The wider the transition band, the easier it is to comply with the insertion loss requirements in pass-band and stop-band.

5.1 Choice of Cut-off Frequencies

As a first choice the cut-off frequencies are put in the centres of the transition bands. If f_1 and f_2 are the two border frequencies of a transition band (for example, f_1 = end of pass-band, f_2 = beginning of stop-band) then the cut-off frequency should be tentatively made

$$f_c = \sqrt{f_1 f_2},$$

unless special reasons demand a different choice. Later on during the design it may become necessary to shift the cut-off frequency closer to the pass-band or closer to the stop-band, depending on the results of the design.

5.2 Determination of the Image Impedances from the Pass-Band Insertion Loss Requirements

The practical pass-band of a filter does not fully cover its theoretical pass-band owing to mismatch between the frequency-variable image impedances and the constant terminating resistances. The mismatch becomes large near cut-off frequencies because here the image impedances approach zero or infinity.

From the permissible maximum insertion loss variations or minimum return loss in the practical (that is specified) pass-band, the matching factor p_0 with the permissible maximum deviation from 1 can be calculated. This is done with the help of the formulae given in paragraph 4.

From p_0 and the required coverage of the theoretical pass-band the function of the image impedances can be determined. In practice there are three principal types of image impedances to choose from in the following order of complexity:

Constant-k image impedances m-derived image impedances Double-derived image impedances	mid-series and mid-shunt types.

As the required number of circuit elements for realizing these image impedances increases with their order of complexity, a first attempt is always made with the simplest type of image impedance.

The subsequent considerations apply to low-pass filters but they can, in an analogous way, be extended to any filter type.

5.2.1 **Constant-k Image Impedances of a Low-pass Filter**: The two types of constant-k image impedances of a low-pass filter are given by the following expressions:

(i) Mid-series type:

$$Z_{IT} = R_0\sqrt{1-\Omega^2} \quad \ldots\ldots\ldots \quad (5.1)$$

(ii) Mid-shunt type:

$$Z_{I\pi} = \frac{R_0}{\sqrt{1-\Omega^2}} \quad \ldots\ldots\ldots\ldots \quad (5.2)$$

R_0 = nominal image impedance
$\Omega = f/f_c$ = normalised frequency.

The two impedance functions are inverse to each other with respect to R_0:

$$Z_{IT}Z_{I\pi} = R_0^2$$

For a terminating resistance R and a permissible maximum value of p_0 (>1) the nominal image impedance is:

(i) Mid-series type: $R_0 = R\,p_0$

(ii) Mid-shunt type: $R_0 = R/p_0$

In both cases the upper limit of the practical pass-band is:

$$f_1 = f_c\sqrt{1-1/p_0^4} \quad \ldots\ldots\ldots\ldots \quad (5.3)$$

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5.2.2 m-Derived Image Impedance of a Low-Pass Filter: If the useful part of the theoretical pass-band does not cover a wide enough frequency band with constant-k image impedances, an attempt must be made with m-derived image impedances.

The **mid-series** type of m-derived low-pass filter image impedance has the following function:

$$Z_{ITm} = R_o \frac{\sqrt{1 - \Omega^2}}{1 - \Omega^2 (1 - m^2)} \quad \ldots\ldots (5.4)$$

m is the factor of the m-derivation. The function has a pole (value of infinity) in the stop band at the normalised frequency:

$$\Omega_\infty = \frac{1}{\sqrt{1 - m^2}} \quad \ldots\ldots (5.5)$$

and the image impedance function Eq. (5.4) may be written with Ω_∞ as a parameter instead of m :

$$Z_{ITm} = R_o \frac{\sqrt{1 - \Omega^2}}{1 - \Omega^2/\Omega^2_\infty} \quad \ldots\ldots (5.6)$$

For values of m < 0.7 or of Ω_∞ < 1.4 the functions of Eqs. (5.4) and (5.6) have in the pass-band a minimum, R_o, at $\Omega = 0$, and increase with rising frequency to a maximum, Z_{max}, at the frequency

$$\Omega_m = \sqrt{\frac{1 - 2m^2}{1 - m^2}} = \sqrt{2 - \Omega^2_\infty} \quad (5.7)$$

They then decrease to zero at the cut-off frequency $\Omega = 1$, reaching their minimum value R_o again at the frequency:

$$\Omega_1 = \frac{\sqrt{1 - 2m^2}}{1 - m^2} = \Omega_m \Omega_\infty \quad \ldots (5.8)$$

The impedance maximum is:

$$Z_{max} = \frac{R_o}{2m\sqrt{1 - m^2}} = \frac{R_o \Omega^2_\infty}{2\sqrt{\Omega^2_\infty - 1}} \quad \ldots (5.9)$$

If the nominal image impedance, R_o, is so chosen that the geometric mean of R_o and Z_{max} is equal to the termination resistance R, then the theoretical pass-band is most efficiently used and Ω_1 is the limit of the practical pass-band. Within this band the maximum value, p_o, of the matching factor is:

$$p_o = \frac{R}{R_o} = \sqrt{\frac{\Omega_\infty}{2m}} \quad \ldots\ldots (5.10)$$

For a given value of p_o the appertaining values of m and Ω_∞ can be calculated with the following formulae:

$$m^2 = \tfrac{1}{2} (1 - \sqrt{1 - 1/p_o^4}) \quad \ldots\ldots (5.11)$$

$$\Omega^2_\infty = 2p_o^4 (1 - \sqrt{1 - 1/p_o^4}) \quad \ldots\ldots (5.12)$$

and with Eq. (5.8) the practical limit of the pass-band can be calculated.

The **mid-shunt** type of m-derived low-pass filter image impedance is inverse to the mid-series type with respect to R_o

$$Z_{I\pi m} \; Z_{ITm} = R_o^2$$

and its function can therefore be obtained from Eq. (5.4) or (5.6) by interchanging the expressions in numerator and denominator.

The best use of the theoretical pass-band is made for $R_o = R\,p_o$ where again the relation between p_o, m and Ω_∞ is given by Eqs. (5.10), (5.11) and (5.12). The practical pass-band limit is calculated with Eq. (5.8).

If the filter is to be built in a ladder structure, the bulk of it will be a chain of matched T– or π– sections with constant-k image impedances. To get m-derived image impedances at the filter terminals, matching sections must be connected to the ends of this chain of sections, which at one side have the constant-k image impedance of this chain, whereas at the other side they have the required m-derived image impedance. Such matching sections are produced by cutting an m-derived T– or π– section in two halves. The image attenuation of these matching sections which have an attenuation peak at Ω_∞, must be taken into account during the subsequent image attenuation design of the filter.

5.2.3 **Double-Derived Image Impedances of a Low-Pass Filter:** If the coverage of the theoretical pass-band by the practical pass-band is still not adequate with an m-derived image impedance, a double-derived image impedance must be used.

The **mid-series** type for low-pass filters has the following function:

$$Z_{ITmm}' = R_o \frac{\sqrt{1-\Omega^2}\,[1-\Omega^2(1-m^2)]}{1 - \Omega^2(1 - m^2m'^2)} \quad (5.13)$$

m and m' are the factors of the double-derivation : m of the first derivation, m' of the second derivation.

The image impedance function has a pole at frequency $\Omega_{\infty 1}$ and a zero at a frequency $\Omega_{\infty 2}$(> $\Omega_{\infty 1}$),both of which are in the stop-band and are given by:

$$\Omega_{\infty 1} = \frac{1}{\sqrt{1 - m^2m'^2}}$$

$$\Omega_{\infty 2} = \frac{1}{\sqrt{1 - m^2}} \quad \ldots\ldots (5.14)$$

If the double-derived image impedance is produced by matching sections connected to the ends of a ladder filter composed of T– or π– sections with constant-k image impedances, then the two matching sections have together an image attenuation which is equivalent to that of two m-derived full sections with attenuation peaks at $\Omega_{\infty 1}$ and $\Omega_{\infty 2}$ given by Eq. (5.14). This image attenuation must be taken into account during the subsequent image attenuation design of the main part of the filter.

In the pass-band the double-derived image impedance function of Eq. (5.13) has for properly chosen values of m and m' two maxima of equal value, R_o, one at $\Omega = 0$, the other one fairly close to the cut-off frequency. Between these two maxima is a minimum whose value, Z_{min}, depends of m and m'. Above the second maximum the image impedance decreases rapidly to zero at the cut-off frequency, passing the value Z_{min} again at a frequency Ω_1 which is the practical limit of the pass-band. In the frequency interval from 0 to Ω_1 the image impedance varies twice between the maximum R_o and the minimum Z_{min}, and for best match to a constant resistance R within this interval the maximum value p_o of the matching factor is:

$$p_o = \sqrt{R_o/Z_{min}} \text{ for } R_o = Rp_o$$

In the book by Guillemin (quoted in paragraph 1.6) on page 351 (1935 edition), Fig. 132, the relation is given between m and the percentage of impedance variation around an average value, and also between m and the percentage of the theoretical pass-band which is not covered. Fig. 133 on the same page gives the corresponding relations for m'.

The **mid-shunt** type of double-derived low-pass filter image impedance is again inverse to the mid-series type with respect to R_o and has a function which can be obtained from Eq. (5.13) by interchanging the expressions in numerator and denominator. Under equivalent conditions to the mid-series type, the mid-shunt image impedance varies in the pass-band in the interval from 0 to Ω_1 between a minimum value R_o and a maximum value Z_{max}, and for best match to a constant resistance R, the maximum value p_o of the matching factor is:

$$p_o = \sqrt{Z_{max}/R_o} \text{ for } R_o = R/p_o.$$

5.3 **Calculation of the Required Minimum Image Attenuation**:

With the image impedances at the filter terminals established, the required image attenuation in the stop-band can be calculated with the help of Eq. (4.15) in the general case, or with Eq. (4.16) in the case of symmetrical and antimetric filters.

Considering the two latter filter types, and disregarding the basic loss A_t in antimetric filters because it has no influence on the loss discrimination between pass-band and stop-band, Eq. (4.16) yields:

$$\alpha_{min} = A_{Lmin} + 6 - 20 \log \frac{1 + p^2}{2p} \quad \ldots\ldots (5.15)$$

where A_{Lmin} is the specified minimum insertion loss in the stop-band.

The matching factor p can be calculated from the image impedance function and the terminating resistance:

$$p = \left|\frac{Z_I}{R}\right|$$

For **constant-k** image impedances of low-pass filters the matching factor in the stop-band ($\Omega > 1$) is as follows:

Mid-series type:

$$p = p_o \sqrt{\Omega^2 - 1} \text{ with } p_o = \frac{R_o}{R} \quad (5.16)$$

Mid-shunt type:

$$p = \frac{1}{p_o\sqrt{\Omega^2 - 1}} \text{ with } p_o = \frac{R}{R_o} \quad (5.17)$$

With equal parameters p_o the reflection loss function Eq. (4.17) yields in both cases identical loss values for identical values of Ω, i.e. like in the pass-band, the reflection loss in the stop-band is the same for mid-series and mid-shunt type image impedances.

For a quick evaluation of Eq. (5.15) it is advantageous to have the reflection loss A_r as a function of Ω in a graph or in a table (as calculated with Eqs. (5.16) and (4.17) for a series of values of p_o (e.g. from 1.0 to 1.4 in steps of 0.1).

For **m-derived** low-pass filter image impedances the matching factor in the stop-band is:

Mid-series type:

$$p = \frac{1}{p_o} \frac{\sqrt{\Omega^2 - 1}}{|1 - \Omega^2/\Omega^2_\infty|} \text{ with } p_o = \frac{R}{R_o} \quad (5.18)$$

Mid-shunt type:

$$p = p_o \frac{|1 - \Omega^2/\Omega^2_\infty|}{\sqrt{\Omega^2 - 1}} \text{ with } p_o = \frac{R_o}{R} \quad (5.19)$$

In both cases the value of p_o giving the best coverage of the theoretical pass-band is obtained from Eq. (5.10) and the reflection loss values are then identical in both cases for equal Ω– values.

The calculation of the minimum image attenuation with Eq. (5.15) is again facilitated if the reflection loss function Eq. (4.17) is evaluated as a function of Ω with Eq. (5.18) or (5.19) and tabulated for a series of properly selected Ω- and Ω_∞– values.

For **double-derived** low-pass filter image impedances the procedure is analogous to above. The matching factor is calculated from Eq. (5.13) where R_o is replaced by p_o (slightly larger than 1.) A tabular or graphical representation of A_r as a function of Ω is not justified as it is too involved. The evaluation is carried out by first calculating p and then reading A_r from a graph which represents A_r as a function of p.

5.4 Design of Image Attenuation Characteristic

The image transfer constant of a composite filter, consisting of matched sections connected in tandem, is the sum of the image transfer constants of the individual sections:

$$\theta = \sum_{s=1}^{n} \theta_s = \alpha + j\beta$$

where $\alpha = \sum_{s=1}^{n} \alpha_s \qquad \beta = \sum_{s=1}^{n} \beta_s$

In the case of a ladder filter, the sections have T– or π– structures and are constant-k or m-derived with constant-k image impedances at their terminals. The purpose of m-derivation, as far as the image attenuation is concerned, is to get more flexibility of the image attenuation characteristic of a section, without altering its image impedances. A constant-k low-pass filter section, for example, has one attenuation peak at infinite frequency. By m-derivation this peak can be shifted to any frequency between the cut-off frequency and infinite frequency. The image attenuation characteristic is correspondingly changed.

The image transfer constant of a halved T– or π– section with Z_a as its series arm impedance and Z_b as its shunt arm impedance is, according to Eq. (2.2), given by the function:

$$\theta_{hs} = \coth^{-1} \sqrt{\frac{Z_a + Z_b}{Z_a}} \quad (5.20)$$

After mid-series or mid-shunt m-derivation the function of the image transfer constant becomes:

$$\theta'_{hs} = \coth^{-1} \frac{1}{m} \sqrt{\frac{Z_a + Z_b}{Z_a}} \quad (5.21)$$

5.4.1 **The Image Transfer Function of a Low-Pass Filter:** When a low-pass filter section is formed by m-deriving a constant-k low-pass filter T– section with the inductances L/2 as series arms and the capacity C as shunt arm, or by m-deriving a corresponding π– section with the inductance L as series arm and the capacities C/2 as shunt arms, then its image transfer constant is, as calculated with Eq. (5.21),

$$\theta_s = 2\coth^{-1} \frac{1}{m} \sqrt{1 - \frac{4}{\omega^2 LC}} \quad (5.22)$$

Its cut-off angular velocity is given by:

$$\omega_c = 2\pi f_c = \frac{2}{\sqrt{LC}}$$

With the normalised frequency $\Omega = f/f_c$ the image transfer constant is:

$$\theta_s = 2 \coth^{-1} \frac{1}{m} \sqrt{1 - 1/\Omega^2} = 2 \coth^{-1} \frac{\sqrt{1 - 1/\Omega^2}}{\sqrt{1 - \Omega^2_\infty}} \quad (5.23)$$

In the last part of this formula the relation of Eq. (5.5) is used for expressing m, namely:

$$m = \sqrt{1 - 1/\Omega^2_\infty} \quad (5.24)$$

For frequencies below the cut-off frequency the expressions in Eq. (5.23) become imaginary, that is the image attenuation is 0 and the image transfer constant is:

$$\theta_s = j\beta_s$$

with $\beta_s = 2 \text{ ar cot} \frac{1}{m} \sqrt{1/\Omega^2 - 1}$ .. (5.25)

For frequencies above the cut-off frequency the expressions behind the ($\coth^{-1}$) – sign are real and smaller or larger than 1. In the first case, that is, in the interval $1 < \Omega < \Omega_\infty$, θ_s is complex with:

$$\alpha_s = 2 \tanh^{-1} \frac{1}{m} \sqrt{1 - 1/\Omega^2},$$

$$\beta_s = \pi \quad (5.26)$$

In the second case, that is in the interval $\Omega_\infty < \Omega < \infty$, θ_s is real with:

$$\alpha_s = 2 \coth^{-1} \frac{1}{m} \sqrt{1 - 1/\Omega^2},$$

$$\beta_s = 0 \quad (5.27)$$

At $\Omega = \Omega_\infty$, $\alpha_s = 2 \coth^{-1}(1) = \infty$ that is, there is an attenuation peak. At $\Omega = \infty$, $\alpha_s = 2 \coth^{-1} 1/m$, that is the more the attenuation peak approaches the cut-off frequency ($\Omega_\infty \rightarrow 1$, $m \rightarrow 0$), the smaller becomes the attenuation at large frequencies.

5.4.2 **Construction of the Image Attenuation Characteristic of a Composite Low-Pass Filter:** By evaluating Eqs. (5.26) and (5.27) as functions of Ω for a series of judiciously selected values of Ω_∞ and tabulating the result or plotting it on graph paper, an aid is obtained for building up the image attenuation characteristic of a composite low-pass filter from the image attenuations of the individual sections. Graphs of this sort can be found in text books on filter design. A very elaborate table is in the book by Storer listed in paragraph 1.6.

In order to find an image attenuation characteristic which envelops the required minimum attenuation curve as closely as possible, a likely number of filter sections is chosen and for each section an attenuation peak frequency is selected, preferring values for which there are curves in the graph or which are listed in the table. By adding up at a series of frequencies all the attenuation values contributed by the various sections, the image attenuation characteristic of the total filter is obtained. A comparison of this characteristic with the required minimum curve shows if and how the attenuation peak frequencies of the various sections have to be shifted and, possibly, the number of sections altered to get the best possible fit. This trial and error process may have to be repeated several times. By fulfilling the image attenuation requirements with a minimum number of sections the composite filter can be built with a minimum number of components.

BOOK REVIEWS

RADIO, VOLS. I, II, III.

John D. Tucker & Donald Wilkinson. English Universities Press.

Vol. 1 pp. 177 1957 (reprinted) Aust. Price 14/-.

Vol. 2 pp. 252 1957 (reprinted) Aust. Price 19/9.

Vol. 3 pp. 249 1956 Aust. Price 23/6.

Chapter Headings

Vol. 1. Electricity and Magnetism, Radio, Communication, Aerials & Tuning, Components and Valves, A.F. Amplifiers, R.F. Amplifiers, Power Supplies, Oscillators, Modulation and Detection, Receivers, Measurements in Radio Work, Books for Further Study.

Examples, Numerical Answers, Index.

Vol. 2. R.F. Coils and Capacitors, Electronic Tubes, A.F. Amplifiers, R.F. Amplifiers, Oscillators, Power Supplies, Transmitters, Receivers, Measurements, Acoustic Equipment, Directional Aerials, Radio Communication, Index.

Vol. 3. Aperiodic Amplifiers, R.F. Power Amplifiers, V.H.F. & U.H.F. Amplifiers, Oscillators, Modulation, Radio Transmitters, Aerials and Transmission Lines. Transmission of Electromagnetic Waves, Receivers, Measurements, Power Supplies, Direction Finding, Principles of Picture Transmission Index.

Review

This series of books on Radio has been written specially for students studying for the Examinations in Radio held by the City and Guilds of London Institute and therefore follows very closely the Radio Syllabus of that Institute.

The subject matter is presented in stages appropriate to the successive years Radio I, Radio II, and Radio III of the City & Guilds' courses, and for this reason some portions of the subject matter are repeated in several parts of the series.

The style used by the authors is clear and precise. The volumes are well indexed, generous use is made of diagrams, and standard, clearly understood conventions, terminology, abbreviations and symbols are used in both text and diagrams.

Typical questions, many of which are provided with specimen answers, are included at the end of chapters. Numerical answers are provided for all questions requiring such answers and for which complete specimen answers are not given.

A minor misprint appears in the answer to Question 6, at the conclusion of Chapter 9 Volume III (bottom of page 170, Vol. III). The answer given as 6.2 x 10^{-8} volts should read 6.2 x 10^{-6} volts.

The volumes are well printed on good quality paper and are very well bound. The use of a conveniently small page size will assist students who desire to carry the volumes.

The reviewer is of the opinion that the authors have achieved their aim to present a clear explanation of radio engineering phenomena for students.

Although aimed at students taking the British City & Guilds examination it is felt that the volumes will be of great value to students presenting themselves for the Technician, Telecommunication, Radio, and Senior Technician Telecommunication, Radio, Examinations of the P.M.G.'s Department.

E.J.W.

A COMPENDIUM OF MATHEMATICS AND PHYSICS

D. S. Meyler and O. G. Sutton, 1958
English Universities Press Ltd., pp. 384
—Australian price 46/6.

In this book, the authors have set out to meet the needs "of two classes of readers: research workers who require a reference book in which they can look up a theorem or a formula to find out in what condition it holds, and how to apply it, and undergraduates or technical students who, as an aid in preparing for examinations or for other reasons, want a summary of what is known in various branches of Mathematics and Physics".

The first seventy per cent. of this useful book is by Dorothy S. Meyler, and is devoted to 22 chapters and 8 tables relating to pure mathematics; the subjects range from arithmetic, theory of equations and determinants, through plane, spherical and solid geometry, differential and integral calculus, to differential equations and a final brief chapter on statistics. There are tables of limits, derivatives and integrals, as well as Bernoulli's and Euler's numbers and sums of infinite series.

This section of the book is no mere collection of facts; there are explanations in support, and all but seven of the chapters contain diagrams of commendable clarity. Comprehensive though this section is, it would benefit by the addition of an illustrated chapter on curves and their equations.

The Physics section, by Dr. Sutton, is contained within just over one hundred pages and fifteen chapters, covering a wide range of subjects. In addition to the basic fields of mechanics, heat, light, sound, magnetism and electricity, there are separate (though short) chapters on elasticity, surface tensions, viscosity, electronics and atomic physics. For good measure, a chapter on meteorology is provided. (The author is Director-General, Meteorological Office, London).

Diagrams are sparse in this section of the book, where their illustrative value would perhaps be even greater than in the mathematical section; only two chapters contain diagrams. In the Electricity and Magnetism chapter, it is pleasing to note a table of comparison between m.k.s. and c.g.s. systems of units. Many readers will undoubtedly have been raised on an exclusive diet of c.g.s. units, or alternatively, were nurtured on a mixture of c.g.s. and m.k.s. units at a period when the latter were not quite respectable; the author's dual presentation of all appropriate formulae in both systems is appreciated by this reviewer, and should prove valuable to a large number of readers.

Two pages of basic physical constants and conversion factors complete this section of the book, and a separate index is provided for each section.

A compendium is, by definition, an abridgement; and this book is a masterpiece of condensation. Its scope is broad, rather than deep, and the specialist should look elsewhere (indeed, he is so bidden by footnote in some chapters in the physics section) for more esoteric data.

Because of its breadth, and because the information it yields can generally be found only after diligent search in many other books, this book can be recommended for the student and for the telecommunication engineer's bookshelf, where breadth can frequently be accommodated with advantage. The printing and presentation are excellent and (minor, but important point) the paper has a fine smooth texture, yet does not dazzle the reader by reflection from an ill-sited lamp!

The retail price of this book in England is 25/- sterling, but the Australian reader must pay 46/6.—R.G.K.

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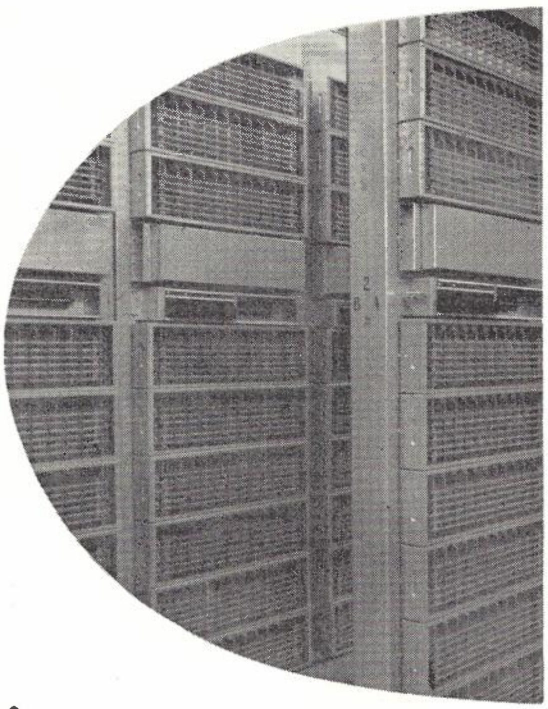

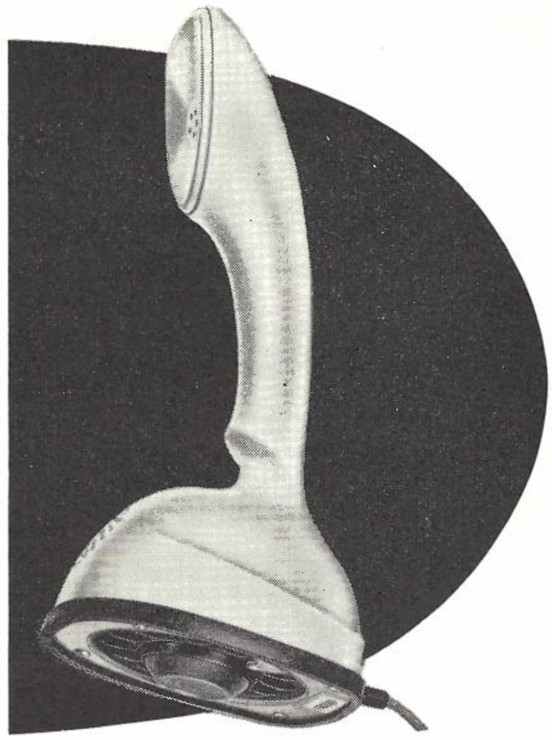

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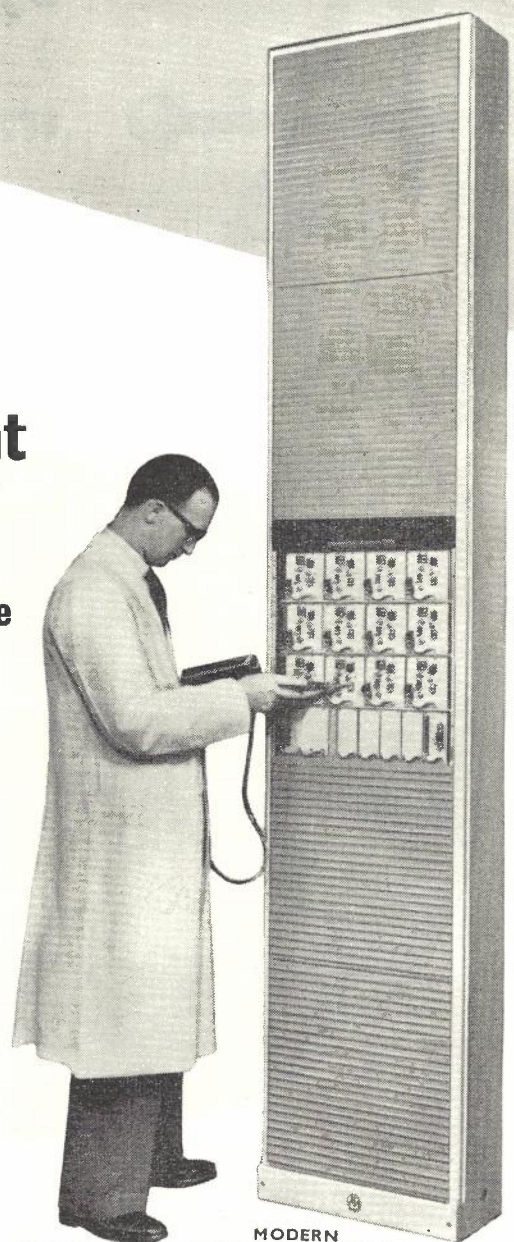

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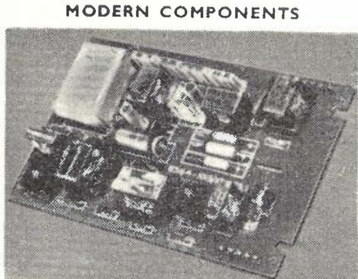

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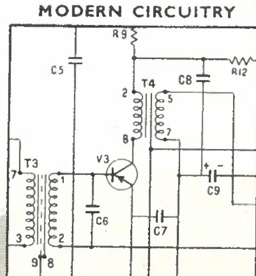

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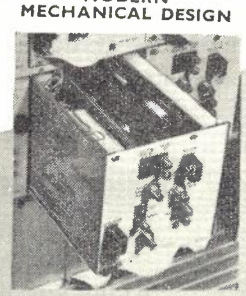

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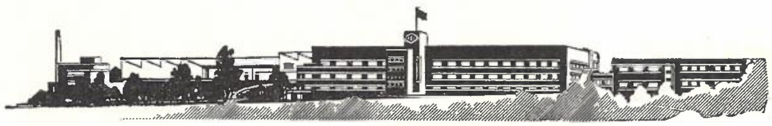

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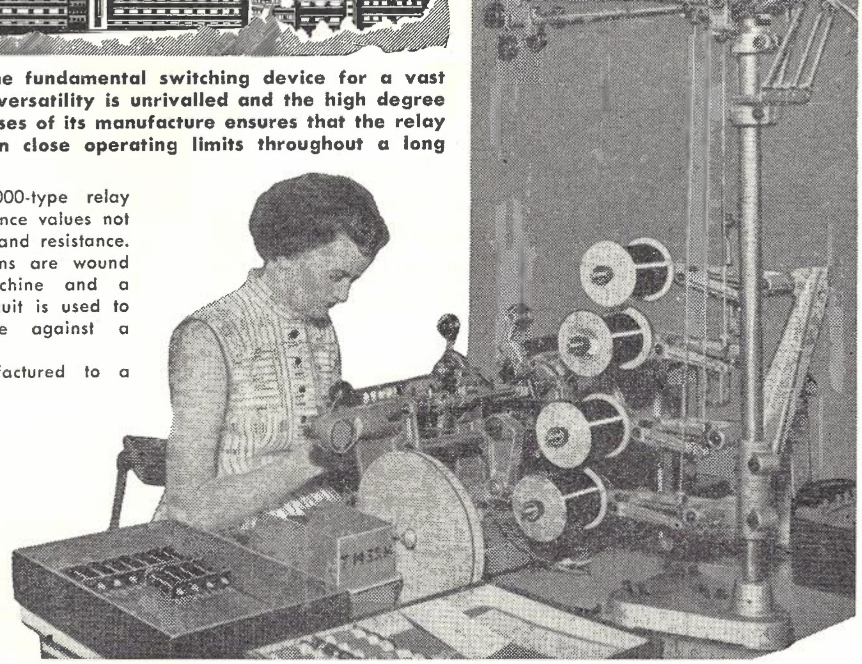

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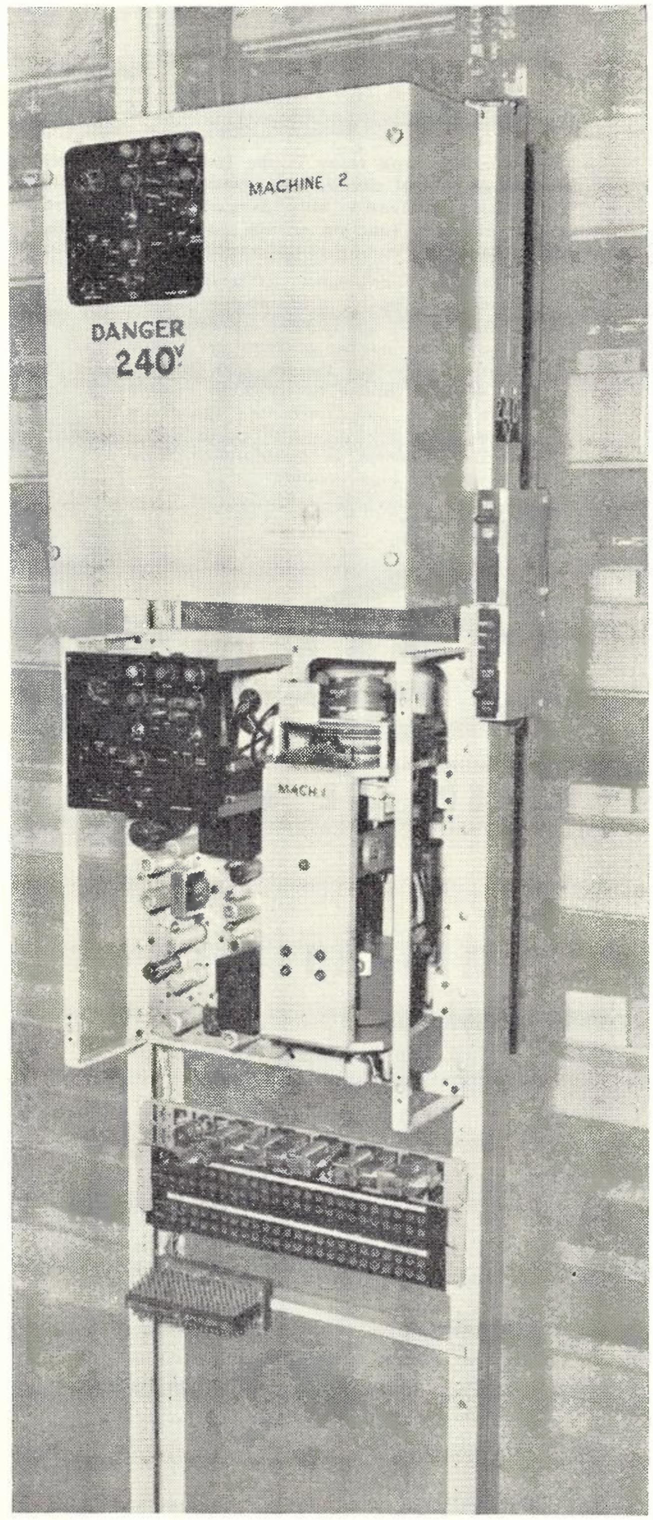

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