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The Reliability of Microwave Radio-Relay Systems

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U.D.C. 621.396.65.004.6

Failures of microwave radio-relay systems are to some extent predictable, and, in most instances, the necessary high degree of reliability can most economically be obtained by the use of complete redundant channels—usually referred to as protection channels—which can be brought into service automatically when required. The degree of reliability given by systems incorporating such protection channels is discussed, taking into account the possible effects of failure of the switching equipment or of common equipment, as well as the effects of human error and maintenance work.

INTRODUCTION

The reliability of a telecommunications transmission system is usually expressed as the proportion of time, taken over a sufficiently long period, for which the system has been available for service. The availability of the system in the future can be predicted from a knowledge of the reliability, provided that it can be assumed that the behaviour of the system will remain unaltered during the period concerned. This assumption is usually justifiable for an established equipment that is not approaching the end of its life. The future availability for service of another, similar, equipment may also be forecast, provided that the conditions of environment and maintenance are also similar, though such forecasts may be inaccurate during the early life of a newly-installed system.

Failures may occur due to causes which do not accord with previous experience, though such failures are rare in well-engineered systems. The unpredictable nature of failures of this kind places them beyond the scope of normal reliability-assurance techniques, and other precautions, such as the provision of redundancy within a network or the provision of strategic reserves of equipment, are taken.

Predictable failures on microwave radio-relay systems arise from equipment failures, human errors and fading. Fading accounts for only a very small amount of lost-circuit time in well-planned systems, and it will not be considered further in this article.

Equipment Failures

It is inherent in even well-designed electronic equipment that it is liable to failure during the course of its useful life. This tendency to failure can be controlled either by ensuring that the equipment has a very high intrinsic reliability, or by providing stand-by equipment that can be brought into service after a failure. Extremely reliable equipment is very costly, and it can be used economically only in circumstances where repair is either impossible or very expensive. In more commonplace situations it is less costly to employ equipment made to good commercial standards, and then to obtain any required improvement of reliability by the provision of sufficient redundant equipment. In radio-relay systems redundant equipment is provided in the form of complete stand-by channels (protection channels), which are automatically brought into service when required, and also as shelf-spares of plug-in assemblies which permit the rapid replacement of a defective unit.

Failures due to Human Error

There are at least prima facie grounds for supposing that the frequency with which mistakes that lead to channel failure are made by skilled maintenance staff depends upon the amount of work that they are required to perform on the equipment. This in turn depends upon the intrinsic reliability and stability of the equipment. It is thus possible to regard human-error failures of this type as an aspect of equipment reliability, and to take account of such failures in the value assigned to the reliability of the equipment.

There is a second class of failure due to human error that arises from the casual intervention of non-skilled persons. The incidence of faults of this type depends upon how often stations are visited by persons other than the maintenance staff, and is, in the long term, unpredictable.

PROTECTION CHANNELS

Most microwave radio links are provided with one or two protection channels, together with an automatic channel-switching system. Fig. 1 shows in outline a typical arrangement, in which six channels are used to provide four working channels and two protection channels. One switching system of this kind has been described in detail in this Journal.*

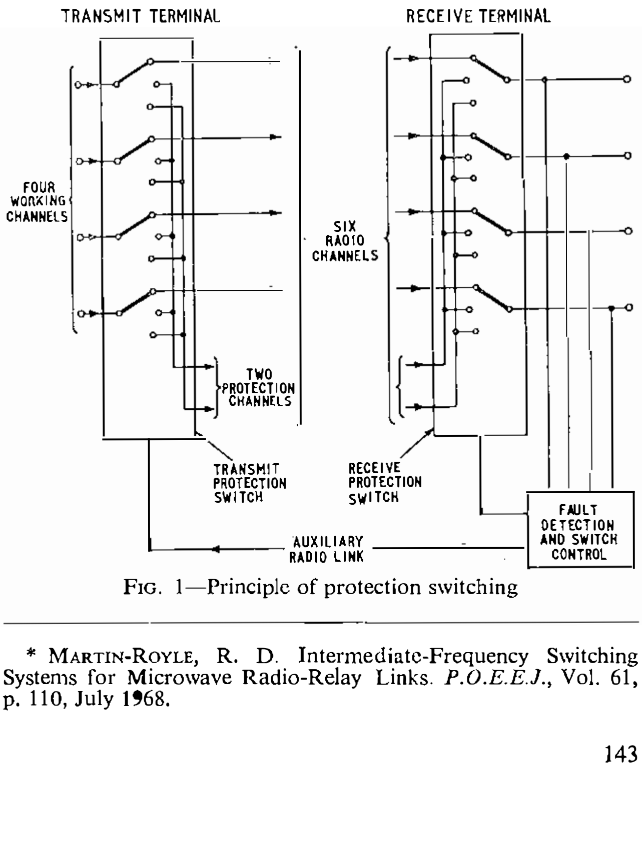


FIG. 1—Principle of protection switching

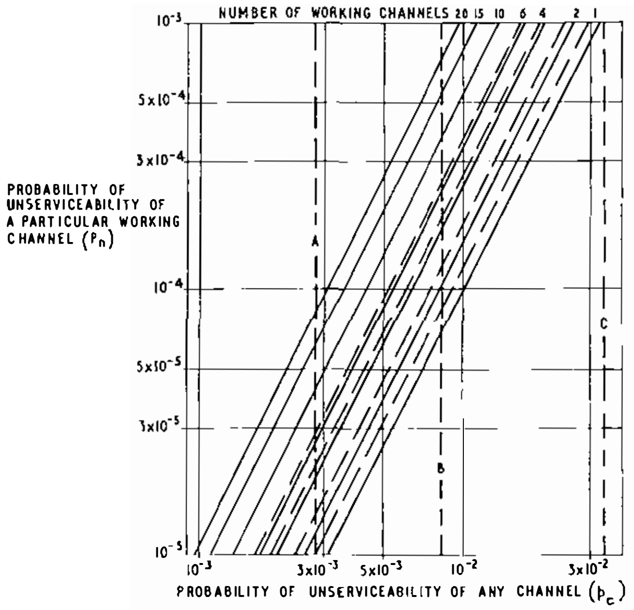
† Development Planning Division, Telecommunications Headquarters.

* MARTIN-ROYLE, R. D. Intermediate-Frequency Switching Systems for Microwave Radio-Relay Links. *P.O.E.E.J.*, Vol. 61, p. 110, July 1968.

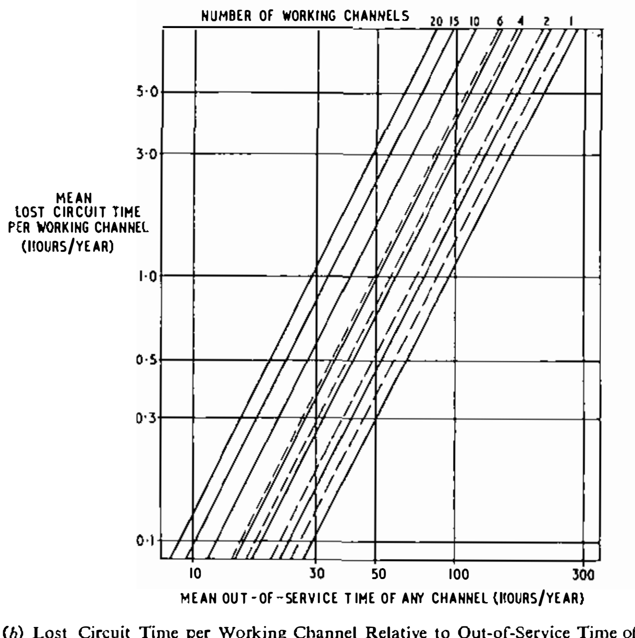
The improvement that may be obtained in the reliability of a system through the use of protection channels depends on the number and the reliability of the protection channels, and on the number of working channels protected. The extent of the improvement can be estimated, provided that it is possible to assume that failures occur randomly and independently in all the channels of the system. This assumption requires that the equipment should be free from design weaknesses which lead to non-random, or systematic, failures, and also that faults that occur simultaneously on more than one channel from a common external cause should be considered separately.

In a system having a total number of channels m, each of which has a probability that it will be unserviceable at any time of p_c, the probability P that n channels will be simultaneously unserviceable is given by

$$P = p_c^n(1 - p_c)^{(m-n)} \frac{m!}{(m-n)!\,n!}.$$

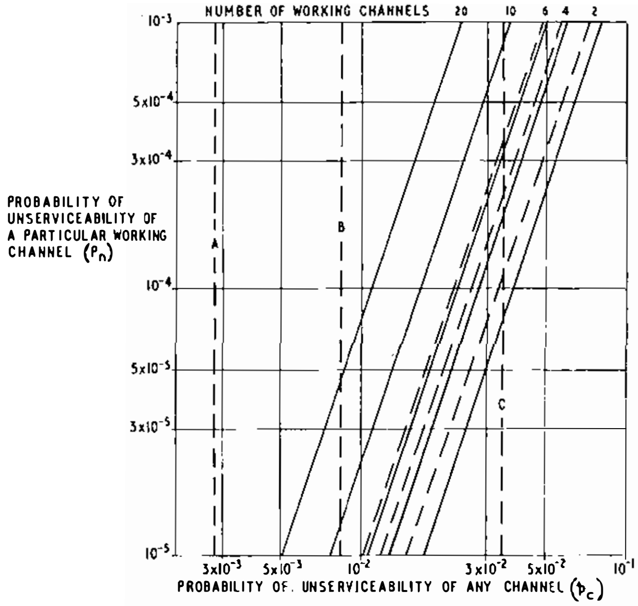


(*a*) Probability that a Particular Channel will be Unserviceable



(*b*) Lost Circuit Time per Working Channel Relative to Out-of-Service Time of Any Channel
—— $p_s = 0$ ---- $p_s = 0{\cdot}5p_c$

FIG. 2—Reliability of systems having one protection channel



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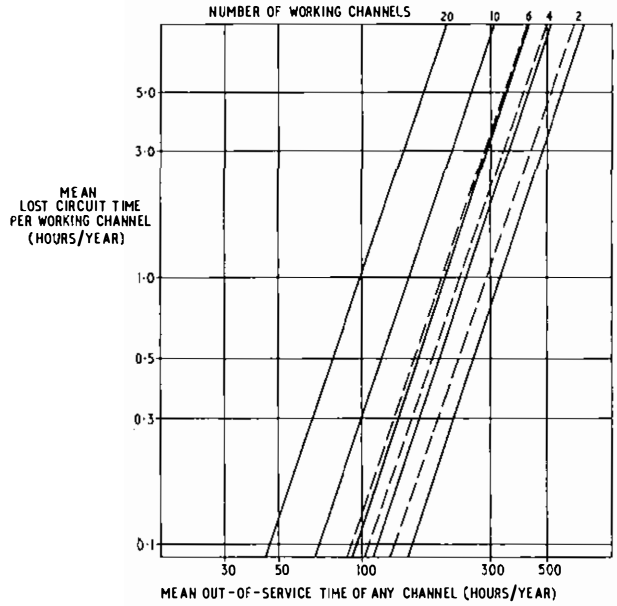


(*b*) Lost Circuit Time per Working Channel Relative to Out-of-Service Time of Any Channel
—— $p_s = 0$ ---- $p_s = 0{\cdot}5p_c$

FIG. 3—Reliability of systems having two protection channels

The system will be unserviceable in some degree whenever n exceeds the number of protection channels available, r. The total probability that one or more working channels will be out of service is thus $\sum_{n=r+1}^{m} P$. Fortunately, in practice p_c is a small number, and the value of P for $n = (r + 1)$ is usually an acceptable approximation. This value of P is the probability that any one working channel will be unserviceable. The probability that a particular working channel will be unserviceable is

$$P_n = \frac{P}{m - r}.$$

Fig. 2 and 3 show P_n plotted against p_c for systems having one and two protection channels, respectively.

Use of Protection Channels to Carry Occasional Traffic

Some protection channel-switching systems permit access to protection channels when they are not otherwise in use, so that the protection channels may be used to transmit traffic of a kind that can tolerate interruption. The probability that a channel will be unavailable for use in this way is the sum of the probabilities that it will be required to replace a failed channel, and that it will itself be unserviceable.

The protection channel of a single-protection-channel system will be unavailable for external use with a probability of

$$(m - r + 1)p_c,$$

and the second-choice protection channel of a two-protection-channel system will be unavailable with a probability

$$p_c + \frac{(m - r)(m - r - 1)}{2} p_c^2.$$

The second term of this expression is negligibly small compared with the first, and, for practical purposes, the second-choice protection channel has the reliability of an unprotected channel.

Biassed Protection-Channel-Switching Systems

Switching systems are available for use on single-protection-channel radio systems in which one or more working channels may be given priority of access to the protection channel. Such switching systems have the effect of distributing the total probability of unserviceability of the system unequally between the working channels.

If a single channel is given priority over all other channels the probability of unserviceability of that channel becomes that of a system which has one working and one protection channel. If the remaining working channels are all of equal rank then the remainder of the total probability of unserviceability of the system is equally distributed between them. Thus, a system of seven working and one protection channels in which the probability of unserviceability of an unprotected channel is 10^{-2} can be arranged to have one working channel with a probability of unserviceability of 10^{-4} and six of $4 \cdot 5 \times 10^{-4}$. Alternatively, if all seven channels were ranked in descending order of priority of access to the protection channel then the probability of unserviceability of the channel ranked seventh would be 7×10^{-4}, while that of the remaining channels would be uniformly distributed between 10^{-4} and 7×10^{-4}.

FAILURE OF SWITCHING SYSTEM

As is shown in Fig. 1, the replacement of a defective channel by a protection channel is made by two switches, one at each end of the system, which are linked by a signalling system and are operated by switch-control equipment in response to signals from fault-detection equipment. This complex of equipment, which will be referred to as the switching system, is liable to failure, but the equipment is so designed that the only failure mode to have significant probability of occurrence in practice is the non-operation of the switches in response to the appropriate stimuli. "Fail-safe" techniques are used to ensure that the switch positions remain unaltered under any foreseeable fault condition of the switching system.

Thus, failure of the switching system does not, of itself, cause loss of service on any working channel, and neither does the simultaneous failure of the switching system and a protection channel. Loss of service on a working channel due to a switching-system failure occurs only when there is a failure of that channel at a time when the switching system is already out of service.

The probability that a particular working channel and the switching system will be unserviceable at the same time is $p_s p_c$, where p_s is the probability that the switching system will be unserviceable. However, this probability includes occasions when failure of the working channel occurs before failure of the switching system, so that a change to a protection channel (which requires a negligibly short time) is not prevented. As there is an equal chance that either failure will be the first to occur, the probability that a working channel will be unserviceable due to failure of the protection switching system is

$$P_s = 0 \cdot 5 p_s p_c$$

The reliability of switching systems is likely to be better than that of channel equipment, partly because the equipment of the auxiliary radio-link that is used for the transmission of switching-control signals is much simpler than that of the main channels, and partly because the control and switching equipment benefits from the redundancy of equipment necessary to obtain the "fail-safe" facility. Fig. 2 shows how the reliability of working channels is affected by a switching system in which the probability of unserviceability is one half of that of a radio channel.

In systems having two protection channels it is usual to duplicate the auxiliary radio-link, but not the remainder of the switching system. The effect that this has on the overall reliability of the switching system is to change the probability of unserviceability from p_s to p_s^a, where a has a value between 1 and 2 depending on the proportion of switching-system failures that originate in the auxiliary radio-link. Fig. 3 shows the effect on the reliability of a radio system having two protection channels and two auxiliary radio channels when the value of a is $1 \cdot 5$.

In bothway radio systems which are intended for frequency-division multiplexed telephony signals it is possible to make use of an otherwise unused portion of the baseband of a channel in the return direction for the transmission of switching-control signals, so avoiding the use of an auxiliary radio-link. The reliability of this type of switching system depends in part on the reliability of a radio channel, but, in practice, it is unlikely to differ appreciably from that of systems which use auxiliary links.

SHELF SPARES

The total out-of-service time of a channel during a specified period depends upon the number of failures that occur during the period (failure-rate), and on the average time taken to restore the channel to service.

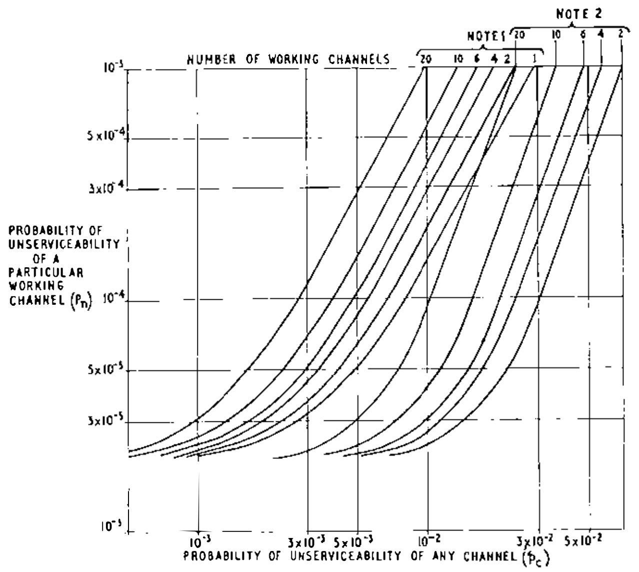
The equipment failure-rate of an established radio system is mainly determined by factors that are beyond the control of the user of the system, so that it must be accepted as a system parameter. The time taken to restore a faulty equipment to service, however, depends upon the availability of men and materials, and is controllable. Both men and materials are costly to provide, so that it is uneconomic to exceed by very much the minimum provision necessary to secure an adequate standard of reliability. The supply of materials is more amenable to control than is the supply of maintenance manpower, because modern radio-relay systems are so undemanding of maintenance attention that manning levels tend to be determined mainly from considerations of prudence.

The restoration of service in radio-link equipment is generally brought about by the replacement of exchangeable units, and spares are provided for the purpose. The quantity of spares provided determines their availability, and, hence, the time required for the restoration of service and the reliability of the system. This is illustrated in Fig. 2(*a*) and 3(*a*), where the vertical dashed lines marked A, B, and C show the conditions resulting from three different availabilities of spare units for an otherwise unchanged system. The conditions that apply to lines A, B and C are given later under "Reliability and Cost."

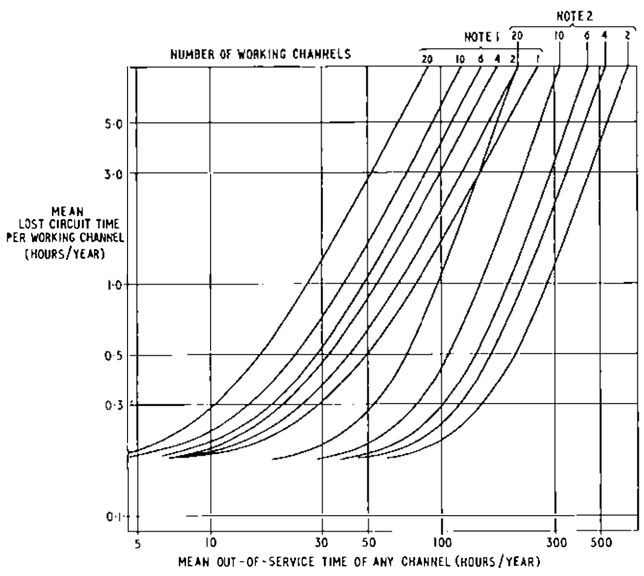
COMMON EQUIPMENT

Most radio-relay systems contain some equipment that is common to all channels of the system, failure of which causes the failure of all channels. The sub-systems that are usually shared by all channels, and without which the system cannot function, are the power plants and power-distribution systems, and the aerials and feeder systems. Aerial supporting structures and even buildings are also in the class of common equipment, but no failure-rate can be assigned to them.

The lost circuit-time due to common-equipment failures contributes independently of all other causes to the total lost circuit-time of a working channel, and it is desirable that the reliability of the common equipment should be of a high order, particularly where more than one working channel, or more than one system, are served. In such circumstances the probability of failure of the total of the common equipment should preferably be several times smaller than that of the working channels. Fig. 4 illustrates the case in which the probability of failure of the common equipment is 2×10^{-5}, which might be considered an appropriate level in a system where the overall probability of failure of a working channel was set at 10^{-4}. When applied to a system 100 miles long a probability of failure of 2×10^{-5} allows only some 1·6 minutes of out-of-service time due to common-equipment failure per station per year, or, more plausibly, one 2-hour failure at any one station during the 15-year life of the system.



(a) Probability that a Particular Channel will be Unserviceable



(b) Lost Circuit Time per Working Channel Relative to Out-of-Service Time of Any Channel

Notes: 1. Systems with one protection channel: $p_s = 0{\cdot}5p_c$
2. Systems with two protection channels: $p_s = (0{\cdot}5p_c)^{1{\cdot}5}$
3. Probability of unserviceability of common equipment $= 2 \times 10^{-5}$

FIG. 4—Effect of common-equipment failure

EFFECT OF MAINTENANCE WORK

Some radio-relay equipments require that routine-maintenance tasks should be performed at prescribed intervals in order to arrest the deterioration of performance that would otherwise occur, and on all links it is necessary to carry out tests of overall performance from time to time. For both of these purposes the channel concerned is taken out of service and replaced by a protection channel, which is then no longer available for its normal function. The reliability of the link is thus impaired, but the impairment is less than that which applies under fault conditions since, not only are maintenance men immediately available, but they are usually in a position to restore the channel to service very quickly.

The probability that a channel will be out of service for routine maintenance purposes is

$$p_m = \frac{h}{8{,}760},$$

where h is the number of hours per year that a channel is under maintenance.

The probability that any one channel will be out of service for maintenance is, therefore, mp_m.

The probability that the protection channel of a single-protection-channel system, or the second-choice protection channel of a two-protection-channel system, will be required for use is the probability that one or two of the working channels will be unserviceable, which is given by

$$P_m = p_c^r\,(1 - p_c)^{(m-2r)}\,\frac{(m-r)!}{(m-2r)!\,r!}.$$

The probability that there will be loss of service due to maintenance and fault conditions existing at the same time is therefore $P_m mp_m$. However, on half of the occasions covered by this probability the fault condition will occur before the maintenance condition, and in such cases the maintenance work would not proceed. The practical value of the probability is thus $0{\cdot}5P_m mp_m$.

Also, in practice, the period for which service was lost would be limited by emergency restoration to service of the channel under maintenance, so that the probability must be modified by the factor $\frac{2t_r}{t_m}$, where t_r is the mean time of emergency restoration to service of a channel under maintenance, and t_m is the mean duration of a maintenance period.

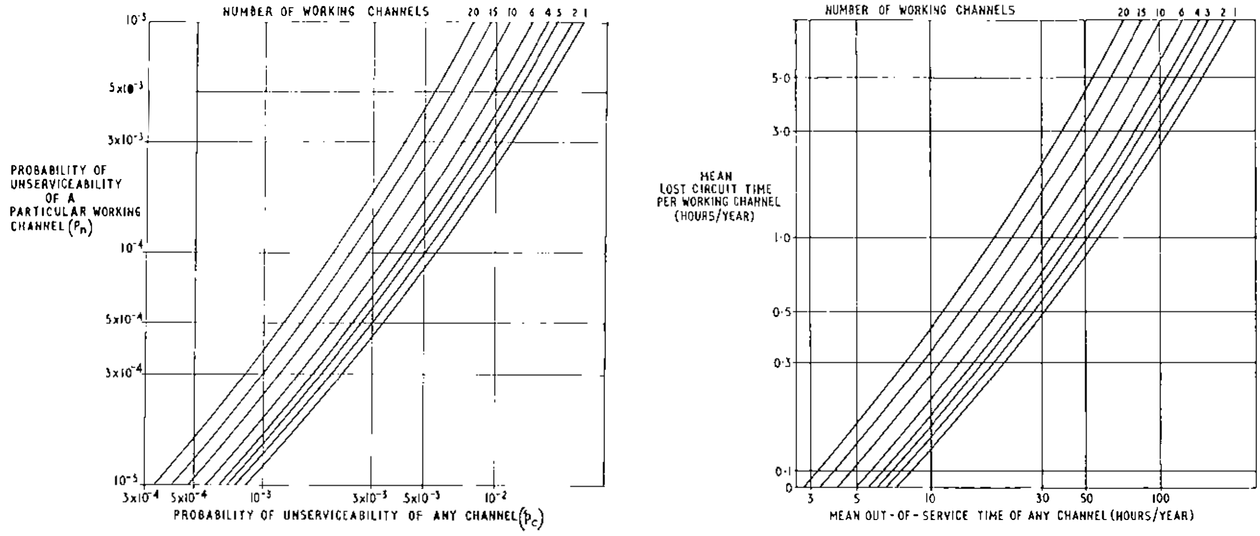
Thus, the probability that a particular working channel will be unserviceable due to the unavailability of a protection channel because of routine maintenance work is

$$P_s = \frac{1}{m-r}\,P_m m p_m \frac{t_r}{t_m}.$$

This factor is normally of practical significance only in systems that require frequent routine maintenance attention and which have a single protection channel, but it may become significant in any system of which unusually high reliability is demanded.

OVERALL RELIABILITY

The total probability that a channel will be unserviceable is the sum of the probabilities of unserviceability due to channel-equipment failure, protection-switching-system failure, common-equipment failure, and the effect of routine maintenance work. The results of one such summation are shown in Fig. 5, which relates to systems having a single protection channel, where the probability of unserviceability of the switching system is 0·5, and that of the common equipment is 0·01 of that of an unprotected channel. Each channel is assumed to be out of service for routine maintenance for 50 5-hour periods per year, with a mean time of restoration in an emergency of 10 minutes.



(*a*) Probability that a Particular Channel will be Unserviceable

(*b*) Lost Circuit Time per Working Channel Relative to Out-of-Service Time of Any Channel

$p_s = 0 \cdot 5 p_c$, t_r = 10 minutes, t_m = 5 hours, p_m = $2 \cdot 85 \times 10^{-2}$
Probability of unserviceability of common equipment = $0 \cdot 01\ p_c$

FIG. 5—Total reliability of systems with one protection channel

RELIABILITY AND COST

The costs incurred in improving the reliability of an unprotected radio channel are the capital cost and the present value of the annual maintenance charges of the redundant equipment. The deployment of redundant equipment should be that which offers the required reliability at the least cost. The best deployment in any circumstances depends, not merely on the intrinsic reliability of the equipment, but aslo upon the local conditions. It is, therefore, necessary to test a number of locally viable schemes, and, for the purpose of illustration, three schemes which are broadly applicable in the United Kingdom will be examined. These are as follows.

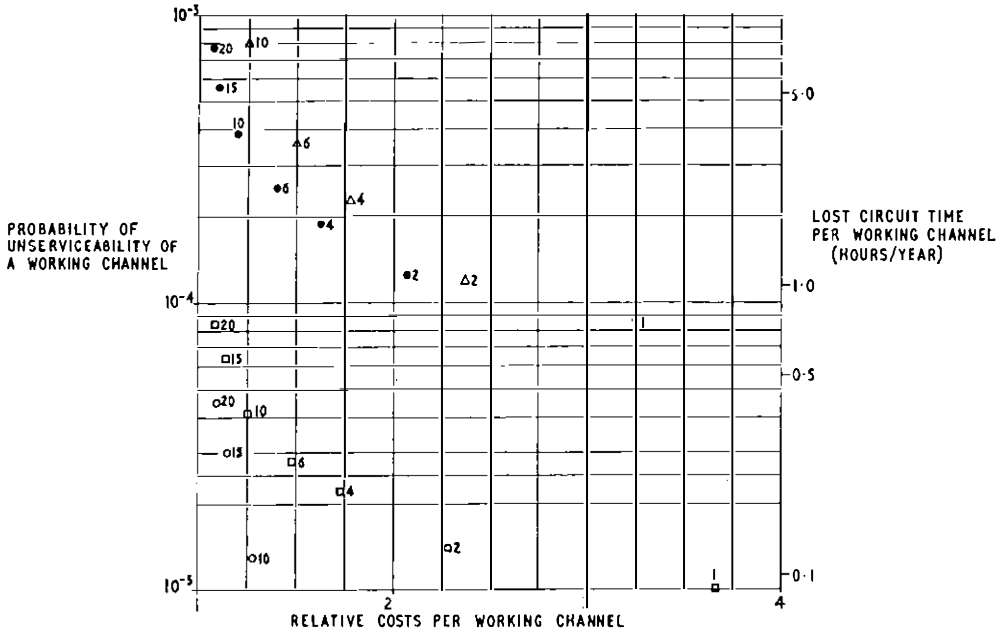
(*a*) A complete set of spare units is held at each radio station. The average time required for restoration of service after a fault is 3 hours.

(*b*) A complete set of spares is held at intervals of 100 miles along a route. The average time for restoration of service after a fault is 9 hours.

(*c*) Spares are held centrally and serve many routes. The average time of restoration is 36 hours.

The vertical dashed lines on Fig. 2(*a*) and 3(*a*) marked A, B, and C indicate the out-of-service times corresponding to schemes (*a*), (*b*), and (*c*) when applied to a 100-mile link for which the fault-rate is 1·7 faults per terminal or repeater channel-equipment per year; the intercepts of these lines with the curves indicate the working-channel reliability to be expected.

The revenue-earning capacity of a system depends upon the number of working channels, so that the cost of measures taken to improve reliability should be expressed in terms of the cost per working channel. In Fig. 6 the sum of the estimated equipment costs and present value of maintenance costs per



□ One protection channel, scheme (*a*)
● One protection channel, scheme (*b*)
○ Two protection channels, scheme (*b*)
△ Two protection channels, scheme (*c*)

The numbers shown against each point indicate the number of working channels

FIG. 6—Reliability relative to equipment and maintenance costs per channel for systems about 100 miles in length

channel for various numbers of working channels are shown plotted against the resulting reliability. It is evident that when the best deployment of redundant equipment is used a relatively small increase in expenditure can yield a marked improvement in reliability.

For the purpose of this illustration the effect of the common equipment has been excluded from consideration, but, as Fig. 4 indicates, common-equipment reliability is a limiting factor, and further costs may be incurred in improving the common-equipment performance if the limit that it sets is approached or exceeded by the reliability of the channel equipment.

Telephone-Exchange Equipment Planning and Design

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The planning and design of a telephone exchange must take account of many complex factors so that the individual exchange may correctly and economically fulfil its function in the network. The necessity for close liaison between telecommunications planning engineers, architects, civil engineers, equipment manufacturers and installers is stressed, as well as the need to follow a master plan for the network as a whole. As well as discussing planning and design, and questions of economic provision periods, contractual arrangements are also briefly reviewed.

INTRODUCTION

In a modern telephone system the sizes and roles of individual exchanges will differ considerably, and, therefore, a wide variety of operational facilities and service parameters need to be included in their basic design. The planning of a new telephone exchange must take these factors into account; it must also take into account the equally important need to provide in the right place, and at the right time, the necessary switching plant, apparatus accommodation and the associated line plant. Advance and accurate planning in the long term, as well as in the short term, is of paramount importance if this integration exercise is to be a complete success; these points are emphasized in the following paragraphs, where brief mention is also made of the more detailed aspects of exchange design. In some respects the information given reflects British Post Office practice; nevertheless, the principles involved apply equally to many other telephone systems.

LONG-TERM PLANNING

The development of a telephone switching system requires the provision of plant at the appropriate time to cope with the demand as and when it occurs, and this can mean not only the purchase of exchange switching equipment, but also the purchase of a suitable site and the erection of a new building. These operations frequently take many years to complete, and it is essential to foresee their need sufficiently far in advance to enable the necessary relief action to be taken. A regular review, therefore, of the rate of growth of every existing exchange in an established network, whether manual or automatic, becomes an important feature of planning. The comparison of the current rate of growth with the capacity of existing equipment, accommodation and site gives a useful indication of the date when the capacity of the existing plant, and, on occasions, the building, may be expected to be exhausted. In countries where growth rates are likely to change rapidly a very frequent review is, of course, desirable.

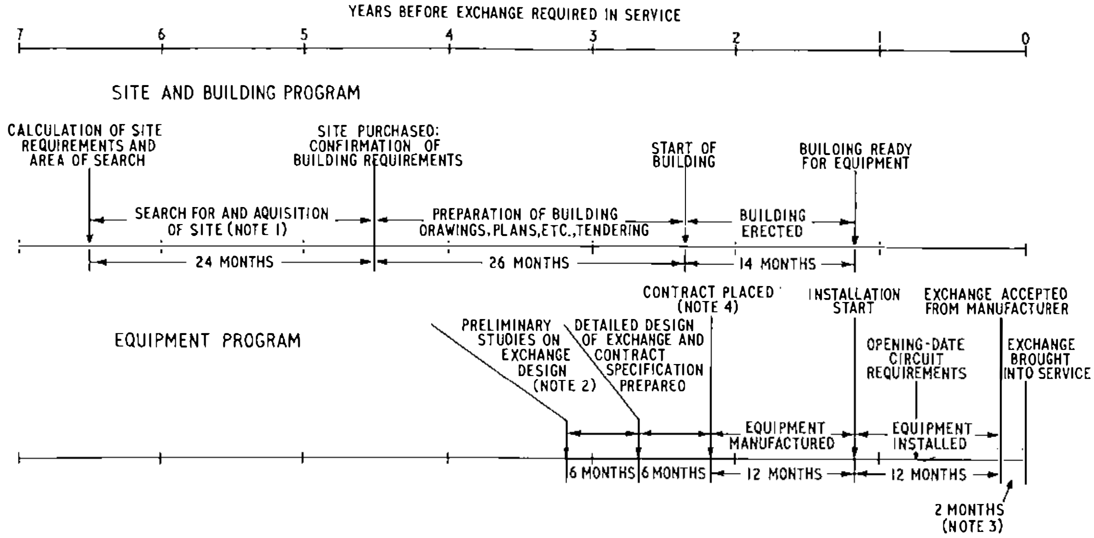
The early detection of exhaustion of plant capacity enables the appropriate remedial action to be taken, and, ideally, such action should be along the lines of some predetermined development plan. A master plan showing the longer-term pattern of development for individual exchanges, as well as for the system as a whole, should always be available. These plans should not only indicate the definite lines to be followed during the next few years, but should also give a reasonably firm indication of the trend thereafter, together with some indication of the cost of the work involved.

The master plans should indicate the position of existing plant throughout the appropriate charging groups, and should include existing boundaries and any proposed boundary changes. The intended course of development for all the internal and external plant to meet the forecast demands for service should be clearly described. Details of the proposed locations, size, and status of new trunk and local switching units, locations of auto-manual centres, sites and buildings, proposals for major changes in line plant, and plans for the replacement of existing exchange equipment should be recorded. The master plans should also contain sufficient information to permit the ready appreciation of the effect, on the long-term development of the system, of changes in demand, introducing new facilities, and of changes in national policy.

PROGRAM OF OPERATIONS

The provision of a new telephone exchange requires close liaison between the planning engineers of the telephone operating organization, the architects responsible for the building, the civil engineers responsible for erecting the building, the equipment manufacturers and the equipment installation staff. Fig. 1 sets out the main stages involved in the planning and provision of a large non-director group

† Network Planning Division, Network Planning and Programming Department, Telecommunications Headquarters



Notes: 1. This period varies considerably.
2. Includes determination of numbering scheme, dialling and signalling facilities, and S.T.D. access.
3. Commissioning and testing period, which will vary according to local circumstances.
4. Earliest date for letting equipment contract is date for letting building contract.

FIG. 1—Typical timing for planning a large group switching centre

switching centre (G.S.C.) with its associated auto-manual centre. It clearly shows the extent to which the building, equipment-planning and manufacturing work must be carried out as simultaneous operations. Typical timing is shown for the years in advance of the date when the new exchange is required to carry traffic. Specific mention is not, however, made of the related stages: local-line and main-line provision plans.

In order to control and supervise all the various aspects of plant provision a detailed "control-sheet program" is prepared as soon as planning work commences, and many administrations, including the British Post Office, are applying the critical-path method (C.P.M.) to assist in this respect.

BUILDINGS AND SITES FOR TELEPHONE EXCHANGES

Buildings

Until recently the exchange-accommodation needs in the British Post Office were based on a 20-year design figure, but now buildings are designed to cater for a predetermined capacity rather than for a specific number of years. One of the major factors leading to this change was the introduction of the unit method of equipment layout, described in the section below on "Layout of Apparatus." The new basis of design achieves economy in building costs and minimizes the effect of inaccuracies in long-term forecasts. It means that buildings are being designed to provide an initial capacity for a period, chosen to suit local circumstances, of from 10–20 years. The factors which may influence the choice of the building-design period include the form of the exchange-numbering scheme, the effect of site dimensions on building shape, and growth forecasts.

Telephone buildings may be either designed on an individual basis or they may be provided to conform to one of a variety of standard plans. Standard buildings are attractive in that they generally offer a reduction in the time needed for their detailed planning, and the use in the future of industrialized-system techniques should result in a reduction in building-erection times.

Individual design of larger telephone buildings is desirable in that the accommodation will be required to house racks of comparatively heavy telephone-switching or transmission equipment. The width of the building, the overall height of the rooms and the strength of floors must, therefore, be designed with these factors in mind. Moreover, some telephone buildings must also accommodate auto-manual centres and the associated operator welfare and training facilities.

Sites[1]

When the equipment and other accommodation details have been calculated and the size of building determined, it is possible to decide the size of site required. To safeguard future development, any new site should be of sufficient size to permit a 100 per cent extension to a 20-year building.

The choice of site is important, and it is not only necessary for the correct size of site to be sought, but, also, the site location must be best from the telephone service-provision point of view. The site selected should permit easy access for telephone cables and should involve minimum expenditure on their initial installation and subsequent maintenance. The level of subsoil water, nature of subsoil, atmospheric conditions, fire risks, availability of staff, and accessibility to heavy transport are other factors which can affect the final choice.

Layout of Apparatus

It is the practice in most countries, and was the practice in the United Kingdom until a few years ago, for the apparatus racks and distribution frames in local and trunk exchanges to be grouped in types, space being reserved within each group for future extension. Present policy, however, favours the layout of equipment on a unit basis, with different types of equipment physically grouped together to permit easy replacement in age groups. Similar arrangements are now being applied to Strowger exchanges in other parts of the world.

At this time, when new switching techniques are being introduced, the unit method of layout has an added advantage in that spare space is left in areas large enough to permit the introduction of new types of equipment in self-contained units. Apart from saving some internal cabling it offers some maintenance advantages from the managerial point of view. The unit layout of some large trunk exchanges permits the earlier utilization of plant; it also disperses racks of high heat dissipation, thereby easing air-conditioning problems.

PRELIMINARY EXCHANGE-DESIGN INVESTIGATIONS

Before the detailed design of an exchange can commence there is a need to assess the future level and distribution pattern of the traffic to be handled. This work cannot be completed, however, until some preliminary studies are finalized: the more important of these are described in the following paragraphs, and, as shown in Fig. 1, are investigated at least 6 months before the commencement of detailed equipment-design work.

Routing and Signalling

Under some circumstances a choice exists as to whether direct routes should be provided to carry calls to particular destinations or whether the calls should be routed via an intermediate tandem exchange. A cost comparison is frequently required to decide between the various alternatives, having regard to the cost of line plant, and tandem-switching, transmission and signalling equipment. In some switching systems the routing-digit capacity and translation facilities of the controlling register-translators must also be taken into account when deciding the routing pattern to be followed.

With the Strowger switching system used by the British Post Office it is readily possible to develop a trunk and junction line network having a basic star configuration augmented, as justified, in a delta fashion, by direct routes between individual centres. The final pattern represents an optimum arrangement, as the basic pattern enables any subscriber to be connected to any other within the network, whilst direct auxiliary routes may be provided when the amount of traffic to be carried makes them an economic proposition. These routes may be fully-provided, or they may operate on a high-usage basis, with traffic overflowing on to another route.

In conjunction with investigations into routing it is necessary to decide the dialling and signalling techniques to be employed on all routes radiating from the exchange in question. In any developing system there will be a gradual conversion from the older manual system to a fully-automatic system, and it is also possible that there will be plans for the introduction of high-frequency line plant or radio-link systems. In such cases it will be necessary to study throughout the design period, in detail, not only the characteristics of the line plant to be used but also any changes in the method of working that are likely to arise at the distant-end exchanges. In this respect, a closely co-ordinated line and equipment program can yield worthwhile dividends.

Numbering-Scheme Design

When subscriber trunk dialling (S.T.D.) is first introduced into a country there is a need to design a national numbering scheme with the main object of allocating a unique national number to each subscriber within the system.[1,2] Any such scheme should make allowances to accommodate the growth of the system for the next 50–100 years, and should allow for the fact that the network will eventually become accessible to subscribers in other countries by means of international subscriber dialling.

In general, the subscriber's national number is divided into two portions: the first is a code to identify the exchange to which the subscriber is connected, and the second is the subscriber's local number. There are a number of ways in which the code portion of the national number may be allocated, and these vary from a scheme based on the geographical location of the exchange to a scheme based on less rigid procedures. For example, it is possible to divide a country into 10 large geographical regions, each of these being sub-divided into 10 smaller areas which are, in turn, further sub-divided into groups of up to 10 local exchanges. Alternatively, a scheme could be based on the allocation of the national-code portion of the national number to every exchange in the country in a purely arbitrary manner. It can be argued that the first scheme offers advantages in the simplicity of the design of control equipment, whereas the second scheme has the advantage that any spare codes in the numbering range may be allocated to any exchange in the system. The latter scheme can also more easily accommodate changes in forecast and unforeseen developments in any one area. In the British Post Office a single code, usually of three digits, identifies all exchanges within one numbering area, i.e. the number-group code.

As the majority of number-group codes in the British Post Office system have now been allocated, the major task at the numbering-scheme planning stage involves the design of a scheme to serve local exchanges and the selection of codes required for access to dependent exchanges. This work must be carried out in advance of the detailed exchange design to ensure that time is available for economic studies and any negotiations with local-government town-planning authorities.

Number schemes for local exchanges are normally designed for a period of 30 years and it is, therefore, necessary to determine beforehand the multiple requirements throughout this period. Long-term forecasts are inherently liable to inaccuracies, and a 30-year design period is chosen as a compromise between the additional cost that might be involved in planning a numbering scheme to cater for a longer period and the expense of subscribers' number changes which might occur if the life of the numbering scheme is planned for too short a period.

A well-designed numbering scheme should not only cater for the foreseen development in an economic manner, without the inconvenience and expense of changing subscribers' numbers within a 30-year period, but should also permit easy evolution into the next numbering range. Moreover, with the introduction of S.T.D., a requirement is imposed that codes for access to dependent exchanges in the home and adjacent numbering groups must not be changed within the foreseeable future, because of the national repercussions in the form of directory changes. This has a distinct bearing on the design of the numbering scheme at any G.S.C.

In the design of the numbering scheme for a multi-exchange area it is desirable to know the average calling rates of the subscribers connected to individual satellite exchanges, and to bear these figures in mind when deciding which exchange should be allocated 6-digit numbers in a mixed 5-digit and 6-digit linked-numbering scheme. Knowledge of the distribution of calls during the 30-year period is also necessary to permit the economic location of the tandem equipment required for the routing of traffic between exchanges, in particular, from a 5-digit satellite to 6-digit satellites which might share a first-selector level.

In the British Post Office system the numbering schemes are designed on the basis of either 4-digit, mixed 4-digit and 5-digit, 5-digit, or mixed 5-digit and 6-digit numbers. Several of the larger non-director linked-numbering schemes are already using mixed 5-digit and 6-digit numbers. In some of the very large centres served by non-director switching equipment in other countries, mixed 6-digit and 7-digit working has been introduced, for example in Los Angeles, Melbourne and Sao Paulo.

The exchange systems serving the six largest cities in the United Kingdom use a form of register-translator, sometimes known as a director, to control the switching of local traffic. The exchanges are linked by a 7-digit numbering scheme, and each subscriber's number consists of a 3-digit exchange code followed by a 4-digit number, e.g. 222 1234.

The design of a numbering scheme to serve an area using either director equipment or a similar type of register-control equipment must take full account of the total number of exchanges likely to be installed during, at least, the next 50 years. Once the number of digits to be allocated to individual exchange codes has been decided and the exchange control equipment designed accordingly, it could become a major task to increase the number of digits comprising the individual exchange code, but, subject to this maximum limitation, the introduction of additional digits in the subscribers' numbers does not necessarily involve the provision of additional switching stages, although it could involve a marginal increase in the time involved in setting up a call.

Where a small number of exchanges are to be served by a register-control system a 2-digit exchange code might suffice, but for larger systems a 3-digit code would be a wise investment.

EXCHANGE DESIGN

General

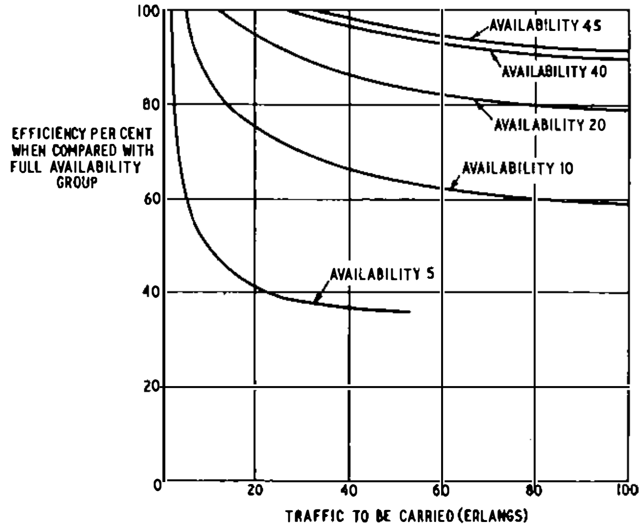
The design of an exchange may be undertaken as part of a long-term economic study or immediately prior to its purchase from a telephone-equipment manufacturer. In either circumstance the aim of the design engineer is to provide the necessary operating and traffic-handling facilities at a predetermined grade of service consistent with the adoption of sound engineering practices and the economic use of the switching equipment.

It is essential that, by the time the design stage has been reached, all planning decisions regarding the function and the status of the exchange shall have been made. Any attempt to reconsider basic planning at this late stage is almost certain to delay the opening of the new exchange. Data showing the traffic characteristics and its distribution should also be available.

The degree of detail to which an exchange is designed depends on the extent to which the telephone administration concerned wishes to specify its requirements to the equipment manufacturer. In some countries only broad parameters are given; in others, as in the British Post Office, a much more detailed specification is prepared. If the telephone administration has sufficient design staff available there are some worth-while advantages to be obtained, not the least of which is matching, as closely as required, the type of switching equipment to be provided to the needs of the system and to the traffic carried, within the framework of an overall long-term plan for the development of the system. In this respect, standardization of the type of switching plant has obvious advantages.

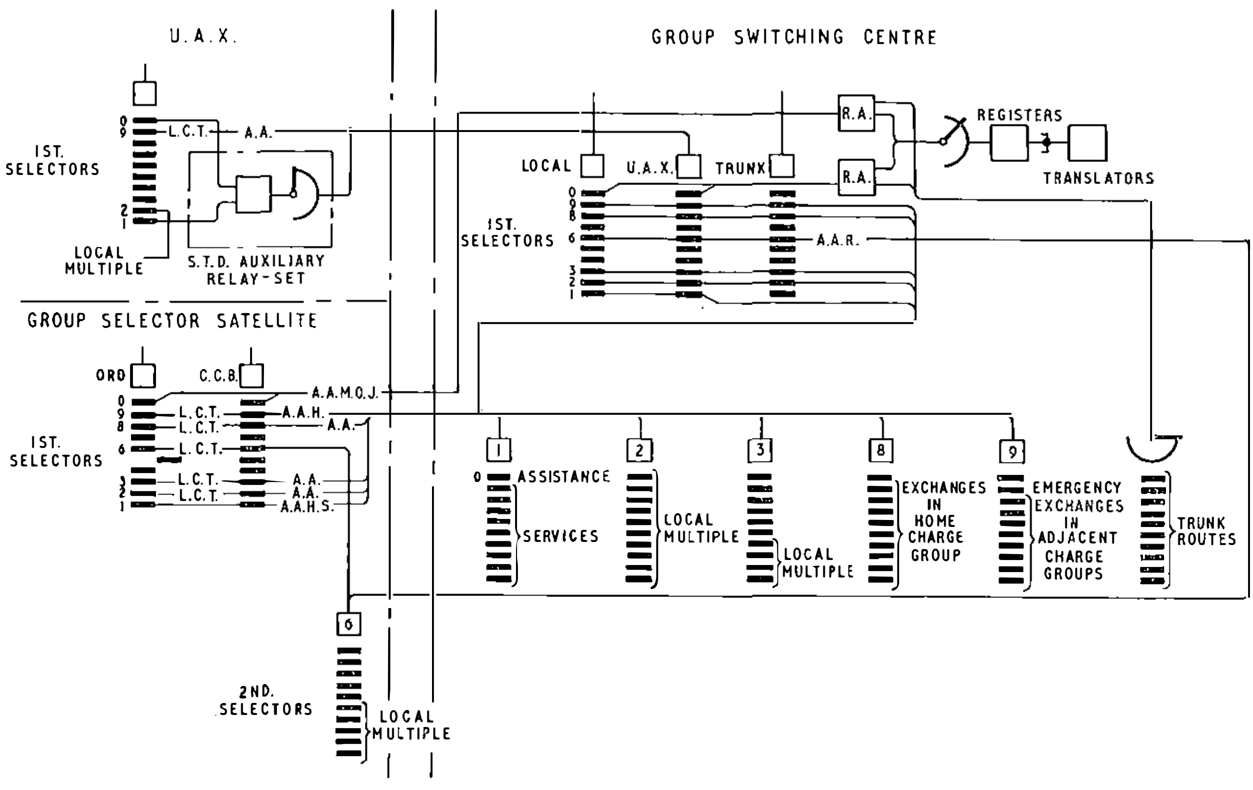
Exchange Trunking

In most types of telephone exchange some items of plant are not directly related to the amount of conversational traffic to be switched, and the numbers of these items are usually specified in accordance with a predetermined standard of provision. The quantities of other items of plant, including



Grade of service: 0·005

FIG. 2—Efficiency relative to selector availability



L.C.T.—Local-call-timing relay-set
A.A.M.●.J.—Auto-auto relay-set with metering-over-junction facilities
A.A.H.—Auto-auto relay-set with manual hold or fee metering
A.A.H.S.—Auto-autorelay-set with manual hold or unit-fee metering and coin-slot control
A.A.—Auto-auto relay-set without regenerator
A.A.R.—Auto-auto relay-set with regenerator
R.A.—Register-access relay-set

FIG. 3—Simplified trunking diagram of G.S.C. and dependent exchanges

the switching train or matrix, must be calculated from the traffic data.

The inherent flexibility of the stage-by-stage method of selection used in Strowger-type exchanges enables an economic overall design to be achieved. For example, auto–auto relay-sets and local-call-timing equipment may be located in the trunking to offer maximum cost advantage, and routes destined to carry large quantities of traffic may be allocated to the early switching stages thereby giving not only equipment economies but also reductions in the call set-up times.[3] Uniselectors may be also used instead of line finders in those exchanges which have a fairly high originating calling rate.

The efficiency of a group of interconnecting circuits, measured in terms of the erlangs carried per circuit, increases as the size of the group becomes larger. This is another factor which must not be overlooked when switching traffic through an automatic exchange. A graphical comparison of the variation of efficiencies with availability is shown in Fig. 2. Similar factors should also be taken into account when deciding the type of switching device to be used.

Under normal circumstances, however, practical difficulties rule out any attempt to use a variety of switching devices within an exchange or even within an exchange system. In trunk tandem exchanges it may be found that motor-uniselector group selectors with an availability of either 22 or 45 are desirable if access is to be given to expensive trunk circuits.

It will be clear from the typical trunking diagrams shown in Fig. 3 that the stage-by-stage method of selection may be used at small unit automatic exchanges (U.A.X.s). The system can also be designed to serve subscribers in the largest and busiest capital cities and can be adapted to meet changing traffic patterns and facilities. In the British Post Office system, for example, the introduction of S.T.D. facilities was a relatively straightforward operation. Moreover, it has been possible to arrange for the register-translator control equipment, installed at a central point, usually at the G.S.C., to deal only with those calls, i.e. S.T.D. calls, which benefit most from this method of control.

It is noted that the quantities of register-translator equipment to be provided are based on the number of calls originated rather than on the conversational erlangs generated. The numbers of multi-frequency senders/receivers required for high-speed signalling over the transit network are also calculated from the number of calls to be switched over the routes in question.[4]

Other Design Features

The trunking pattern of any exchange dictates the traffic routing to be followed and, when established, the next stage of design can proceed. Once again certain fundamental principles are involved, and the more important of these are as follows.

Grade of Service

The grade of service to be given by the equipment in a Strowger system is normally specified on a stage basis, but in other systems an overall standard may be specified. In general, switching equipment in the British Post Office system is provided on the basis of one lost call in 200 during the exchange busy hour, although lower standards are adopted on the more-expensive trunk circuits.

Interconnexion Methods

Throughout the British Post Office Strowger system either the full-availability method or the grading method of interconnexion is used to connect one rank of switches to the next. The actual grading facilities are generally made a feature of the equipment racks in order to avoid the disadvantages associated with separate grading frames or racks.[5]

Formulae have been derived to enable the traffic-carrying capacity of gradings to be readily calculated, and these make allowances for the nature of the traffic carried, e.g. pure chance, or smooth.

Design of Gradings

To complete the design of a highly efficient grading it is necessary for a variety of other factors to be taken into account; these include the correct choice of groups in a grading, the grading formation, the allocation of trunks to grading outlets, and, where appropriate, limiting the number of trunks connected to a grading.

Equipment-Provision Periods

Whereas a telephone-exchange building may be designed to meet accommodation requirements for a period of up to 20 years, the switching equipment is best provided in instalments to more closely match the actual increase in demand. The initial installation and each extension is, therefore, designed to cater for a much shorter period.

For many years it was British Post Office policy to provide the fixed equipment, e.g. racks and banks, to meet a 5-year equipment-design period but selectors and relay-sets were provided to cover only the 2-year demand. Recent studies have indicated, however, that shorter provision periods for both racks and jacked-in items offer further economic and other advantages, and shorter provision periods have been adopted.

Small Electronic Exchanges

The small electronic exchanges designated TXE2 now being introduced into the British Post Office network lend themselves to a slightly different design approach from that described in the preceding paragraphs. This difference arises mainly from the fact that the system is based on the use of a register-controlled switching matrix employing reed relays for cross-point connexion. Fig. 4 is a typical trunking diagram, showing only the speech path.[6]

All originating calls are routed via A, B and C switches to a register; calls destined for subscribers on the same exchange are then routed via own-exchange supervisory relay-sets and the D, C, B and A switches to the wanted lines. Subscribers' line circuits and associated A-switch units are provided in multiples of up to 25 to form groups, each being capable of carrying a maximum of 7 erlangs of bothway traffic over 25 trunks to the B-switches. These groups are then combined in threes to form major groups, with each major group or part comprising five B-switches having five inlets from each group and outlets to every C-switch.

C-switches, although always 10 in number, will be of various sizes, according to trunking requirements, and the number of inlets per switch is therefore governed by the number of major groups. The number of outlets per switch allows for the number of supervisory relay-sets to which access is required.

PREPARATION OF CONTRACT SPECIFICATION

The extent to which the technical and operational parameters of the equipment are given in a contract specification depends to a large degree on the size of the telephone operating company and, hence, the availability of staff to deal with these matters. Traditional relationships which exist between the administration and the equipment manufacturer may also influence the details given and any tendering procedures involved.

The specification must, of course, include the commercial conditions as well as the technical requirements, and these will vary from administration to administration, but, in general, will include the price to be paid, the terms of payment, guarantees, and delivery terms.

In the British Post Office, contract specifications are prepared for new exchanges and for extensions to existing exchanges. Each states in detail the type, quality and facilities

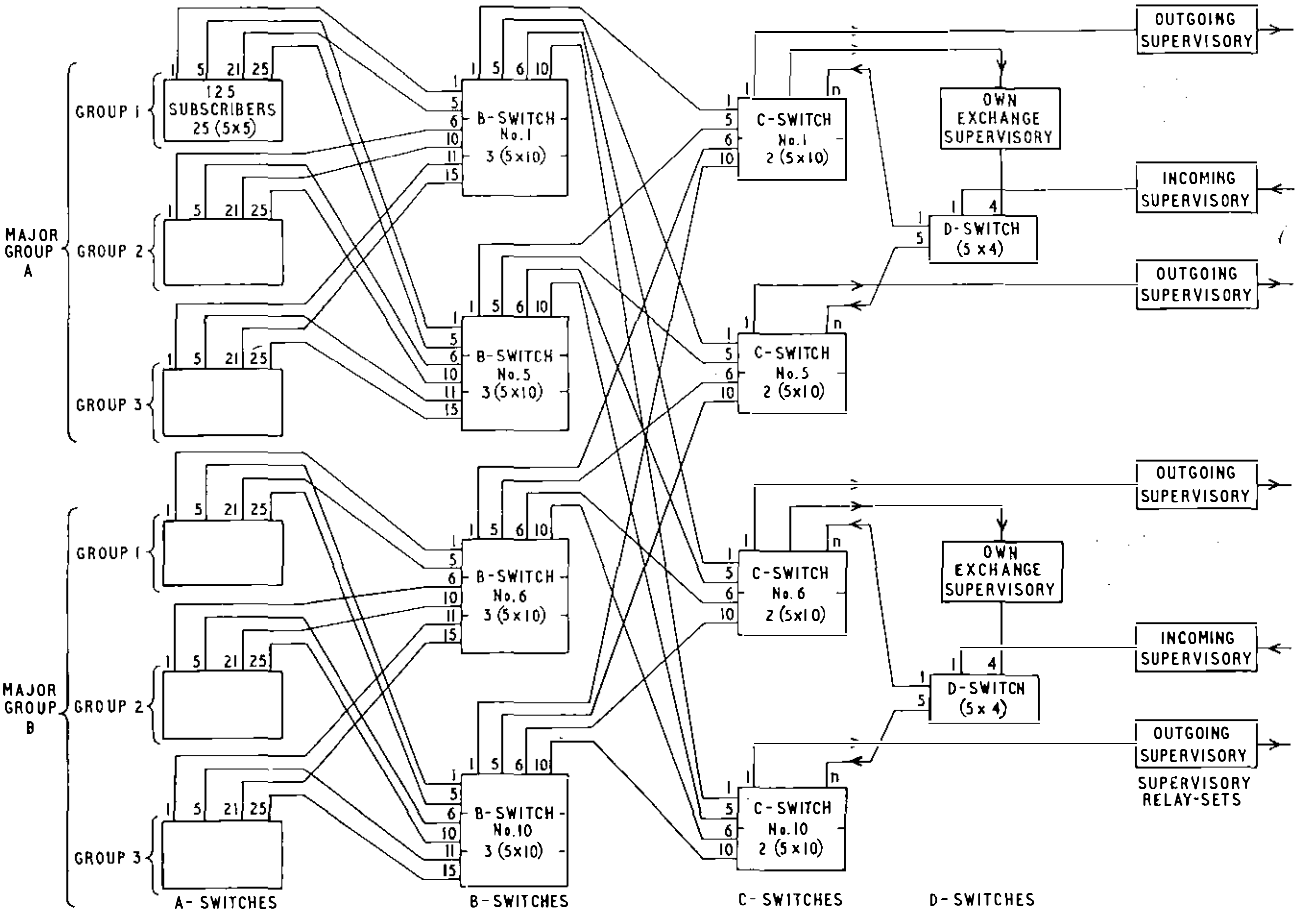


FIG. 4—Typical trunking of TXE2 exchange

of the equipment to be provided. It also specifies equipment quantities, trunking arrangements, layout of the apparatus on the exchange floor, standards of equipment, standards of cabling, and standards of installation to be adhered to by the manufacturer's installation staff.

In some overseas administrations the contract covers not only the provision and installation of the new equipment, but also provides for its maintenance over a specified number of years. This latter scheme has the advantage that time is available for local staff to be trained and become proficient in the maintenance of the exchange equipment. The same advantage could be obtained if the equipment manufacturer employed staff loaned from the local telephone administration for the installation of the new equipment.

The system adopted by the British Post Office whereby the contract specification gives precise information offers some useful advantages. For example, no compatibility problems are likely to arise from the introduction of a new exchange into an existing system, such problems being anticipated and allowed for in the individual circuit designs. Moreover, it is unnecessary to check the circuit design of the equipment being provided at every exchange. The British Post Office is also in a position to obtain standard operational tolerances on interconnecting circuits throughout the whole network.

Before the commencement of the installation work by the equipment manufacturer, the British Post Office normally appoints a Clerk of Works with the responsibility of ensuring that the standard of installation and related contract specifications are complied with.

OPENING-DATE REQUIREMENTS

It will be seen from Fig. 1 that this stage is shown at least 6 months prior to the opening date of the new exchange. Several tasks are completed at this time including (*i*) a final check of the forecast traffic details used in the original design, (*ii*) final arrangements for any changes to existing subscribers' numbers, (*iii*) a final check that equipment of the correct type has been provided at all the other exchanges with routes to or from the new exchange (this is of particular importance when a large trunk-switching centre is to be opened), and (*iv*) a final check of the arrangements to coordinate the completion of trunk and junction circuit connexion, circuit line-ups and circuit testing with the provision of the terminating equipment, and also for the extensive re-routing of calls which could result from the opening of the new exchange.

CONCLUSIONS

This article has mentioned briefly the main aspects of the work involved in the planning of telephone-exchange equipment. Although the British Post Office has for many years adopted as standard the Strowger method of switching, the planning principles and the design techniques which have been described are equally applicable to other developing systems. In the future the integration of more electronic and crossbar switching equipment into the existing network will almost certainly bring about some detailed changes in installation practice, design techniques and allied matters, but it is unlikely that the general planning and program principles will be materially affected.

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An Introduction to Automatic Controls for Central Heating

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U.D.C. 536.58: 697.3

A proper understanding of automatic control systems is essential to engineers responsible for the design, installation and maintenance of heating, ventilating and air-conditioning installations. For the specialist a detailed course of study is warranted but there are many others for whom an understanding of the basic principles and their application is sufficient. In this article the fundamental requirements for automatically controlled heating systems are outlined, and examples of control-system elements used in fairly straight-forward applications are described.

INTRODUCTION

Ideal comfort conditions are dependent on many factors* but the prime requirement in this country is heating during the winter. With the introduction of teleconununications equipment having high heat dissipation, it is becoming necessary in apparatus rooms to provide cooling and humidity control in summer time, but, for office accommodation, air conditioning is not yet considered essential. Acceptable conditions can generally be provided by maintaining a mean dry-bulb temperature of 62°–68°F in winter, and central heating is, therefore, the major accommodation service in most Post Office buildings.

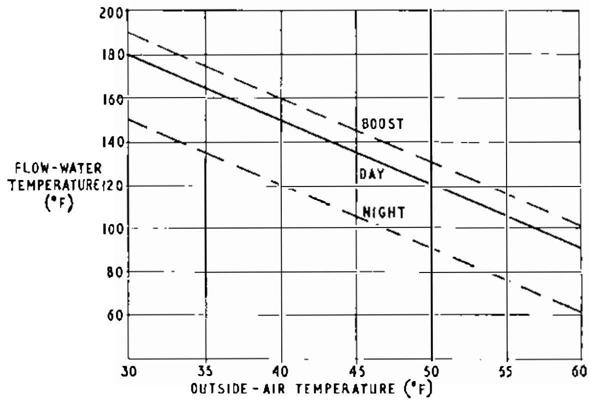
Automatic control of central heating has in recent years become more and more an integral part of the installation, while the subject of controls has developed into a complex and exact science. The choice of a control system is now a determining factor in the design of any reasonably-sized heating installation.

CONTROL REQUIREMENTS

A heating system comprises heat-producing equipment, such as a boiler, connected by a means of distribution to heat-emitting equipment, such as radiators, unit heaters or convectors. Most systems are designed so that, when the outside air temperature is 30°F, the heat output from the radiators is sufficient to meet the heat losses from the building and maintain the desired room temperatures with a water-flow temperature of 180°F. When the outside temperature is above 30°F, less heat will be required, so the output from the radiators should be reduced to prevent overheating and consequent wastage of fuel. Overheating of a normal type of building represents a wastage of between 4 per cent and 5 per cent of the total fuel consumption for every 1°F that room temperatures exceed the desired value.

The function of the control equipment is to regulate the output of the heating equipment in a manner that will result in the desired room temperatures being maintained within reasonably constant limits despite variations in the independent factors which influence temperature conditions. Chief among these factors is the outside air temperature; others are heat dissipated within the rooms by occupants or machinery, ventilation rates, solar-radiation heat gains, and the cooling effect of winds. A system which takes all these variable factors into consideration and does so individually for each room is the ideal, but such an arrangement, although technically feasible, would have a high initial cost. A crude system, on the other hand, would be expensive in fuel costs. In practice, therefore, control systems effect a compromise, aiming at the ideal as far as is practical.

In the most commonly-adopted method the automatic control regulates the heat output of the whole installation by adjusting the temperature of the main flow water in response to changes in the outside air temperature. This "outside compensation" of the flow temperature is made to be a linear relationship and can be shown graphically as in Fig. 1. The



Operational Settings

Outside Compensation:	90°F
Night Setback:	30°F
Morning Boost:	10°F

FIG. 1—Heating-control characteristics

slope of the graph represents the amount of compensation, and this is pre-set on initial calibration to suit the thermal characteristics of the building. For every value of outside temperature the flow temperature is set to a corresponding value which will give the required heat output from the radiators to achieve room temperatures of 65°F.

When the building is unoccupied it is usually unnecessary to keep the rooms up to normal temperatures and the heating plant can be switched off to save fuel. While it is off, the heat stored in the fabric of the building continues to be lost and room temperatures will fall. As this heat loss must be made good before normal temperatures can be restored, the plant must be re-started some time before the staff comes on duty. In cold weather the boiler-capacity margin may be insufficient

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to restore the overnight loss with normal compensated-flow operation. To cope with this situation, two alternative methods of operation may be adopted.

The plant can remain off at night but, when started up, the output is increased for a predetermined period until day-time room temperatures are attained. This is known as a "morning boost" condition, but, although an effective method, it has the following drawbacks in very cold weather. To protect the water in the system against freezing, a frost thermostat must be provided to start the burner, if necessary, during its off period. When the boiler is off overnight and has cooled down considerably, it is subjected to severe thermal shock when the burner starts. Until the boiler is warmed up there is a likelihood of condensation of sulphuric acid from the flue gases, leading to corrosion in the boiler flue-ways.

Alternatively, the plant can be run overnight at a reduced output, thereby reducing the heat lost and, consequently, the amount to be replaced in the morning. This arrangement, known as "night set-back" or "night depression," overcomes the disadvantages of the former method while still offering savings in fuel consumption. The thermal characteristics of the building and its location will determine which method gives the greater savings.

During night depression or morning boost the outside compensation relationship remains unchanged but the operating range is lowered in one case and raised in the other (see Fig. 1). As with compensation, the amount of depression and boost is pre-set on initial calibration. Change-over from one condition to another is usually effected by a time switch programmed to suit the occupancy of the building. Most commercial equipment also provides facilities for manual over-ride of the time switch, enabling the plant to be run continuously in any one condition.

It will be apparent that the disadvantage of the compensated-flow system, as described, is that heating for the whole building is dictated by one thermostat on the assumption that all parts of the building have a constantly similar heat requirement. In large buildings, particularly where different parts are used for different purposes, some rooms may suffer variations in temperature greater than is acceptable. Individual control of the heating equipment in such rooms may be necessary because outside compensation will not respond to incidental heat gains occurring within the rooms. In very large buildings and in tall tower blocks there may be significant differences in the outside temperature conditions prevailing at various parts. It is usual in these cases to divide the heating installation into a number of zones, each zone being controlled independently by a separate outside compensation system. Such installations will have multiple boiler plant and will invariably require individual control on some rooms as well, with the result that the overall control system becomes large and complex.

CONTROL APPLICATIONS

Boiler Control

The first essential function in an automatic heating system is control of the heat output from the boiler by regulating the firing rate in the furnace so that the boiler-flow temperature remains constant. Methods of firing will depend on the type of fuel being used, as this may be solid, liquid or gas. The normal arrangement is to use a temperature sensing device in the boiler flow to control the operation of the automatic stoker, the oil burner or the gas valve, as the case may be. For small-sized and medium-sized boilers, an on/off control is the simplest arrangement. A flow thermostat starts the burner when the temperature falls below the required value; this is normally 180°F but it may be 190°F if morning boost is to be applied. When this temperature is reached the burner is shut off, whereupon the temperature will fall until the thermostat re-starts the burner. A slight difference in the on and the off switching points is inherent in the thermostat, and the amount of this differential, coupled with the load on the boiler, determines the length of time the burner will fire each time it starts.

On larger boilers frequent starting and stopping of the burner is undesirable and a closer control of the output is required. Two-stage firing can be arranged by switching the burner to a high or low rate under the control of a double thermostat. A more precise control is possible by modulating the flame to give a continuously variable firing rate. This requires a control system having a variable output, as the fuel and air supplies must be regulated while the burner is running.

Outside Compensation

A temperature detector fixed on a wall outside the building measures the outside air temperature and causes the necessary proportional adjustment to the set point of a thermostat in the water-flow pipe. Compensation can be applied directly to the boiler output thereby varying the operating temperature of the boiler, but there are disadvantages in this. When return-water and flue-gas temperatures are low there is the danger of condensation, particularly with oil or gas firing, and this has a very damaging effect on the boiler. Another disadvantage is that some parts of the installation, such as unit heaters or a domestic hot-water calorifier, require water at a higher constant temperature than is sometimes available from a compensated flow.

A better arrangement is to allow the boiler to run at a constant high temperature and to control the flow temperature for the heating circuits by means of a mixing valve (Fig. 2).

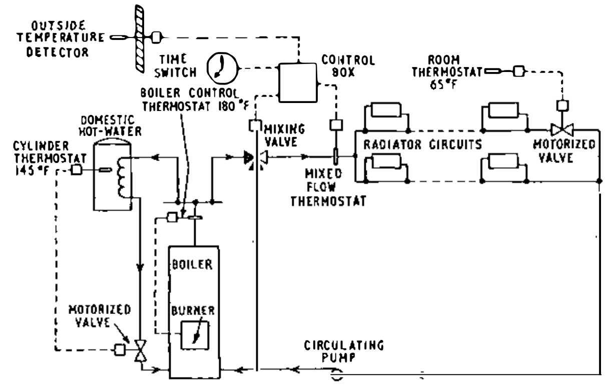


FIG. 2—Application of controls to a small heating installation

Low-temperature return-water is mixed with water from the boiler to give a resultant mixed flow. The position of the mixing valve is regulated so that the relative amounts of boiler water and return water give a constant flow temperature as long as the outside temperature remains unchanged. A rise in outside temperature will cause the flow-thermostat setting to be lowered and the mixing valve will, therefore, allow a greater proportion of return water, resulting in a lower value of flow temperature. The opposite effect will occur on a fall of outside temperature. Set-back and boost are achieved by biasing the relationship between the outside detector and the flow thermostat to alter the operating range.

Local Controls

The need for local control of the heat emitters in some rooms has already been mentioned. Overheating can be prevented by a room thermostat which closes a valve to shut off the water flow to radiators in that room, or, alternatively, individual radiator valves may be thermostatically controlled. The situation where one room must be kept up to normal temperature at night when the main-flow temperature is depressed can be catered for in this manner. By increasing the installed radiator surface a room temperature of 65°F can be met under night set-back conditions. Overheating with normal flow-temperatures during the day is then prevented by a room thermostat set at 65°F.

Unit heaters will not operate satisfactorily in the same circuits as radiators because the lower values of compensated flow-temperature result in relatively cool air being blown by the fans. Control is best effected by installing the unit heaters on a separate circuit supplied from the unmixed boiler flow which is maintained at 180°F. Their output is then regulated by switching the fans on and off with a room thermostat.

CONTROL-SYSTEM ELEMENTS

An automatic control system for a complete installation is built up from one or more control-system elements. Some of these may be combined to interact with each other, while others will perform independent operations. Each control element is, in itself, a closed-loop system in which information about any change of a controlled condition is fed back to equipment that will counteract the change and restore the

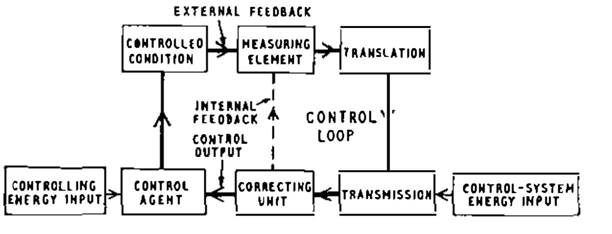


FIG. 3—Block schematic diagram of closed-loop control system

desired value of the condition (Fig. 3). A closed-loop system must perform the following basic operational functions.

(*i*) Measure changes in the controlled condition.

(*ii*) Translate the measurement into energy of appropriate direction and amount.

(*iii*) Transmit the control energy from the point of translation to the point of corrective action.

(*iv*) Use this energy to position a corrective unit which will carry out the corrective change.

(*v*) Detect completion of correction.

(*vi*) Terminate the call for correction, to prevent over-correction.

The controlled condition may be the temperature of air in a room or of water in a pipe, but could alternatively be pressures or levels, and could be in any medium. The functions within the loop are performed by devices appropriate to the operation of the system. Examples of such devices are given in Table 1.

Table 1

Function (See Fig. 3)	Examples
Controlled Condition	Water temperature; air temperature
Measuring Element ..	Bi-metal; bellows; thermistor
Translation	Switch; variable resistance
Transmission	Pipes; mechanical linkages; electrical circuits
Correcting Unit ..	Valve; damper; switch
Control Agent ..	Water flow; air flow
Controlling Energy ..	Heat from boiler
Control-System Energy	Electricity; compressed air

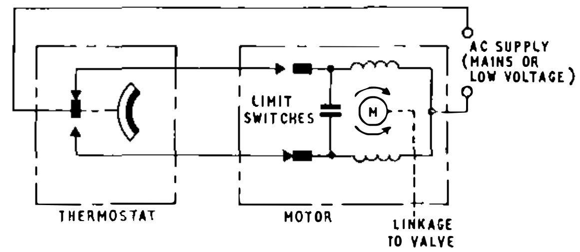
Systems are classified into types acording to the means used for translation and transmission of the control functions. Control-system elements are classified into groups according to the method by which the system acts. Three basic modes of operational action are possible with any of the various types of system.

Type of System	*Mode of Operation*
Electric Electronic Pneumatic Hydraulic Mechanical	Two-position Floating Proportional

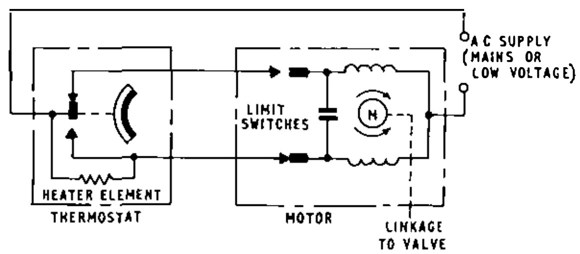
There are, of course, many variations and extensions of design within each mode to meet the numerous applications for which each one is suited; this applies not only in the field of heating but also for ventilation, air conditioning and industrial processes. Electric and electronic systems are those most commonly used in the British Post Office heating installations and so examples from these will be described to explain the operational principles of the different modes of control.

Two-Position Control

The basis of two-position control is a thermostat having a snap-action switch. Movement of a bi-metal sensing element in response to temperature change operates the switch to close or open an electrical circuit. A finite temperature difference is necessary for the sensing element to change the switch position in each direction, and this gives rise to the operating differential. Two-position control of a motorized valve is shown in Fig. 4(*a*). Operation of the thermostat completes



(*a*) Simple



(*b*) Timed

FIG. 4—Two-position control

the circuit for a split-phase reversible a.c. motor which drives in the appropriate direction until disconnected by a limit switch at the end of its travel. Motor drive is transmitted via reduction gears and a linkage to move the valve stem.

Once energized the motor must run to one or other of its extreme positions and remain there until the sensing element changes through its differential. The valve will, therefore, be either fully open or fully closed and the controlled temperature will fluctuate up and down between two extremes. In theory, this fluctuation would be the amount of the thermostat differential, but, in practice, there is a certain amount of over-shooting and under-shooting due to time lags in the control system and the heating system, which delay the response of the sensing element. For this reason simple two-position control is rarely used for constant-temperature regulation. It is, however, widely used in another form as an open-loop system for alarms and safety devices.

Timed Two-Position Control

With timed, or accelerated, two-position control the circuit arrangement is similar to simple two-position control except that a small heater element is included in the thermostat (Fig. 4(*b*)). The action of this heater, placed adjacent to the sensing element, overcomes the disadvantage of cyclic variations in the controlled temperature. The heater warms up and cools down alternately as it is switched on and short-circuited by the thermostat contact. This results in the motorized valve opening and closing at a fixed rate giving an average flow and, hence, an average output from the heating circuit. If the ambient temperature at the thermostat falls, then the sensing element will warm up more slowly and cool down more quickly, thus altering the on-to-off ratio. The motorized valve remains open for a longer time during each switching cycle, so the average flow is increased. A rise in ambient temperature produces the opposite effect, thus decreasing the average flow. Since the thermostat detects general changes in ambient temperature rather than cyclic changes produced by the controlling action, the fluctuations in controlled temperature due to system lag are greatly reduced. A relatively smooth control is thereby obtained, producing a system suitable for air-temperature or water-temperature control where normal transfer lag is inherent.

Floating Control

Floating control employs a measuring unit having a change-over contact with a mid off-position (Fig. 5). The

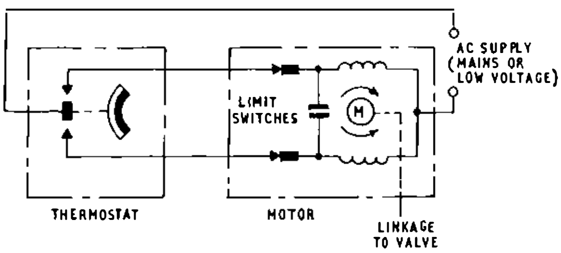


Fig. 5—Floating control

contact makes on one side or the other at each end of the sensing-element differential. While the controlled condition is within the differential, the contact is floating in its mid off-position. When the contact makes, the control motor drives in the appropriate direction and continues until the sensing element detects the restored condition, at which point the contact breaks and the motor remains in its new position. The valve may, therefore, take up any position between fully open or fully closed.

If the system is slow in responding to corrective action, the motor will drive each time until its limit switch operates, thus causing the control to become unstable. Floating control can only work satisfactorily in systems with a fast reaction rate having very little lag, and where changes in load are slow. It is, however, very accurate when operating correctly in a suitable application such as pressure regulation or liquid-level control.

Proportional Control

In proportional control the measuring unit operates on a different principle from that used in two-position and floating control; instead of a switching action, its output is a variable quantity which causes the correcting unit to be set to a position proportional to the amount of deviation of the controlled condition from its desired value. For temperature control the sensing element is a vapour-filled sealed bellows which expands and contracts in response to changes in temperature. This is connected to the arm of a potentiometer so that movement of the bellows is translated into variations in electrical resistance. The control potentiometer is in the circuit of a balance relay, the single floating contact of which controls the reversible motor. Fig. 6 shows the control in its mid-position.

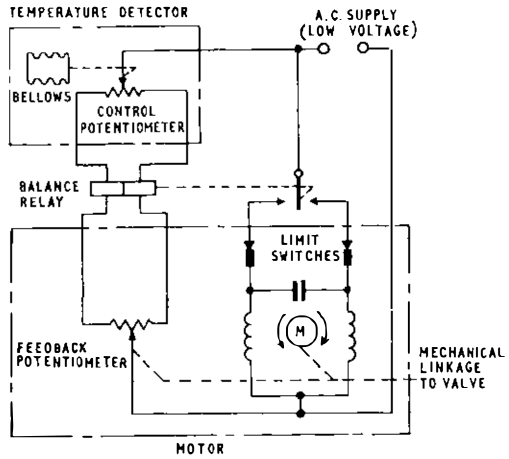


Fig. 6—Proportional control

With the control in its mid-position, current through the two halves of each potentiometer and through each coil of the balance relay will be equal, so the relay contact is floating and the motor is disconnected. Movement of the control potentiomcter to a new position will increase the current through one coil and decrease the current through the other coil, causing the balance relay to operate and complete the motor circuit. The motor drives in the direction appropriate to the control-potentiometer movement. At the same time, the motor feedback potentiometer moves in the opposite direction to restore current balance through the parallel circuits of the relay coils. On reaching balance the drive is disconnected and the motor remains in its new position. The amount by which the motor moves is proportional to the amount by which the control potentiometer has moved, and the motor can take up any stationary position between either end of its operating range. Thus, the motor position is a continuous linear function of the controlled temperature and there is a different position for every value of controlled temperature.

The range of temperature values corresponding to full movement of the motor is termed the proportional band of the system. Internal feedback results in a very stable controlling action, but the temperature will be somewhere within the proportional band rather than precisely at the desired value. This offset can be kept small if the external transfer lag is not excessive. Where an offset of a few degrees is acceptable, proportional control will, therefore, give excellent results.

Electronic Proportional Control

Electronic control systems have a very quick and sensitive response and differ from most others in that the sensing element is separated from the measuring and controlling elements. The sensing element, which is normally a thermistor, has a variable resistance-temperature characteristic. Being simple in construction, with low mass and having no moving parts, the thermistor provides rapid response to load changes. The changes in resistance are, however, too small to permit the element to be used directly in a relay circuit so it must operate in conjunction with an a.c. bridge and an amplifier (Fig. 7). Strictly speaking, the amplifier is the only electronic portion, but sensing and translation are effected by static devices and the name "electronic" is given to the whole system. The output relays and motors are, of course, electro-mechanical.

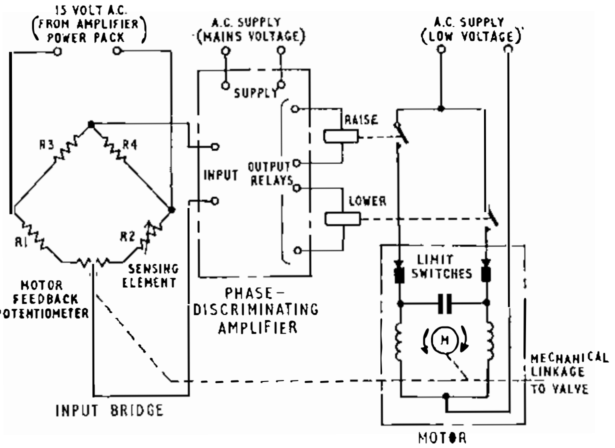


FIG. 7—Electronic proportional control

From an initial-balance condition any change in sensing-element resistance results in bridge unbalance, producing an a.c. signal across the bridge output. The phase of the signal will indicate the direction of the change, and the amplitude will indicate the magnitude of the change. The output from the bridge is fed into a phase-discriminating amplifier, and the system is calibrated so that the signal voltage will be zero when the controlled temperature is at the desired value. A deviation in temperature causes a change in sensor resistance, resulting in a signal to the amplifier. Depending on the phase of this signal the appropriate output relay will operate to drive the motor in the required direction. Motor drive continues until the feedback potentiometer has restored the the bridge balance condition, thus removing the input signal from the amplifier.

The input bridge of an electronic control circuit can easily be adapted to give many facilities. For example, resistor R3 can be replaced by a second sensing element so that the system output is then the vector sum of two independently variable inputs. This can form the basis for an outside-temperature compensation control, with the R2 sensor in the mixed-water flow, the R3 sensor measuring the outside air, and the motor controlling the mixing valve. Further resistors can be incorporated into the bridge under the control of a time switch to give the necessary biasing conditions for set-back and boost operation.

Proportional-Plus-Integral Control

It is possible to combine the stability of proportional control with the accuracy of floating control, even in applications where transfer lags are great and load changes are rapid.

In a particular form of floating control the rate of driving the correcting unit is made proportional to the deviation from the desired value; the motor drives while a deviation exists, but at a decreasing speed as the desired value is approached. This is known as integral control, and it can be used to correct the offset inherent in a proportional-control system. Difficulties arise if proportional control alone is applied to systems having large transfer lag; wide proportional bands must be used to avoid hunting and this results in large offset.

When proportional and integral action are used together, the proportional action of the combined system responds to changes in load and sets the motor to an appropriate position. Integral action continues to drive the motor by a series of pulses until the desired value of the controlled condition has been reset. The rate of these pulses is proportional to the amount of offset and will decrease towards zero when the desired value is reached. Comparatively-wide proportional bands may, therefore, be used to achieve stability because integral action will continue as long as a deviation exists and until the offset is eliminated.

A detailed explanation of the electronic circuits for proportional-plus-integral control is beyond the scope of this article. Briefly, however, the motor-feedback potentiometer, instead of being in the input bridge, is arranged to cause unbalance within the amplifier when proportional action has occurred. This produces the pulsed output to drive the motor until the desired value is reached. The input bridge balance is thus restored and the amplifier input-signal disappears.

CONCLUSIONS

At the design stage of an installation the controls have to be selected carefully in order to ensure their suitability for particular applications. No control system can maintain absolutely constant conditions, but this ideal is being more closely approached as the science of control advances. The required degree of accuracy and the availability of control energy must be weighed against complexity and cost in choosing the type of system to be employed for a particular installation, and in choosing the mode of operation for the individual control-system elements.

A very wide range of control equipment is now commercially available from the many manufacturers in this field, and introduction of transistor-type amplifiers is leading to the more sophisticated electronic systems being used for applications hitherto considered uneconomic. Controls are, therefore, being incorporated into heating installations of all sizes to an ever increasing degree, and, with rising fuel costs, it is imperative that the equipment functions correctly to do the job for which it is provided. This establishes the need for adequate knowledge and understanding of the principles involved so that operation and maintenance will be of the necessary high standard.

Book Review

"Antennas." L. B. Blake. John Wiley and Sons, Ltd. 415 pp. 138 ill. 56s. (cloth) 30s. (paper).

This well-prepared textbook has clarity of presentation and careful attention to the correctness of terminology (American). It is intended for the technician who prefers not to become involved in higher mathematics and for the professional engineer not working on this rather specialized subject. It makes pleasant reading and, for the more intent, provides problems and exercises which are given at the end of each chapter.

The first three chapters deal with electromagnetic waves in general terms, using optical principles to illustrate their characteristics, and they include the principles of transmission lines, the behaviour of waveguides and components, and descriptions of the terms and components used in aerials.

Chapter 4 covers the basic forms of radiating elements, including long-wire and loop aerials, slot radiators and methods of feeding aerials.

Basic array theory, with illustrations of various forms of arrays, are given and a chapter is devoted to reflectors and lenses followed by various "special" types such as the log-periodic, biconical and direction-finding aerials. In this era of space communications, low-noise aspects are given only a small section in the penultimate chapter, although an elementary treatment of noise is given in the final chapter on measurements. This chapter also completes some of the definitions used in this field. The author finally quotes a claim for a low-noise aerial having a noise temperature of 4·5°K. This is an improbable figure, and it is surprising that this flaw should appear in an otherwise excellent book.

I. A. R.

Ploughs for Laying Duct and Cable

F. L. BEST and R. W. MARTIN†

U.D.C. 631.312 : 621.315.235 : 621.315.671

Increasing use is being made of ploughs to lay cable and duct direct in the ground. This is a brief account of the general practice of mole ploughing as carried out by the Post Office and the development of ploughs for the job. The major factors and conditions affecting the methods employed and the design of the ploughs, together with techniques which may be exploited on new designs, are described.

INTRODUCTION

Using a mechanical aid to bury wire or cable direct in the ground is not new. It is recorded that during the Crimean War an ordinary ploughshare was used to make a furrow in which wires for telegraph circuits were buried.

In principle, cable and duct could be laid by plough in almost any condition of ground if the cable plough is sufficiently robust, sufficient power is available to pull it, there is sufficient room to operate and the degree of soil disturbance and surface damage can be tolerated. For example, given adequate power and a stout plough it would be possible to plough in a cable along a concrete airport runway but the surface damage would be intolerable.

In general, the design of cable-laying machines has been based on agricultural moledrainers or subsoilers.

The moledrainer is a machine for making land drains and consists essentially of a vertical blade with a mole, a length of round steel bar about 2–3 in. diameter, attached to the lower end. As the blade is pulled through the ground, the mole compresses the earth and leaves a drainage channel in the soil. Moledrainers were developed early in the 19th century when mobile steam ploughing engines became available and were able to provide the power necessary to pull a moledrainer blade through the soil.

A typical arrangement of a mole and blade is shown on the Ransome moledrainer, model C.1.E. (Fig. 1). On this particular machine the depth can be controlled by a hand-operated screw jack so that it is possible to maintain a steady slope when making a land drain.

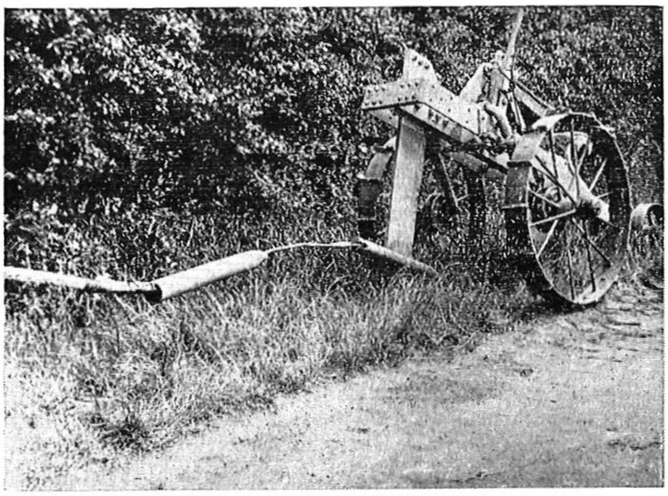


FIG. 1—Ransome C.1.E. moledrainer showing connexion of the cable to the mole

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EARLY DEVELOPMENT

The moledrainer, then, was a simple and quick, if brutal, method of forming a long hole in the ground and the hole was enlarged as necessary by expanders following a short distance behind the mole to which they were attached by a short length of chain. The possibility of drawing in a cable in a similar manner offered an economic system of cable installation. The cable was attached to the mole by a short length of galvanized-iron wire, which acted as a mechanical fuse to avoid overstressing the cable, and the leading end of the cable was protected by a metal sleeve (Fig. 1).

However, the method was not so simple or as effective as would appear from first studies. The cable had to be protected against mechanical damage and corrosion and, when so protected and armoured, the cables were stiff and rough. As a result, because of heavy friction between the cable and the wall of the moledrained channel, it was, at times, only possible to pull in very short lengths of cable before the mechanical fuse failed. It was then necessary to cut the cable and start pulling in another length from the point at which the mechanical fuse had failed. This, of course, made the job rather slow and increased the number of joints, the positions of which could not be determined in advance. Nevertheless, in the 1930's a number of junction cables were laid in East Anglia where soil conditions are favourable[1] and during the 1939-45 war a considerable amount of cable was installed by moleplough around airfields and other military installations.

During this period, a method was devised whereby the cable was laid by passing it down a guide tube attached to the rear of the moledrainer blade. This method placed no strain on the cable so that unarmoured cables could be used and, barring obstacles, the length of cable which could be laid was limited only by the standard lengths of cable.

In 1947 the Post Office purchased a number of Ransome model C.1.E. moledrainers which were modified for cable laying by fitting one, two or three cable tubes behind the blade, as shown in Fig. 2. Thus it was possible to lay up to three cables simultaneously.

OPERATING REQUIREMENTS

Much work was done with these machines despite certain shortcomings. The Ransome plough was heavy, about 11 cwt, and required a clear path 5 ft wide in order to operate. If obstacles were encountered, cable could not be removed from the guide tubes without cutting it and the moledrained channel left in the soil was used as a run by rodents which seem to thrive on pitch, hessian and lead, and caused a considerable amount of cable damage.

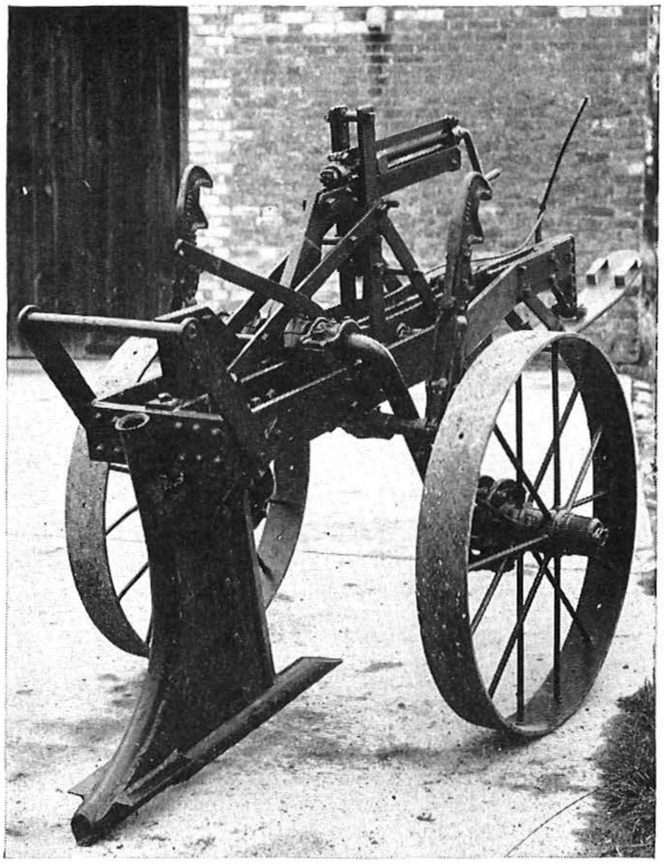

FIG. 2—Ransome C.I.E. moledrainer modified for cable laying by the addition of cable tubes.

The last two disadvantages could be overcome by fitting a cable guide with a removable back, instead of guide tubes, and redesigning the mole so that soil was left loose and collapsed on to the cable. Even so it was realized that if the best use was to be made of cable ploughs then a machine designed to operate within the limits imposed by the geography of the country was required.

In some parts of the world, notably North America and Australia, conditions have made it possible to develop and use large moleploughs pulled directly by large caterpillar-tracked tractors which sometimes also tow a cable-drum trailer behind the plough.

Rural conditions in the United Kingdom often consist of narrow winding roads with restricted grass verges which have an underlying mat of roots from adjacent hedgerows and trees; the verge may also be bordered either by an embankment or a ditch with gullies at frequent intervals to allow rain water to drain off the road into the ditch. Sometimes there may be only a ditch or embankment and it may be necessary to lay a cable in either one of these. These conditions impose many limits on both the design of the mole-plough and the method of operation.

The method most suitable for general use in this country is to haul the plough by winch. The winch is fitted to an industrial-type wheeled tractor which has a hinged-sprag type anchor at the rear and is also often equipped with a hydraulically-operated loader that is used for handling the plough and drums of cable.

This method is very flexible because it is only necessary to find stations for the tractor at intervals not exceeding the length of the winch rope, 225 ft, and the plough can be pulled through quite narrow gaps providing it is possible for the tractor to take up a position on the far side of the gap. The tractor positions need be only approximately in line with the line of the cable route because the direction of pull can be adjusted, as necessary, by passing the rope through a suitably positioned snatch block. This may be attached to a spade-type anchor or tree or any convenient point stout enough to withstand the strain.

This method of working entails using a mechanical fuse to limit the line pull so that the stability of the tractor is not endangered or the structure overstressed. The fuse breaks at a predetermined load and, when breaking, dissipates a large proportion of the strain energy of the winch rope so that the rope does not flail dangerously. The fuse used by the Post Office consists of a length of seven-strand 8 s.w.g. stay wire with an eye formed at each end. The fuse is 3 ft long and the nominal breaking strain is 9,800 lb. Rope strain energy is dissipated by the elongation which the fuse undergoes between the yield point and the breaking stress.

The plough itself must be quite narrow, preferably not more than 18 in. wide at any point, and, in order to minimize cable damage, it must not make a channel which can be used as a rodent run. It must be strong enough to withstand direct pulls of 5 tons plus shock loads caused by striking underground obstructions, and yet it must be reasonably light and fairly portable. Also it should preferably be simple to manufacture, maintain and repair.

A number of small skid-type agricultural moledrainers were investigated and some, such as the Auto-Mower machine (Fig. 3), although readily adapted for cable laying,

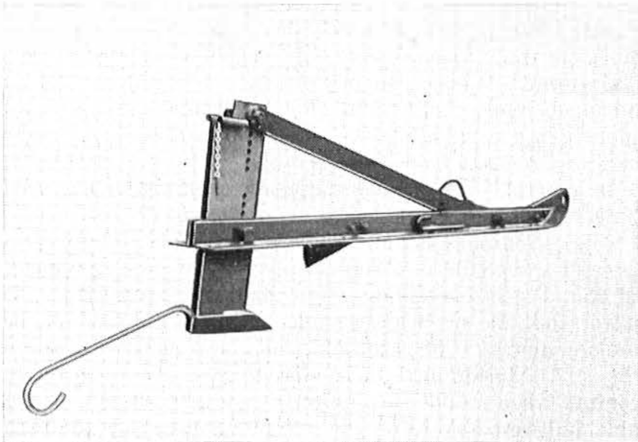

FIG. 3—Auto-Mower skid-type agricultural moledrainer

were not entirely suitable for Post Office work. So in 1953, after a number of experiments, the first Post Office designed machine, Moleplough No. 1, was produced.

MOLEPLOUGH NO. 1

This machine (Fig. 4) is 8 ft 4 in. long, weighs approximately 3¼ cwt, and can lay cable at a maximum depth of 18 in. It is made of mild-steel angle, sheet and bar except for the blade, for which a higher-tensile steel is required, and the seat spring that is made of a high-carbon spring steel.

At the foot of the blade, in place of the round mole used on agricultural moledrainers, is a flat plate 4 in. wide and ½ in. thick. The front end of this plate is pointed and chamfered and is turned down at an angle of 15 degrees. This turn-down at the front of the foot produces a downward force which helps to keep the blade in the ground at the set depth. The passage of this blade through the ground leaves the subsoil loose around the cable and so prevents the formation of an open rodent run.

The cable guide fits immediately behind the blade and tapers in cross-section from ¾ in. wide at the leading edge to 1½ in. wide at the rear. The removable back enables cable to be easily placed in the guide and removed without cutting. The rotating-disk coulter at the front of the plough cuts cleanly through grass and roots to a depth of 3 in. and helps to minimize surface disturbance. The seat at the rear end is

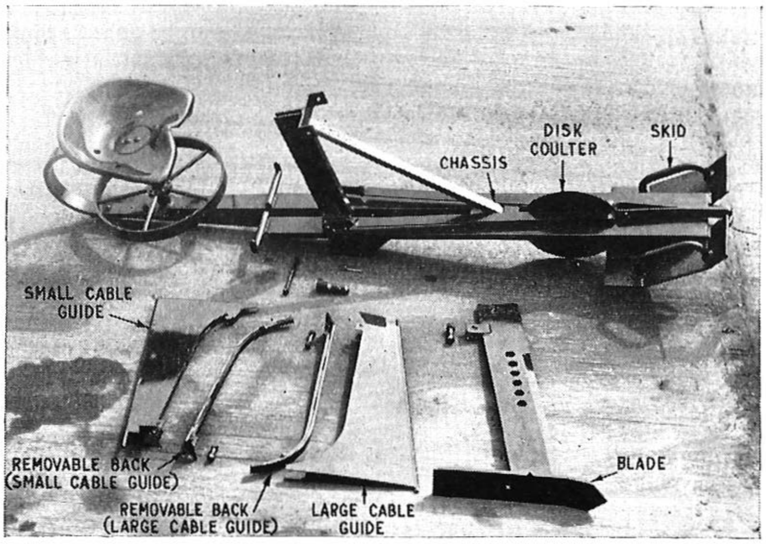

FIG. 4—Post Office Moleplough No. 1

intended for one man to sit on the machine and feed the cable in to the cable guide and the wheel underneath the seat enables the plough to be moved for short distances in wheelbarrow fashion.

The machine has not changed basically since its introduction but a number of modifications have been made to simplify or improve construction and the cable guide, which originally could accommodate one cable 1 in. diameter and one cable 0·8 in. diameter, can now take two cables 1·125 in. diameter.

The Moleplough No. 1 operates satisfactorily in both light and heavy soils which are generally free from large stones but, in other conditions, there is often difficulty in maintaining depth and the force needed to haul the moleplough is often more than would appear necessary.

A great increase in the use of moleploughs was brought about by the advent of polythene-sheathed cable which was lighter, more flexible and cleaner to handle than its lead-sheathed counterpart and could be buried direct in the ground without any additional protection against corrosion. A machine capable of working satisfactorily in a wider range of conditions and able to lay larger diameter cables was therefore required.

In 1959 the National Institute of Agricultural Engineering (N.I.A.E.) carried out a number of tests with a Moleplough No. 1[2] and concluded that several factors were contributing to the excessive draught or force required to pull the machine and other unsatisfactory features. These were primarily:

(*a*) The narrow slit made by the blade was expanded by the diverging side plates of the cable guide. The soil exerted considerable friction on the side plates and so increased the draught.

(*b*) The junction between the vertical part of the blade and the foot was a dead spot over which the soil did not flow. Blocks of soil collected at this point on both sides of the blade and friction between these blocks and the surrounding soil increased the draught.

(*c*) Depth-control skids on the chassis, and adjacent to the blade, pressed down on the wave of soil raised by, and flowing past, the blade and so increased friction between the machine and the soil.

(*d*) The weight of the plough, plus the downward force exerted by the soil on the blade foot, was insufficient to overcome the upward force exerted by the soil on the near vertical blade, hence the difficulty in maintaining an even working depth.

The N.I.A.E. also concluded that the most important fault in design was the attempt to make a wide slit by expanding a narrow one: use of a wide blade, with side clearance to reduce soil–metal friction, would have considerably less draught.

Following on from this work, the N.I.A.E. designed a new cable-laying plough (Fig. 5) using as the main working part a standard commercial subsoiler tine with a replaceable point. The tine was non-adjustable and so the operating depth was adjusted by a variable geometry chassis.

Twelve machines were made to this design and placed in service. Their performance was generally good, the draught

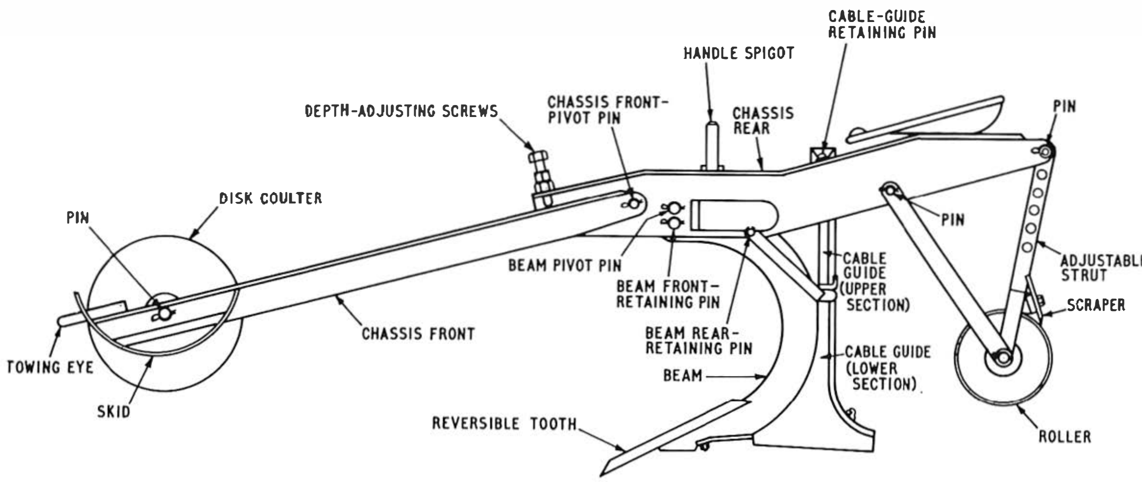

FIG. 5—National Institute of Agricultural Engineering cable-laying plough

in particular often being some 30–35 per cent lower than that of a Moleplough No. 1 operating in similar conditions but the chassis exhibited a number of weaknesses and there were handling difficulties due to the size and weight of the machine. A plough was therefore designed employing the same basic principles as the N.I.A.E. plough insofar as its mode of operation in the soil was concerned but with a fixed chassis and an adjustable blade. This machine was designated Moleplough No. 2.

MOLEPLOUGH NO. 2

The chassis of the Moleplough No. 2 is constructed largely of rectangular steel tube and rests on the ground at two points only, the front skid and the rear roller, as shown in Fig. 6. In between these points the chassis is clear of the

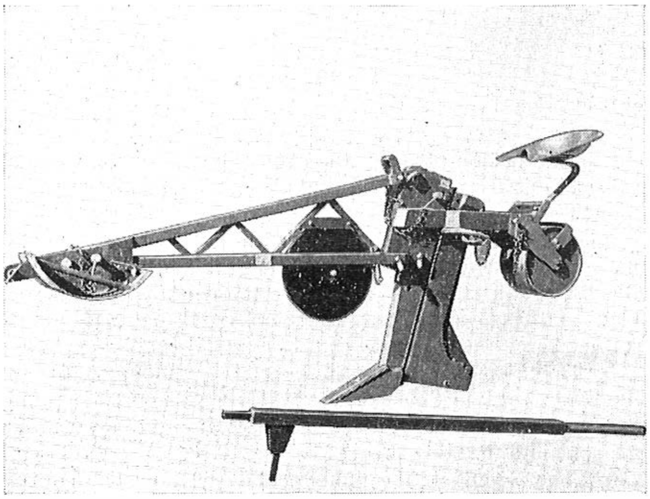

FIG. 6—Post Office Moleplough No. 2

ground and so does not restrict the wave of soil flowing past the blade. The blade is 1½ in. thick and the depth at which cable is laid is regulated by a series of holes in the blade, the maximum depth being 18 in. Two cable guides are provided, the larger one being able to accommodate cables up to 1¾ in. diameter, including Cable, P.C.Q.T. (Motorway). This larger cable guide is thicker than the blade and so, in order to relieve soil pressure on the side plates, the leading edge of the guide has been made approximately ½ in. thicker than the body of the guide and is stepped to give side clearance.

The blade has a replaceable foot and some of the downward force exerted by the soil on the foot is transferred to the roller and is utilized to assist in flattening the ridge of soil raised by the passage of the blade.

The disk coulter is placed much nearer the blade than on the Moleplough No. 1 and this close coupling of coulter and blade makes it easier to negotiate sharp bends.

Despite extensive use of high-strength lightweight sections in the construction of the plough it became apparent that the weight and size of the machine as a whole would create some manual-handling problems and difficulty in transporting it in smaller vehicles, e.g. Land Rovers. The chassis has been constructed, therefore, in five parts, skid, front chassis, blade housing, roller and handle. The blade and cable guides are the other main components. All parts are assembled by pins most of which have drop noses to retain them in position and are rust-proofed by sheradizing. The handle fits into a socket in the blade housing and can be arranged either vertically or horizontally. A lifting point is fitted so that the machine as a whole can be lifted if a suitable mechanical aid is available.

Because of the urgent demand for moleploughs, the Moleplough No. 2 has been manufactured and placed in service after a comparatively brief development period and further work remains to be done to improve its performance and to enable cables to be laid at greater depths.

LAYING DUCT

During the development period of the Moleplough No. 2 a number of trials were made of laying rigid PVC duct by moleplough.[3] The duct was attached to the blade and pulled into the ground behind it in a similar manner to the method originally employed to lay armoured cables.

This required the development of fittings to allow the duct to be attached to the blade and, if necessary, to release it without excavating. Such fittings have been designed for the Moleplough No. 2 and form part of the standard equipment supplied with the machine. The Adapter, Duct Laying, fits to the rear of the blade in place of the cable guide.

NEW PLOUGHS

Experience in recent years has shown the need for a robust plough able to operate in a wide range of conditions, and it is for this purpose that the Moleplough No. 2 has been designed.

Experience has also shown that with the increasing use of moleploughs there is room for a lighter plough specifically designed to work in a limited range of conditions. In fact two other ploughs have been designed and will shortly become available.

The first of these, Moleplough No. 3, will utilize the blade and cable guide of the Moleplough No. 1 mounted in a simplified skid-type chassis based on the Auto-Mower mole-drainer (Fig. 3). This machine will operate satisfactorily in soils generally free from large stones.

The second new machine, Moleplough No. 4, is designed for laying armoured-polythene cables on new housing estates. It will lay cable either 9 in. or 14 in. deep and will have no cable guide. The cable will be attached directly to the lower end of the blade and be pulled into the ground. Because of the smooth polythene sheath, soil-cable friction will be quite low. The Moleplough No. 4 will weigh approximately 120 lb.

NEW DEVELOPMENTS

Recently, the merits of vibrating the blade of a plough in order to reduce soil friction and lower the draught have been investigated.

A considerable amount of work on vibrating-blade ploughs has been done in North America where, in some areas, the formation of hard pan is a growing problem. Hard pan is a consolidated layer of subsoil which tends to form below normal cultivation depths in land subjected to intensive mechanized farming using heavy machinery. Subsoiler tools used to break up this compressed layer require very large forces to pull them.

Reductions in draught of the order of 50–80 per cent may be achieved by vibrating the tool. Power is required to vibrate the tool and this can be supplied by the tractor via a power take-off or by a separate power source mounted on the plough. A vibrated plough also causes less surface disturbance.

American utility companies have taken advantage of this vibration principle to develop cable-laying and pipe-laying ploughs which can lay telephone cables and other services with minimal damage to cultivated grass, etc. The various machines so far developed vary in size from a one-man operated machine powered by a 12 h.p. engine and designed to install lead-in cables to houses across open-plan grass frontages to large machines laying 1½ in.–2 in. diameter cables at 36 in. depth on which the vibrator alone absorbs some 60–70 h.p.

In all but one machine a vertical movement is excited in the blade by two synchronized eccentric masses rotating in opposite directions. In the other machine the blade is positively moved by a slider-crank mechanism and a small orbital movement is produced at the tip of the blade, thus using the inertia of the plough to literally hammer the tool forward through the soil.

In general, the overall power required to operate a vibrating-blade plough is about the same as for a conventional machine but the reduced draught of the former permits the use of lighter tractors with a consequent reduction in surface damage. Vibrating the tool can also reduce the draught enough to enable a tractor to maintain forward movement across soft, slippery or other difficult ground where it is not possible to develop sufficient draught to pull a non-vibrated machine.

Research into modes and frequency of vibration could possibly enable the draught of a plough to be reduced to a fraction of that of current machines. One avenue still to be explored is the use of very high frequency vibration which could have the effect of making the soil around the tool fluid. This technique has already been applied to deep-driven piles with considerable success.

CONCLUSION

The need for a duct-laying and cable-laying machine has led to progressive development and many new avenues are about to be explored. The development of an acceptably-sized self-propelled machine operated by one man and capable of laying 1½ in. diameter cables at 18 in. depth now seems possible.

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A New Cartridge-Type Fixing Gun

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U.D.C. 691.88.087

The cartridge-type fixing gun is a valuable aid in erecting light-load-bearing fixtures. A new type of tool has been adopted that should be safer in use than older designs. The precautions that are essential in using tools of this type are described.

INTRODUCTION

The cartridge-type fixing gun is a fixing tool that can drive a pin or threaded stud into wood, brick, concrete or mild steel without requiring a previously-drilled hole. The energy required to make this type of fixing is obtained from blank cartridges of varying strengths. Over a number of years tools of this type have increased in popularity in the building industry, and, since their original conception, they have undergone changes to make them more reliable and safe.

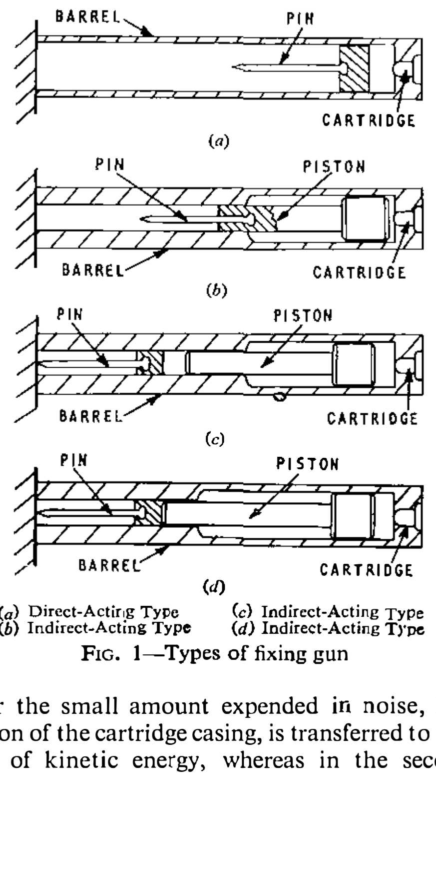
DANGERS ASSOCIATED WITH EXISTING TOOLS

The basic dangers with the cartridge-type fixing gun have been overdriving and ricochets of the pin or stud. Ricochets are caused when the pin or stud is fired into a non-homogeneous material, such as concrete, in which the existence of a piece of hard aggregate may deflect the stud in such a manner that it can turn back on itself with sufficient force to cause an injury to the operator of the tool. Overdriving describes the condition when the pin or stud is fired into a material with too great a velocity, so that it passes through the material and continues in flight as a projectile on the other side.

ALTERNATIVE SYSTEMS OF OPERATION

The principles of operation of the different types of cartridge-assisted fixing tools are as follows.

In the first type (Fig. 1 (*a*)), all the energy from the cartridge, except for the small amount expended in noise, heat and deformation of the cartridge casing, is transferred to the pin in the form of kinetic energy, whereas in the second type



(*a*) Direct-Acting Type (*c*) Indirect-Acting Type
(*b*) Indirect-Acting Type (*d*) Indirect-Acting Type

FIG. 1—Types of fixing gun

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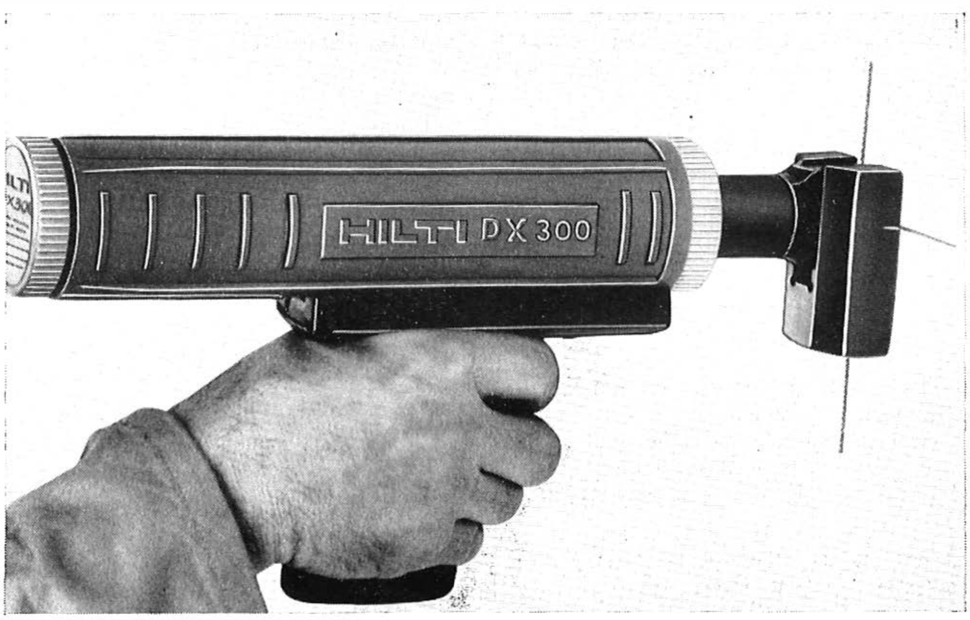

FIG. 2—New-type fixing tool

(Fig. 1(*b*)) the energy from the cartridge is transferred to a plunger which drives the fixing. The second, third and fourth types (Fig. 1 (*b*)–(*d*)) are almost identical in their operation, as the energy from the cartridge accelerates a plunger which in turn drives the pin or stud into the material.

Because of their "direct" operation tools of the first type are referred to as direct-acting tools, whereas the other types are referred to as indirect-acting, since the plunger is an intermediary between the cartridge and the stud or pin. While an impulse of much the same magnitude is produced in each type of machine, the comparatively high mass of the plunger results in much lower muzzle velocities with indirect-action tools. Direct-acting tools have muzzle velocities of 850–1,400 ft/sec, whereas with indirect-acting tools the muzzle velocity lies between 50 ft/sec and 300 ft/sec.

DESCRIPTION OF NEW TOOL

A tool of the low-velocity type has recently been adopted for general use in the British Post Office. The principle used in this tool, of directing the pin or stud into a wall or structure via a plunger, is much safer, and the new item (Fig. 2) embodies the other necessary requirements, which are (*a*) it should be easy to use, and (*b*) it should require little maintenance. This latter requirement involves the number of parts to be dismantled and the ease with which dismantling and re-assembly can be carried out. Fig. 3 shows a cartridge being inserted in the new tool.

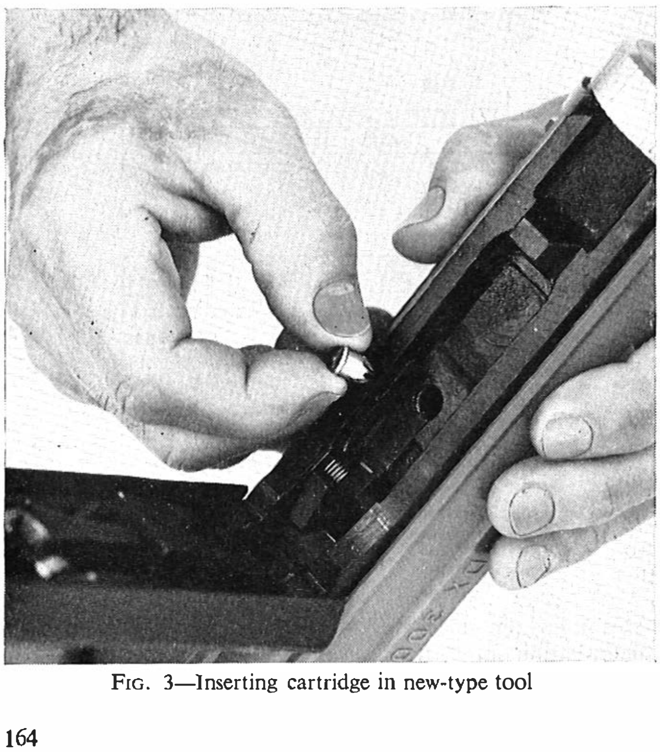

FIG. 3—Inserting cartridge in new-type tool

SAFETY PRECAUTIONS

Used sensibly, the new tool involves negligible risk. As with all power-operated tools, however, it is essential for the operator to observe certain precautions to prevent accidents occurring. The more-important precautions are listed below.

(*i*) Only trained operators should use the tool.

(*ii*) The gun must never be pointed at anybody, and should be kept unloaded when not in use.

(*iii*) The operators should wear eye shields, safety helmets and, if necessary, ear protectors.

(*iv*) The gun must be retained in position for at least 30 seconds if the cartridge fails to detonate.

(*v*) Pins must not be fired into very soft or brittle materials, holes made by a previous attempt, existing holes or near corners of walls.

(*vi*) The tool should not be used in premises where there is a risk of fire or explosion.

(*vii*) When not in use, the gun must always be kept locked in its container.

(*viii*) The weakest cartridge must always be used for the first fixing, progressively stronger cartridges being used, if necessary, to give the correct strength.

PERFORMANCE

Some of the main uses of this tool are: fixing battens for cabling, fixing saddles for conduit, and providing other light-load-bearing fixtures in brick, concrete or mild steel. The tool is already in use and in one Telephone Area two men with one of these guns made 500 fixings in a 10-hour day. This job involved running a cable in a small tunnel where working space was restricted by other plant and by the overall height of the tunnel. Using ordinary methods this operation would have been arduous and costly.

An Electronic Automatic Call Sender for Testing New Telephone Exchange Installations

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U.D.C. 621.395.722.001.41:621.395.63:621.395.345

The advent of electronic telephone exchanges has led to new methods of acceptance testing. The general principles of these new methods are discussed, and the part played by the call sender in the new methods of testing is explained. The operation of the new tester—a multi-sender traffic-simulating equipment—is described, and the development of a more advanced model, using integrated circuits, is mentioned.

INTRODUCTION

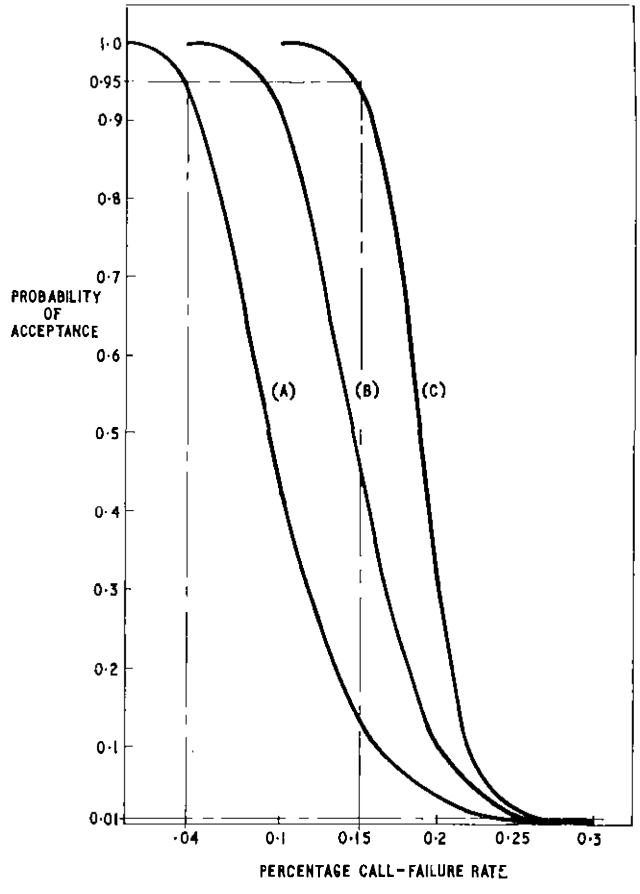
With the arrival of electronic telephone exchanges it has been possible to introduce a new and streamlined method of acceptance testing exchange equipment provided under contract. The use, on site, of functional testers for individual items of equipment is being abandoned, except where such testers are absolutely necessary as commissioning aids. It is held that the nature of the devices used in electronic exchanges is such that, if the general quality of the equipment is sound, the functional tests carried out at the end of the production line at the manufacturer's works should provide a reasonable safeguard against the installation of faulty items. It follows from this that great emphasis must be placed on quality-control methods and a very searching final functional test in the factory, if the obviously unacceptable situation where a substantial quantity of equipment is shown to be faulty in some respect at an advanced stage of the exchange installation is to be avoided.

When a new electronic exchange has been installed for the British Post Office, the contractor carries out a testing process according to a jointly-agreed commissioning schedule. The Post Office clerk of works monitors this process to satisfy himself that each stage has been completed satisfactorily. An exchange is said to be commissioned when all the facilities specified for the system have been provided and tested, all site and factory wiring has been completed and checked, and all equipment provided under the contract is in working order. It is necessary at this stage to provide some final test to assess the quality of service that the public may expect when the exchange is opened. The most satisfactory way of doing this is to pass a number of calls into the system. A representative sample involves a large number of calls, with a sufficient number taking place simultaneously to ensure that the calls are spread fairly evenly over all the exchange equipment. The calls must also be carefully controlled in order that the performance of the exchange may be accurately judged. The automatic call sender described in this article has been designed for that purpose.

FINAL ACCEPTANCE BASED UPON PREDICTED QUALITY OF SERVICE

The final acceptance by the British Post Office of a new telephone exchange installation is based upon the theoretical probability of accepting a unit with greater than a given call-failure rate when taking a sample of finite size with a fixed rejection-figure. An exchange network, during its lifetime will establish an infinitely large number of connexions: this is so irrespective of the size of the exchange or its calling rate. The sample size may therefore be independent of the size of the unit being tested. It is only necessary to ensure that the calls making up the sample are set up in a random fashion.

Fig. 1 shows a family of curves derived from Poisson's exponential binomial limit. Each curve represents the probability of the whole population of calls, i.e. the exchange performance, having a given failure rate, based on the sample



A—Sample size: 5,000 calls; acceptance number: 4
B—Sample size: 10,000 calls; acceptance number: 14
C—Sample size: 30,000 calls; acceptance number: 56

FIG. 1—Family of sampling curves each giving approximately 1 per cent risk of accepting an exchange with greater than 0·25 per cent call-failure rate

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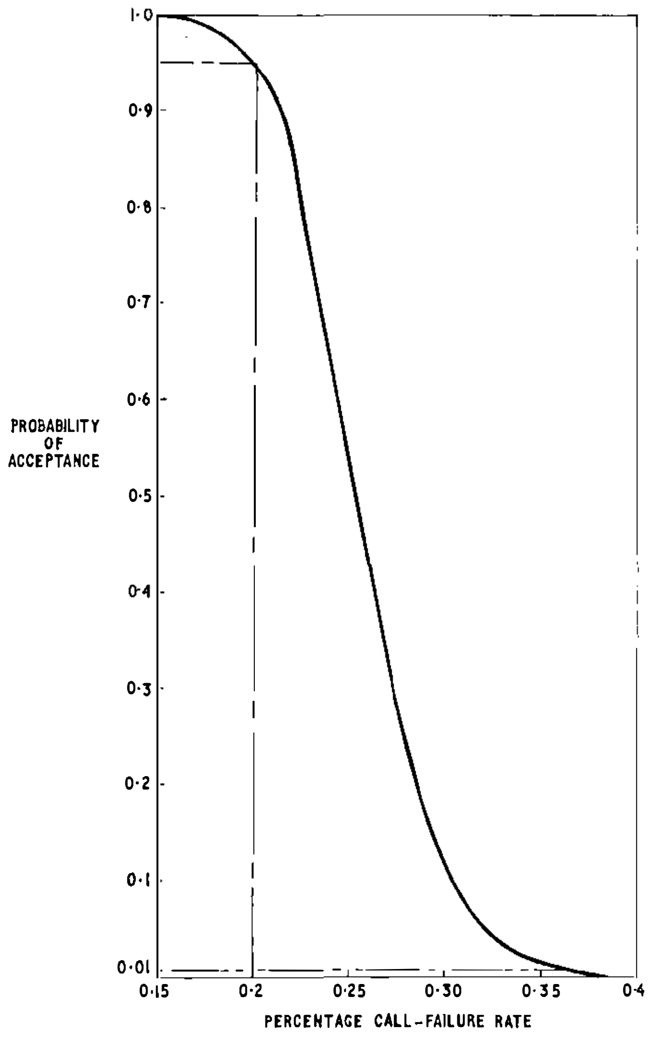
size and rejection figure shown. Thus, taking curve C for a sample size of 30,000 calls, and with an acceptance figure of 56 failures, the probability is less than 1 in 100 that the exchange has a failure rate of 2·5 calls, or more, per 1,000. At the other extreme, the probability is less than 5 in 100 that the true performance is 1·5 call failures, or less, per 1,000. Alternatively, this means that if equipment is manufactured and installed to give a standard represented by a call-failure rate of 1·5 calls per 1,000, there would be a 5 per cent risk of rejecting a particular exchange, using the sample size and rejection figure quoted. The first probability, 1 in 100, is usually taken as the risk to the Post Office of accepting a bad exchange, while the second probability, 5 in 100, is taken as the contractor's risk of having a good exchange rejected. If a smaller sample size is chosen, say 5,000 with an acceptance figure of 4, curve A, the manufacturing and installation objectives become very much higher in order to achieve the same degree of risk. Fig. 2 shows a practical operating curve; the sample size is 20,000 calls with an acceptance figure of 50. Thus, if equipment is manufactured and installed so that an average failure rate of 2 calls per 1,000 is to be expected, the risk of accepting a particular exchange with a failure rate of 3·4 calls per 1,000, or more, is less than 1 in 100. The contractor's risk of having an exchange wrongly rejected, when its true performance is better than 2 calls lost per 1,000, is 5 in 100.

At the end of the commissioning period, when the installing contractor is satisfied with its performance, the exchange equipment is handed over to the Post Office clerk of works so that he may carry out a final acceptance test based upon the principles described above. The clerk of works will prepare a schedule of 20,000 test calls in such a fashion that all types of routing and all classes of subscribers' line circuit receive an appropriate proportion of the total number of calls. Outgoing and incoming routes are tested by temporarily looping outgoing junctions back into incoming junctions, as failures due to the external lines and network must be eliminated. The test programs are so arranged that the maximum number of calls possible take place simultaneously, while at the same time they ensure that no significant risk of congestion is present.



Sample size: 20,000 calls
Acceptance number: 50

FIG. 2—Practical sampling-test curve giving a 1 per cent risk of accepting an exchange with a greater than 0·34 per cent call-failure rate

The call sender pulsing-out circuits (senders) are connected to subscribers' line circuits, which serve as inlets to the network. The call sender is then programmed by writing into its store the first 50 test numbers from the schedule. The 50 subscribers' line circuits selected by this program are individually connected to test-number relay-sets contained in a portable answering circuit. The call sender is then instructed to give the appropriate conditions to the line circuits selected as inlets, depending on whether they are ordinary, shared-service or coin-box circuits, and the test cycle is started. At intervals during the 20,000-call final acceptance test, and in accordance with the schedule prepared by the clerk of works, the program is altered and the inlets changed.

A feature of the new electronic exchanges is their ability to initiate a second attempt to establish a connexion should the first attempt fail. It is therefore necessary, when totalling the failures that occur during the test, to add the second-attempt registrations to the failures detected by the call sender itself. Also, as the test progresses, the fault indication given by the call sender is studied in conjunction with the information given by the exchange maintenance-data recorder. When any pattern is established that suggests that a single fault is causing a significant number of call failures or repeat attempts, the test is stopped. The contractor will diagnose, trace and clear the fault, and the recorded failures that are attributed to this fault are counted as one defect by the clerk of works when he is satisfied that the fault has, in fact, been cleared. This would normally be after a further quantity of calls had been passed without a failure of the same type occurring. As a further aid to fault diagnosis the exchange traffic recorder may be run while the test is being carried out. Any inter-switch trunk that does not appear to be receiving its share of the traffic is checked. At any time during the test, individual failures can be investigated. It is, however, the intention, ultimately, when the quality of the equipment permits, to adhere strictly to the 50-call-failures principle, no fault location taking place during the test.

If at any time the actual failures exceed the acceptance number, set at 50 initially, then the exchange is handed back to the installing contractor for further attention. If at the end of 20,000 calls the acceptance number has not been exceeded, the exchange is accepted from the contractor as fit for service.

DESCRIPTION OF THE SYSTEM

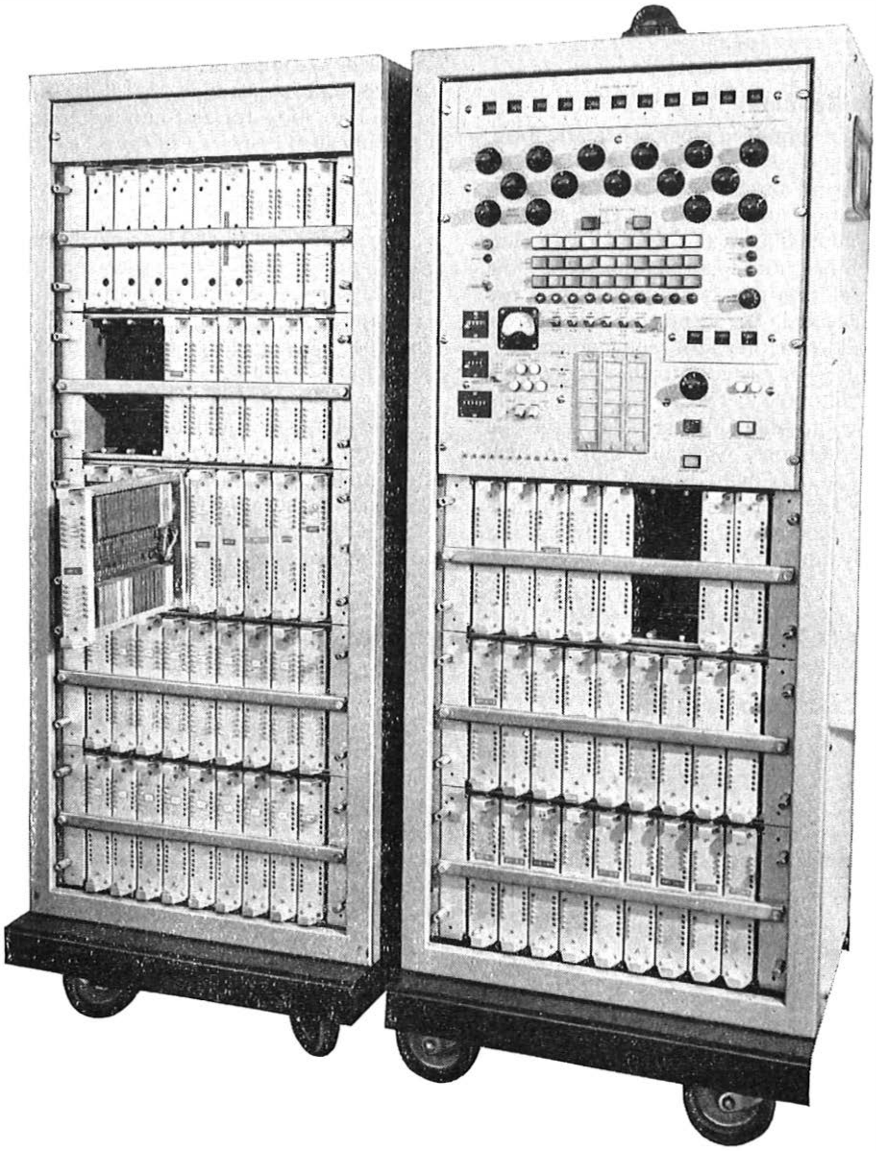
So that the use of the call sender shall be as comprehensive as possible the system has been designed for the following applications.

(*a*) The acceptance testing of

- (*i*) electronic exchanges,
- (*ii*) crossbar exchanges,
- (*iii*) Strowger exchanges,
- (*iv*) p.a.b.x. systems, and
- (*v*) p.c.m. systems.

(*b*) Pre-transfer testing of the trunk and junction network associated with new exchange equipment.

Fig. 3 shows the appearance of the automatic call-sender equipment.



The front covers are removed to show the shelf and tray assembly

FIG. 3—Automatic call-sender

Choice of Answer Condition

Pre-transfer testing of the trunk and junction network involves passing calls from the new exchange equipment over a trunk or junction route into the distant exchange equipment associated with that route. The obvious choice therefore for an answer condition to the call sender is test-number tone (inverted ring-tone) as test-number relay-sets are provided on the basis of one per 1,000 subscribers' lines at all local exchanges. When acceptance testing a new exchange installation the calls must, by the nature of the test, be confined within the unit under consideration. It is, therefore, necessary to provide inverted-ring-tone answer conditions on all the line circuits selected for the program. A portable answering circuit has been designed for this purpose.

Outline of Operation

Calls are passed from individual senders under the control of high-speed common equipment. Each sender is presented on demand with a test number, one digit at a time, according to a pre-determined program. This is done in such a way that no two senders are operating on the same test-number simultaneously, thereby preventing a spurious busy condition being encountered. Each sender is responsible for pulsing-out the digit offered to it and for timing the seizure, inter-digital pause and release functions. The sender will also monitor the progress of the call, having been instructed to react in a particular fashion to all the line conditions likely to occur, i.e. line polarity, earth or disconnexion on the p-wire, dial tone, number-unobtainable tone, ring tone, equipment-engaged tone, busy tone, congestion announcement, test-number tone and metering. A successful call is signified by the receipt of test-number tone after the last digit of the test number has been sent, accompanied by the appropriate metering conditions.

A maximum of 10 senders at a time may be operated, but any number up to 10 may be brought into use. The program will accommodate from 1 to 50 test numbers of from 1 to 10 digits each, as required. There are two modes of operation: manual and automatic. When in the manual mode the call sender will hold a faulty call and display both the nature of the fault and at what stage in the call it occurred. The call sender may be instructed, if required, to step on when engaged tone is encountered. In the automatic mode the call sender will step on if a fault or busy condition is encountered, recording the fact as it does so. When used in this way the call sender may be left unattended, provision being made to extend alarms into the exchange-alarm system for those categories of faults which would prevent the proper functioning of the equipment if not attended to, e.g. failure to release by the subscriber's line circuit associated with a sender.

Allocation of Digits to Senders

Fig. 4 shows the system in simplified block schematic form. Whenever a sender has successfully completed a call, it initiates a new word demand on the common equipment. The test-number information circulating in the store is examined, and the first "address", i.e. test-number time-slot, that is encountered which has not already been used by the sender making the demand, and that is not currently in use by any other sender, is allocated. The identity of this address is written into the sender address store of the sender concerned. The first digit of this address is passed into the sender digit store, and is pulsed-out into the network. As has already been indicated, during the inter-digital pause (i.d.p.), the line is monitored for faulty conditions. Assuming that no such condition is experienced, a new digit demand is made on the common equipment. The sender address store and the sender digit counter are compared with the system word and digit counters, respectively, and when coincidence occurs the next digit in the address currently in use is passed into the sender digit store for pulsing out. This process continues until the last digit is passed from the common equipment, at which time a last-digit signal is generated to instruct the sender to look for test-number tone from line, i.e. a successful call.

Success or Failure

The first burst of 400 Hz tone during the tone-on period of test-number tone will trigger the tone-recognition circuit, and at the same time the incoming lines to the sender are examined for metering conditions. Provision is made to instruct the call sender to respond to the following metering conditions: (*i*) a reversal on the positive and negative wires (*ii*) a +50-volt pulse on the P-wire (*iii*) a +50-volt or −50-volt pulse on the M-wire (Strowger exchanges). The tone-recognition cycle lasts for 12 seconds, this being the minimum period required to accurately recognize all types of tone, and at the end of that time a success signal is generated provided inverted ring-tone has been detected and a meter pulse has arrived.

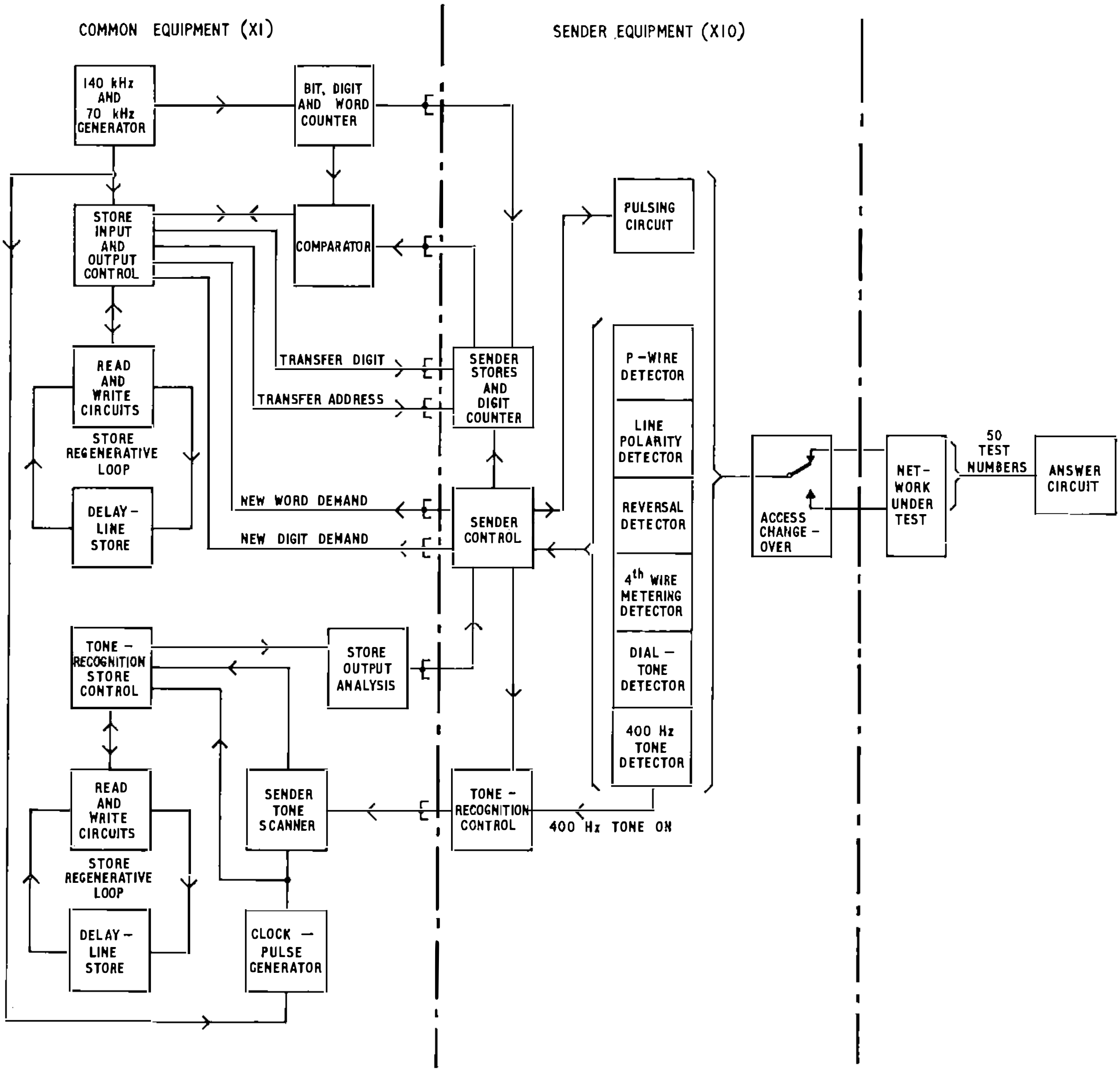


FIG. 4—Simplified block schematic diagram of automatic call-sender

Should the tone-recognition circuit detect either ring tone, busy tone, equipment-engaged tone or congestion announcement, or should no tone be received within 12 seconds of the last digit being sent, then a fault is recorded and the sender is either stepped-on, or the call held and an alarm given, depending on whether the call sender is operating in the automatic or manual mode.

All the senders in use will operate in the manner described above, and when all senders have sent all the test numbers in the program a program-finish signal is generated. This signal will result in either (*a*) change-over to another group of 10 subscribers' line circuits, followed by a repeat of the complete test cycle, or (*b*) the call sender will stop with an audible and visual alarm. Once again this will depend on how the equipment has been set up initially.

Tone Recognition

Each sender contains a detector designed to give a substantially constant output with input tones in the bandwidth 300-500 Hz at levels down to −30 dBm. A 400 Hz tone burst that persists for longer than 100 ms occurring during an i.d.p. or at the end of a call on any sender will trigger the tone-recognition circuit. This initial 100 ms delay is necessary to prevent the tone-recognition circuit being stimulated by switching noise or low-level background noise which contains a 400 Hz component.

The analysis of the tones that are received follows the principles described in a previous issue of this *Journal**. The only significant difference is in the means used.

TABLE 1

Signals Requiring Identification

Signal	Periodicity
Busy tone	375 ms on, 375 ms off
Equipment-engaged tone (Note 1)	400 ms on, 350 ms off, 225 ms on, 525 ms off
Test-number tone (Note 2)	2 seconds on, 1 second off
Number-unobtainable tone	Continuous
Ringing tone	400 ms on, 200 ms off, 400 ms on, 2 seconds off
Congestion announcement	
Tone not recognized (Note 3)	

Notes:
1. The level of the 400 ms period of tone is −6 dB with respect to the others.
2. This is inverted ring-tone modified to the periodicity shown.
3. Required when a tone is received which for one reason or another does not persist long enough to be recognized.

Test-number tone and number-unobtainable tone are timed by simple delay circuits: any tone pulse that persists for 3 seconds is recognized as number-unobtainable tone, and any tone pulse that persists for longer than 650 ms but less than 3 seconds is recognized as test-number tone.

All tone pulses are counted into a store common to all 10 senders on a time-shared basis. Each sender is allocated a time slot containing a tone-length counter, a primary counter, and a secondary counter. The tone pulses arriving at each sender are measured for duration in the tone-length counter, and then transferred to the primary counter and the secondary counter if they exceed 90 ms and 320 ms, respectively. At the end of a 12-second recognition cycle the contents of the primary and secondary counters are read out and decoded.

Should the primary and secondary counters assume any other state than those indicated in Table 2, the outputs are decoded as tone not recognized.

* Measuring Quality of Service on Trunk Routes. FRANCOIS, R. A., and HOLLIGON, E. R. *P.O.E.E.J.*, Vol. 60, p. 227, Oct. 1967.

TABLE 2

Tone Recognition

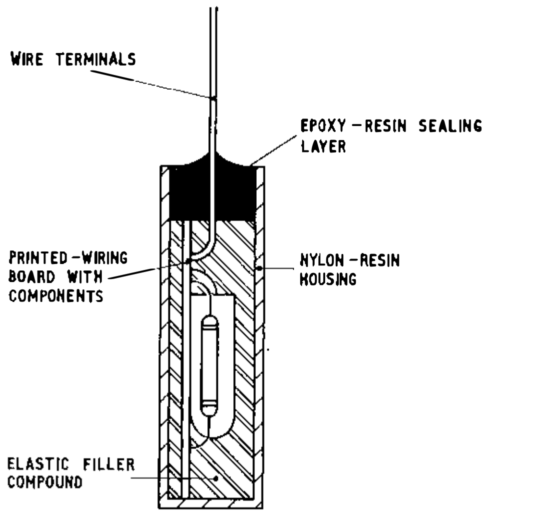
Primary Counter (90 ms)	Secondary Counter (320 ms)	Tone
4 → 10	4 → 9	Ring tone
11 → 18	5 → 9	Equipment-engaged tone
11 → 18	10 → 18	Busy tone
11 → 32	2 → 3 4	Congestion announcement (Note)

Note: This analysis depends on the adoption of a new type of congestion announcement, at present under trial, which will greatly improve the ability of the tone-recognition circuits to detect this condition.

Circuit-Block Logic

In order to reduce the development time of the automatic call sender to a minimum and at the same time achieve a high degree of system reliability, it was decided to use encapsulated-circuit-block logic. The M.E.L. Equipment Company, Ltd., Series 1 100 kHz range was chosen, and the company put their design advisory service at the disposal of the Post Office to co-operate in the design of the high-speed area of the system.

The M.E.L. Series 1 circuit blocks consist of a compatible range of circuit elements, each one encapsulated in a standard module. A typical cross-section of such a circuit block is shown in Fig. 5. There are several advantages to the design



The dimensions are approximately 2 in. × 1 in. × 0·25 in.

FIG. 5—Cross-section of typical circuit block

engineer in using this method. No time need be spent in evaluating components and logic circuits for performance and reliability, and system design is simplified because the rules for inter-connecting the various devices are clearly laid down and will give a guaranteed electrical performance within given operating conditions. The expected reliability is of a high order, since the manufacturing methods used include 100 per cent functional testing before and after encapsulation, quality control incorporating periodical life testing of samples from the production line, and environmental protection of the finished product against pollution, dampness and shock.

Delay-Line Storage

The ultrasonic wire delay-line, Fig. 6, is dependent upon the magnetostrictive properties of the wire for its operation. The line consists of a stable nickel-alloy wire coiled at the

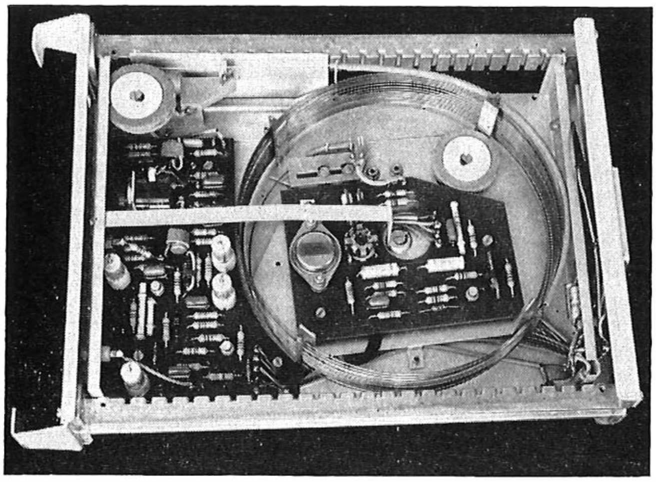


Fig. 6—Ultrasonic wire delay-line

correct radius to avoid dispersion of the signal. At each end of the wire is a length of special high-remanence magnetostrictive wire (Permador) upon which is threaded a simple transducer. The input transducer accepts a triangular current-waveform. This produces a magnetic field which, interacting with the axial magnetic field permanently induced in the wire itself, causes a torsional wave to travel slowly down the line. At the output transducer the mechanical deformation in the wire induces a flux change which is converted to an electrical output at a level of approximately −40 dB relative to the input. This signal is clipped, amplified and re-shaped prior to re-circulation.

The digital information required for the program of up to 50 test-numbers is written into a store consisting of six 3·214 ms ultrasonic wire delay-lines in tandem. This information then circulates and is available as required for use by the individual senders. The store contains 2,700 bits of information made up of fifty words, each consisting of

(*i*) 10, 4 binary-bit digits,
(*ii*) 10, sender-used bits,
(*iii*) one busy bit,
(*iv*) two repeat bits, and
(*v*) one prepare logic bit.

The information is stored serially, and at the operating frequency of 140 kHz each bit occupies a time slot of 7·1428 μs. The total scanning time for the store is therefore 2,700 × 7.1428 μs, i.e. 19·275 ms.

The tone-recognition circuit contains a store in which the tone conditions encountered by each sender are recorded in digital form. This store consists of one ultrasonic wire delay-line of nominal delay 3·214 ms, in series with a 15-stage shift-register used for read-out purposes. The store contains 240 bits of information made up of 10 words (one per sender) each consisting of,

(*i*) word shift, one bit,
(*ii*) tone-length counter, seven bits,
(*iii*) transfer bit,
(*iv*) primary counter (90 ms), six bits,
(*v*) secondary counter (320 ms), five bits, and
(*vi*) four spare bits.

At the operating frequency of 70 kHz each bit occupies a time slot of 14·286 μs. The total scanning time for the store is therefore 240 × 14·286 μs, i.e. 3·428 ms. For reasons of logical manipulation the store is available to accept new information every other scan. The tones, as and when they appear at the input of each sender, are therefore inspected at approximately 6·86 ms intervals. This interval is short enough to avoid any error in the tone analysis.

Delay-line storage was chosen for two main reasons. At the time the design was being considered there was a clear economic advantage for delay-line storage over, say, a ferrite-core store for the bit capacity required in this system. Also the M.E.L. Equipment Company, Ltd., were able to offer a delay-line module that was electrically and physically compatible with the Series 1 circuit blocks, thus saving valuable design time.

Call-Sending Rate

The call sender operates at an average rate of 130 calls per hour per sender, assuming that the program consists of mixed 4-digit and 5-digit codes. A program of 50 test-numbers can be written into the store in about 15 minutes, and the connecting cords changed in about 45 minutes. If it is assumed that an average of seven senders are making calls at the same time, to complete 20,000 calls will take approximately 22 operating hours. Typically, the program will be changed nine times, adding 9 hours, and, if 20 hours are allowed for stoppages, e.g. call traces, fault finding, then the final quality-of-service test can be completed in about 50 hours or, say, 6–7 days. This assumes of course, that the failure rate is within the acceptance figure.

CONCLUSIONS

The first four production TXE2 exchanges have been accepted from the contractors on the basis of a final acceptance test using the automatic call-sender, and following the principles described in the first part of this article. The experience gained from these installations shows that the theoretical advantages predicted for this method of accepting an exchange are capable of practical achievement. There is considerable evidence that many of the faults that can occur on an electronic exchange installation would not be found in any other way, and that exchanges will open for service with a much better performance than would otherwise be so. It is hoped that confidence in this method can be built up to the point where it is possible to substantially reduce the amount of testing carried out at the commissioning stage.

Looking to the future, a second generation call-sender is at present being developed, making use of the considerable advantages now offered by integrated microcircuits. For much the same cost this new version of the automatic call-sender will be approximately half the size and weight with twice the capacity in terms of senders and test-number storage.

ACKNOWLEDGEMENTS

The development of what is a fairly complex system in a comparatively short time was made possible by the co-operation given to the Post Office by the M.E.L. Equipment Company, Ltd., design advisory service.

Measurements on Goonhilly 85ft Diameter Aerial

Part 1—Physical Measurement of the Paraboloid

H. E. PEARSON, B.SC.(ENG.), C.ENG., M.I.MECH.E.†

U.D.C. 621.396.7: 621.317.39: 531.717

The dimensions of the original paraboloid reflector on the Goonhilly aerial were measured by comparatively simple methods appropriate to the relatively coarse tolerances. When a second paraboloid was required with a tolerance of $\pm 0 \cdot 1$ *in., new measuring methods were developed for adjusting the bowl as it was built, and also for measuring the variation of dimensions with a view to optimizing the reflector shape when the aerial was pointing at the geo-stationary satellite, EARLYBIRD. This article describes the work of physical measurement carried out in brief intervals when the aerial was available over the period 1962–67. Part 2 will relate electrical performance measurements on the working aerial to various orders of profile accuracy as measured by the methods described herein.*

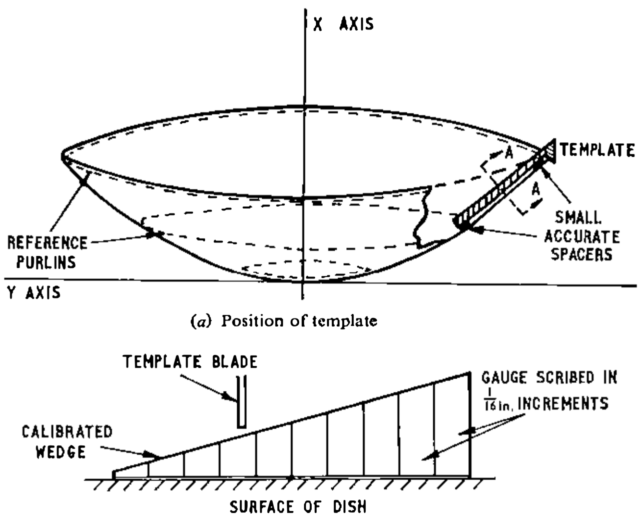
INTRODUCTION

The grade of service which the Post Office can provide from its satellite communication earth station at Goonhilly Downs depends critically upon the accuracy of shape of the 85-ft diameter paraboloid aerial reflector surface. In large aerials of this type, departure from the required form can lead to loss in gain and increase in noise as misplaced parts of the reflector fail to focus wanted incident signals in the required manner and pick up unwanted signals from other directions. The ideal radiation pattern for such an aerial could only be achieved with a geometrically-perfect paraboloid. As it is not practicable to make a perfect bowl or to hold the shape absolutely constant under all varying load conditions due to gravity, wind and temperature changes, tolerances must be arrived at within which a practical and technically-acceptable solution can be obtained at reasonable cost.

The size of tolerance admissible is a small fraction of a wavelength at the frequency of transmission used, in order that elements of reflected energy from the various parts of the bowl may arrive at the focus in phase with each other. In 1960 the highest frequency expected to be used was 4,000 MHz, giving a wavelength of 7·5 cm, or approximately 3 in. An accuracy of one sixteenth of a wavelength was aimed at, hence the desirable bowl tolerance was $\frac{3}{16}$ in. However, as the bowl diameter was so large, and because with the original design of radio-feed unit fitted at the focus, illumination intensity decreased rapidly towards the edge, the tolerance for the outer part of the bowl was relaxed to $\frac{3}{8}$ in. to ease design and construction problems. To measure manufacturing variations and set the bowl within these tolerances, it was thought that a measuring accuracy of $\frac{1}{32}$ in. was adequate and that this could be met with conventional optical levels, steel tapes and special parabolic templates.

MEASUREMENT OF ORIGINAL BOWL

Planes containing the principal axis of a paraboloid have parabolic intersections, planes normal to this axis have circular intersections. These properties were used in building and measuring the first bowl with the aerial axis pointing vertically upwards (Fig. 1). The circumferential structural framing members of the bowl were built as horizontal circles of diameter appropriate to their distance from the apex. Steel plates were laid on these members and the resulting surface errors measured with radial templates of prescribed parabolic form. The template blade was carefully supported at a fixed distance from reference edges of circumferential members so that, allowing for the thickness of plating, the gap between the template blade and the plating surface could be measured by inserting a calibrated wedge. From several hundred measurements it was shown that the specification was well met in the inner area of the bowl but exceeded slightly in the outer area (Fig. 2). At this stage the aerial was put into service in July 1962 for the first communications-satellite experiments with TELSTAR. In addition to the 4,000 MHz frequency for which the aerial had been designed a higher frequency was used in the 6,000 MHz band. The aerial as a whole performed well within this limitation but it was clear from the start that profile improvement was desirable. Not until November was it possible to take the aerial out of service again to work on the bowl to improve its profile accuracy. This was done by a combination of panel beating and heat treatment. Measurements were taken by



(a) Position of template

Note: Equation of paraboloid $y^2 = 85x$

(b) Position of calibrated wedge at section AA

FIG. 1—Geometry of bowl measurement

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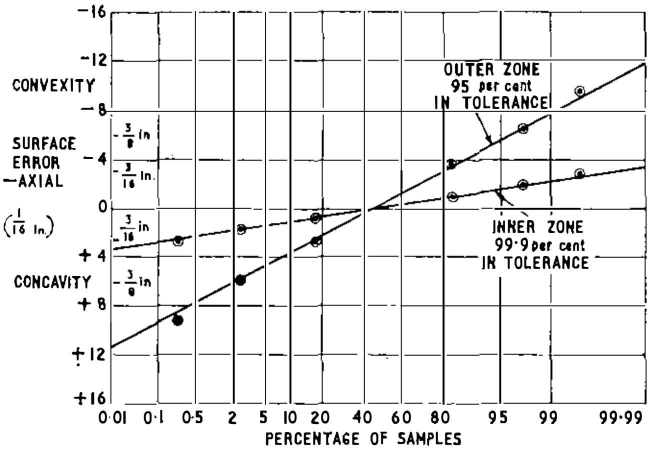
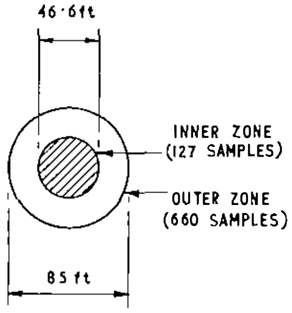


(*a*) Graph of bowl accuracy against percentage of samples



(*b*) Area over which samples were taken

FIG. 2—Original bowl accuracy

the same template and wedge method as before until 98 per cent of the whole bowl was within the specified tolerance.

OPTICAL SURVEYS

General

These first limited excursions into the field of large-scale metrology were a new venture for Post Office engineers as were many other aspects of building an earth station. The methods adopted for measuring the first Post Office 85-ft diameter paraboloid had been simple and straightforward with a probable accuracy adequate for the specification. It was clear, however, that if tolerances were to be tightened, then considerable refinement of methods of measurement would be needed. Furthermore, means would have to be found of measuring the paraboloid shape when the aerial was facing the satellite, not just in the position of manufacture facing the zenith.

Valuable expertise in field-survey work has been steadily developed in the radio external-construction groups over the last three decades. A small number of officers possess the ability to manipulate high-grade theodolites, levels and other survey instruments. This has enabled aerial positions to be fixed and accurate site plans produced, masts, towers and microwave aerials at inland link stations located and orientated, and, at Goonhilly, the aerial centre co-ordinates and physical references for the aerial pointing indicators established. It was natural to look for a paraboloid profile-measuring system using these skills.

Two-Theodolite Surveys

Some promising optical-survey experiments were carried out in 1963 using two ground-mounted theodolites at either end of a fixed base line in front of the aerial, with the bowl facing the horizon. Both instruments were trained in turn on targets fixed to the bowl surface. From the linear and angular information thus obtained the co-ordinates in space of all the targets could be obtained and hence the departure of the actual bowl from its proper shape, or best mean shape, could be derived. The major difficulty of holding the bowl stationary under varying conditions of weather was to some extent offset by the facility of processing results quickly on the Goonhilly computer. This permitted the discarding of wild results and rapid resurvey of doubtful areas under substantially the same conditions of measurement. It appeared likely that this system would yield information good to 0·1 in. when the aerial was pointing at or near to the horizon and during calm weather.

Antenna Theodolite

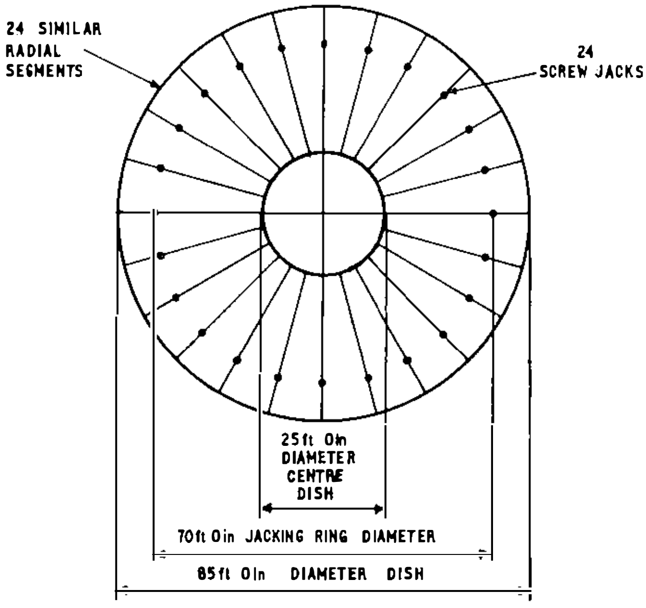
The original bowl was used until August 1964 when the station was closed for modifications to be made including the fitting of a new and improved reflecting surface to the aerial. The new specification required that 99 per cent of the surface should lie within 0·1 in. of a true paraboloid, hence the manufacturing accuracy demanded was of the same order as the measuring accuracy available and further improvements in technique were essential. An opportunity occurred to obtain an up to date appreciation of the work of others at a National Physical Laboratory Standards-Division Round-Table discussion in October 1964. One interesting report described a mechanical modification by the manufacturers to the very type of theodolite used by the Post Office so that it could be used fixed when within a bowl and at any attitude. This antenna theodolite seemed to have the potential of providing valuable information at intermediate angles between the zenith and horizon attitudes so far investigated at Goonhilly. Otherwise no measuring method clearly emerged in the discussion as ideally suited to the particular circumstances involved in making and measuring the new Goonhilly reflector in the following four months.

AERIAL MODIFICATION

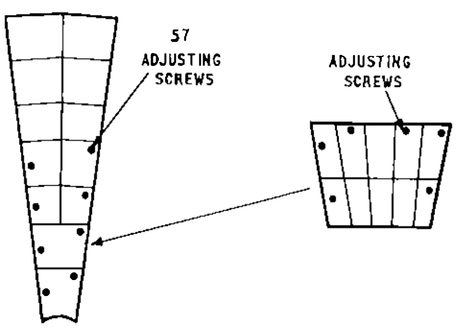
The designers of the new bowl, Husband & Co., consulting engineers, based its accuracy on a 25-ft diameter centre section which could be fully machined on an existing machine tool to within $\pm 0{\cdot}015$ in. of a master template. Outside this rigid centre, 24 similar radial segments, each 15° wide and connected to each other along their edges, would extend the bowl surface out to 85 ft diameter (Fig. 3). Fifty-seven screw links per segment were used to permit the individual panels to be set to the right shape for the segment: 24 screw jacks on a 70-ft diameter circle and at segment junctions were used to enable the segment surfaces to be set to the same paraboloid as the centre dish. The design thus embodied very adequate provision for adjustment: the next problem was to produce a reference system against which adjustment could be made.

Numerically-Controlled Machines

Mechanical-engineering workshop practice had reached the stage where numerically-controlled machine tools could produce three dimensional shapes to an accuracy of 0·010 in. or better over lengths of 30–40-ft whilst on the machine table. On these machines, cutter movement is controlled in three dimensions by a magnetic tape which has been prepared from computed geometrical data. This technique was applied in two ways: first, the steel frames for the individual panels of reflecting surface were machined to shape and second, adjustment template blades were machined. The basic geometrical co-ordinates required in producing the magnetic tapes were printed out by the Goonhilly computer. Whilst it was comparatively easy to arrange for the smaller manufacturing templates for use in the shop to be self-rigid so that they could be handled and used without destroying their accuracy, special measures were needed if the intrinsic accuracy was to be realized in the field when the whole bowl was built up. For this check a full-length radial template was



(*a*) Bowl layout



Note: Edges steel-framed lateral and side members machined on a 3-dimensional miller

(*b*) Segment panel layout (*c*) Basic panel

FIG. 3—New bowl schematic

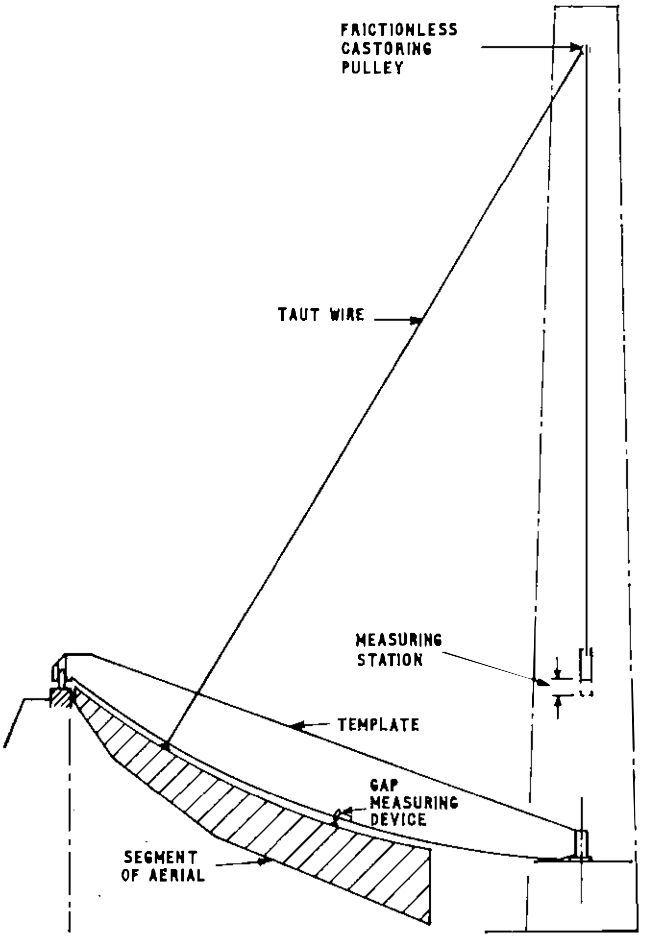


FIG. 4—Measurement test rig

made and fixed in space so that the aerial could be rotated beneath it and the gap between the reference edge and all parts of the surface adjusted. Final surfacing of the reference edge (some 45-ft long) was done on the tape-controlled machine with the template backing-frame or support-truss strained to the deflexion which would occur in use in the measuring position. Such refined methods having been employed in producing an accurate template in the factory the next anxiety was to ensure that the accuracy would not be lost during transport or on application at an exposed location. An indcpendant site checking-system was therefore devised based on a taut wire.

Taut wire method

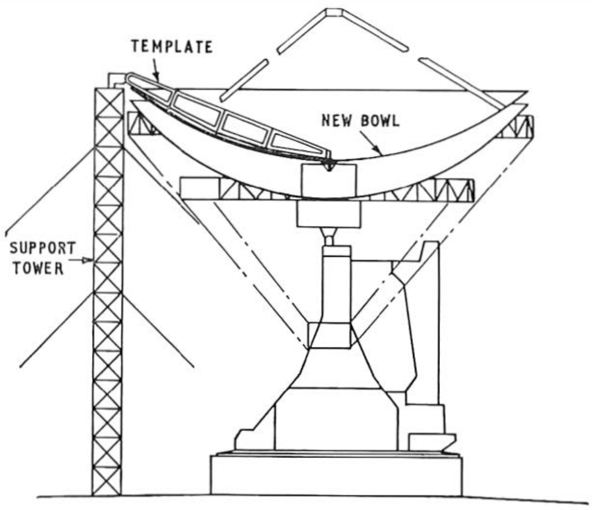
A test rig was prepared on site as shown in Fig. 4, to support three 15° segments facing the zenith, i.e. 45° of the bowl. A tower was erected on the paraboloid axis, from the top of which a taut wire could be applied to any part of the surface of the segments. A length of wire slightly more than twice the total length of the paraboloid yielded a circular swept arc which differed from the required parabolic arc by a maximum of only a few inches, and exact knowledge of the differences was obtained from a simple computer program. The top end of the wire was taken over a frictionless pulley and brought down within the tower to a suitable measuring station. By suitable choice of wire material, gauge and tension, errors were reduced to an acceptable order. The arrangement was tried out on a long straight edge and found to give results accurate within ±0·010 in. of computed values, with a spot repeatability within ±0·003 in., which looked promising. Some mechanical improvements were found necessary when measurements were made on the first deliveries to the site of aerial segments, which were set up in their true position in space by means of an optical level and stick micrometer.

The main template was now erected on the test rig, pivoting at its inner end on the axis and rolling along a track at its outer end. The gap between the reference edge and the reflector surface was adjusted to a nominal design value of $1\frac{1}{2}$ in. at a chosen point, and the variation of gap was measured along the template by means of an internal micrometer. Simultaneous measurement in still air by taut wire and template over the same radial cut on the test rig gave agreement to better than ±0·010 in. and thus gave confidence in the accuracy of the template and in the method to be employed in adjusting the complete reflector surface.

Radial Template Measurements

The template was transferred to the bowl, Fig. 5, again with its inner end on an axial pivot, but this time with the outer end supported on a rigid tower built up from the ground alongside the bowl. By use of the normal azimuth movement of the aerial, any part of the bowl could thus be offered up to the reference edge and adjustments made as required. It had been established earlier that normal azimuth movement would not tilt the bowl by more than a few seconds of arc.

A moving carriage was attached to the template to measure the required gap from end to end, using a pair of linear potentiometer-type transducers in a bridge circuit. The electrical read-out from the bridge circuit was recorded on a



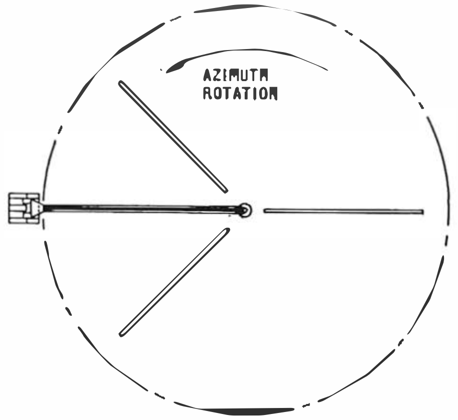


FIG. 5—Profile measurements: template in new bowl

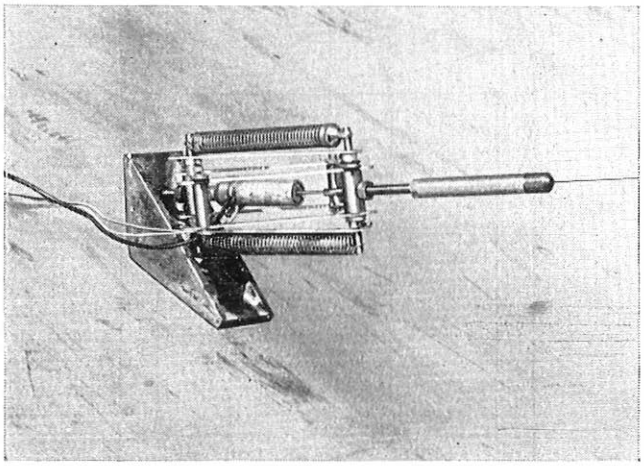
chart recorder calibrated to give a full-scale reading corresponding to $\pm 0 \cdot 150$ in. Agreement between transducers was good to within about $0 \cdot 0065$ in. and reset accuracy about half that value.

Comparison was then made between the transducer-carriage results and spot internal-micrometer readings. By trial survey over sections of the reflector surface, it was found that readings taken every two feet along the template by internal micrometer yielded a good curve not lacking any important information which the continuous trace could complete. From such curves drawn for radial cuts over the centre and edges of each segment it was possible to decide what adjustments to make on jacks and screws and to carry out these adjustments under the template. In the final measurements at constant temperature at night the transducer carriage was not used as the internal micrometer applied every two feet gave a quick positive answer with less complication.

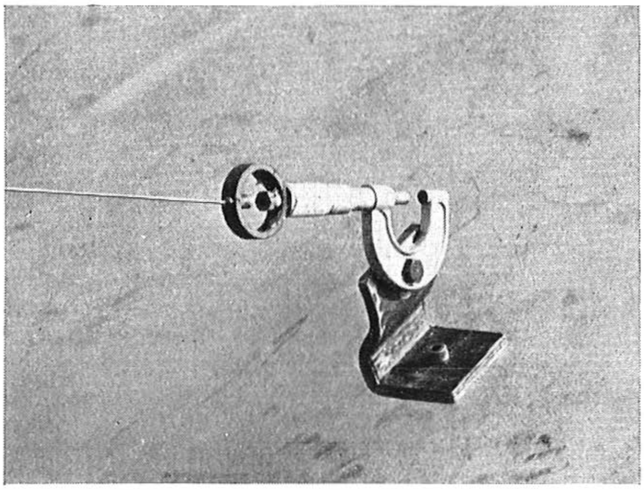
In the time available the surface was adjusted to lie 99 per cent within limits of $+0 \cdot 092$ in. and $-0 \cdot 084$ in., the mean paraboloid being $+0 \cdot 004$ in. away from the design position in the direction of the focus. The template was checked by the taut wire method after use and is available for use on any future bowl of the same geometry.

BOWL DISTORTION MEASUREMENTS

Having set the new bowl to tolerance in the zenithal position it was important to find out if there was any serious distortion of the bowl at other elevation angles. Unfortunately, the imminent launch of the EARLYBIRD satellite did not permit any protracted surveying, and therefore quick, simple measurements of diameter changes were made initially, with a more comprehensive survey planned at a later date when convenient. A taut wire was stretched along the vertical diameter and another along the horizontal diameter, assuming the bowl to be facing the horizon. Each wire had a linear potentiometer-type transducer mounted in a specially designed frame at one end, Fig. 6(*a*), and a micrometer for calibration purposes at the other, Fig. 6(*b*). The transducer formed part of an electrical bridge circuit whose output was fed to a chart recorder. This chart



(*a*) Displacement transducer



(*b*) Calibrating micrometer

Fig. 6—Instruments used in bowl distortion measurements

recorder was calibrated before use by setting the micrometer at its mid position as zero, then altering the micrometer screw on either side of the mid position by specified amounts, noting the recorder reading each time. After calibration in this manner the micrometer was reset at its mid position and played no further part in the measurements until a further calibration check was required. Thereafter, any change in the diameter was shown by an alteration in the potentiometer settings under the control of the spring and taut-wire tensions, which were balanced at the zero position. These measurements showed that there was very little change in the measured diameters as the aerial was moved from facing the zenith to an elevation of about 70°, after which their variation gradually increased as the aerial elevation was reduced to 0°. The vertical diameter decreased by $0 \cdot 19$ in. whilst the horizontal diameter increased by $0 \cdot 24$ in. during the elevational movement, see Fig. 7.

These results alone were not sufficient to determine the actual distortion along the vertical diameter because both points sag in the same direction when the bowl is at 0° elevation. More comprehensive surveys were therefore made with an antenna theodolite mounted at the vertex and with ground-based theodolites. Meanwhile, the existing taut wires were used to monitor static and dynamic changes in the diameters with change of temperature and wind loading.

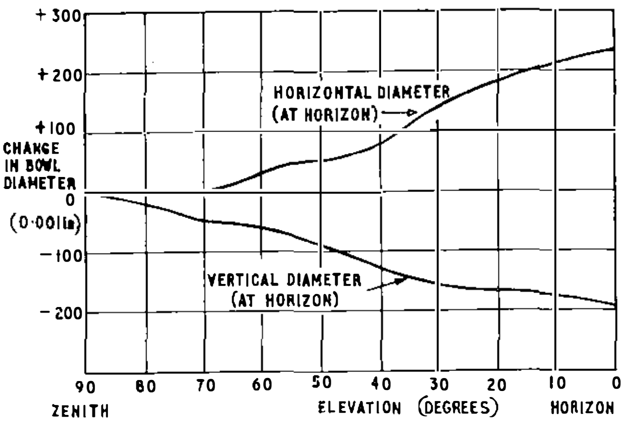


FIG. 7—Variation in bowl diameter with elevation change

Comparison of bowl distortion measurement methods

The optical-survey method of measuring an operational aerial using ground-based instruments was very attractive as it did not involve any work on the aerial itself. Indeed at the beginning of the EARLYBIRD operational era the satellite appeared to be so nearly stationary relative to the earth, that it seemed possible to hope for the aerial itself to be kept stationary and working to EARLYBIRD for a long enough period to permit one whole survey to be made as a completely independent exercise. However, as operational experience was acquired, it rapidly became clear that to keep the service going properly aerial movement would be required too frequently for this to be realized. Nevertheless, the advantage remained that the aerial would in no way be affected by such surveys, which meant that so long as Goonhilly had equal periods of duty, carrying traffic, standing by and standing down, then for two thirds of the time surveys could be made.

The antenna theodolite on the other hand is a special device mounted at the vertex involving an observer with head and shoulders emerging through the hole at the dish centre. Not only must the aerial be out of service for this purpose but it cannot be put back into use until the instrument and observer have been withdrawn and operational conditions restored. Hence, for short time stand-by service availability the aerial could not be so impeded and the amount of time during which antenna theodolite measurements could be made was only one third.

Results

Results obtained by these various methods showed fair agreement in indicating a pattern of distortion increasing in magnitude, but not changing very much in nature, as the bowl was tipped from zenith to horizon. Separate electrical performance measurements showed a corresponding deterioration in the radio characteristics of the aerial to an extent which justified an attempt to improve the bowl shape at the operational attitude. If the aerial was destined to spend a long period facing EARLYBIRD with its bowl tipped to an elevation angle in the region of 28°, then the profile should be made as near as possible the right shape at that angle.

As stated earlier, the design provided for adjustment of major areas of bowl by 24 screw jacks. From a detailed analysis of results related in particular to 24 targets at jacking positions, a programme of progressive jack adjustment was prescribed. The extent of all proposed jack changes was well within the range of adjustment provided and therefore structurally tolerable. The time required to effect the first major change was estimated at 12 hours with electrical measurements before and after to show whether the desired improvement had been achieved. Further minor changes could perhaps be made in shorter periods of time if justified by results. These short time scales were important, not only to minimize the length of time for which the aerial would be put out of service, but also to ensure that before-and-after electrical measurements would be carried out under as near as possible the same conditions.

DISCUSSION OF TECHNIQUE

There is fair agreement between engineers concerned with this sort of work that a tolerance of 0·1 in. on an 85-ft diameter aerial, representing as it does, a tolerance of one part in 10,000, is approaching the economic limit of manufacturing capability, measurement accuracy being one important factor in setting the limit.

The principles adopted throughout the work described have been first, to recognize that against a tolerance of 0·1 in. one requires a measuring tool good to 0·01 in. having measurement units of 0·001 in., and second, to disbelieve any single measuring method in isolation seeking always to confirm it by a second independent method based on separate fundamentals. One thousandth of an inch seems a ridiculously small unit when one is working with cold steel 80-ft above the ground on an exposed coastal plateau at night in mid-winter, but that degree of discrimination was sought and achieved on successive readings within a measuring method. This led to comparison accuracies good to 0·01 in. between methods, and ultimately to accurate knowledge as to whether the specification had been met.

Whether the specification was too tight or not tight enough could only be revealed by electrical measurements at various stages of adjustment and an evaluation of the cost of the last fraction of a decibel required of the aerial. The ultimate objective of the whole exercise of physical measurement of the paraboloid was to provide the information for optimum shape adjustment and so reveal the economic limit of shape control.

ACKNOWLEDGEMENT

Acknowledgement is made to Husband and Co., consulting engineers for aerial, template and reflector petal test-rig design, Hilger and Watts, Ltd., for the antenna theodolite, and Mr. P. W. Harrison of the Standards Division of the National Physical Laboratory.

Trunk Transit Network: Incoming Register-Translators for Director and Non-Director Areas

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The use of multi-frequency signalling in the trunk transit network and the adoption of 4-wire switching between originating and terminal group switching centres has necessitated the provision of additional incoming register-translator facilities at both director and non-director group switching centres. This article outlines the facilities and operation of this new equipment, and describes the circuit principles involved.

INTRODUCTION

Under present arrangements for subscriber-dialled trunk traffic to non-director areas, the controlling register-translator at the originating centre determines, from the numbering-group code that is dialled by the calling subscriber, the translation necessary to route the call to the terminal group switching centre (G.S.C.), and follows this with the local part of the required subscriber's national number. If the terminal G.S.C. serves dependent numbering groups, the controlling register-translator supplies additional routing digits to take the call to a later point in the trunking of the terminal G.S.C.; thence, access is obtained to the objective exchange without further translation. Thus, prior to the introduction of the trunk transit network, incoming register-translators have not been required at non-director area G.S.C.s.

For subscriber-dialled trunk traffic to director areas, incoming register-translators are already provided at terminal centres. When a call has been routed to a terminal G.S.C., the controlling register-translator at the originating centre repeats forward the seven digits representing the required subscriber's number. As soon as the first three digits (the local-exchange code) have been received, the incoming register-translator generates the necessary routing digits to reach the objective local exchange, and then repeats forward the numerical digits of the subscriber's number in order to switch the call at the local exchange. Two types of incoming register-translator—electromechanical and electronic—are in use,[1, 2] and give broadly similar facilities.

This article describes the additional register-translator equipment which must be provided at non-director and director area G.S.C.s to cater for incoming traffic from the new trunk transit network.[3, 4] The register-translator equipment required at originating G.S.C.s to control outgoing traffic to the trunk transit network has been described in a previous article in this Journal.[5]

ADDITIONAL REGISTER-TRANSLATOR EQUIPMENT

It is essential to the transit-network plan that a high-speed inter-register signalling system be used to switch calls over a number of tandem links, and a multi-frequency (m.f.) system has been adopted for both the forward digital signals and for the necessary backward signals, e.g. proceed-to-send, number-received. Also, to meet the transmission objectives, switching is on a 4-wire basis from originating G.S.C. to terminal G.S.C. Switching is 2-wire through, and onward from, the terminal G.S.C. It follows that the equipment to be provided at terminal G.S.C.s to cater for incoming traffic from the transit network must include

(*a*) the line signalling system termination equipment, incorporating 4-wire–2-wire conversion, with access to terminal register equipment and to the G.S.C. 2-wire switching equipment, and

(*b*) the terminal register equipment with associated m.f. receiver-senders.

Basically, the registers are required to control the transmission of backward m.f. signals, to accept, decode, and store the digital signals detected by the associated m.f. receivers, and to convert these signals into Strowger-pulsing form to route calls onward through the G.S.C. and into the local network. Translation facilities are also given, although in the non-director-area equipment the required translation capacity is small.

The equipment arrangements at non-director area G.S.C.s are indicated in Fig. 1. Register and translator facilities are combined into one circuit, and electromechanical equipment is used. An incoming m.f. receiver-sender is directly associated with each register-translator.

The equipment to be provided at director-area centres is shown in Fig. 2. At small centres, electromechanical register-translator equipment will be used. The translation requirements are sufficiently large to justify the use of separate translators, common to a number of registers. At larger centres, the existing electronic register-translators using ferrite cores and transistors will be used suitably augmented with equipment to associate and control m.f. receiver-senders.

INCOMING REGISTER-TRANSLATOR FOR NON-DIRECTOR AREA G.S.C.s

Outline of Facilities and Operation

The block schematic diagram (Fig. 3) shows the main elements of the register-translator for non-director areas. An m.f. receiver-sender is associated with each register-translator. On seizure by an incoming call, the register-access relay-set causes its associated register hunter to search for a free register. When association takes place, the 4-wire line is extended from the incoming trunk circuit via the register-access circuit and register-translator through to the m.f. receiver-sender, and a control signal is applied from the register-translator via the PTS lead to cause the m.f. equip-

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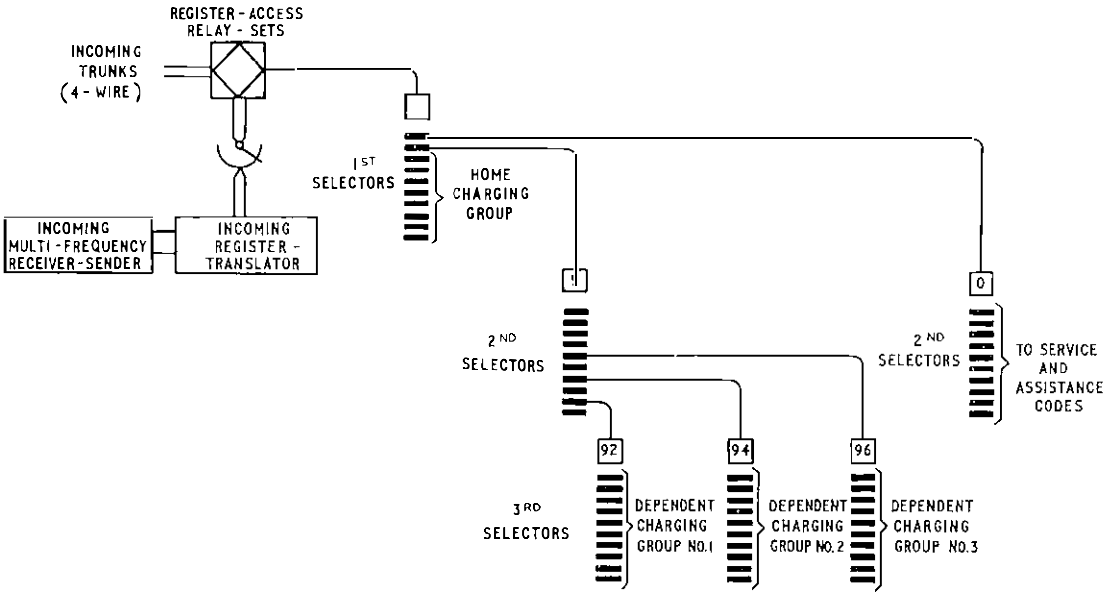
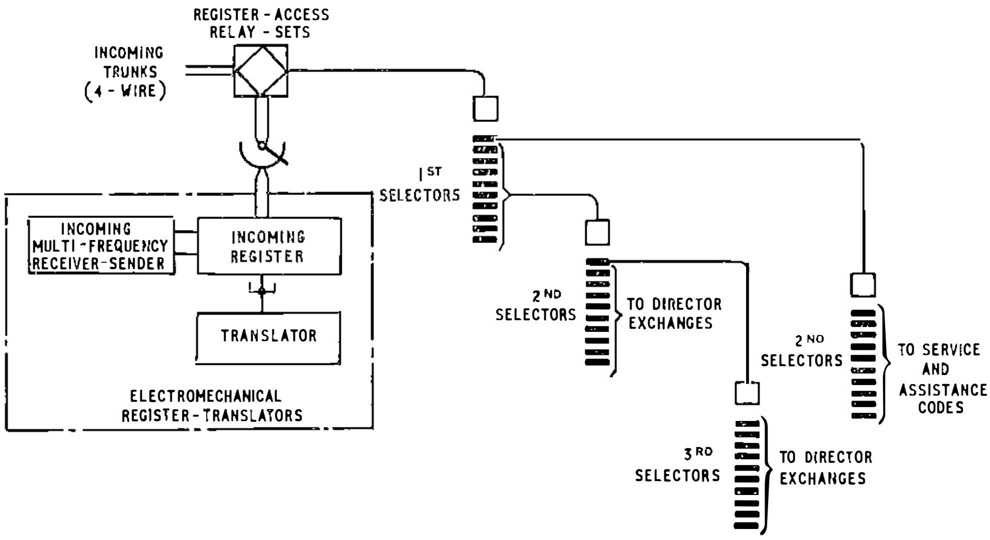
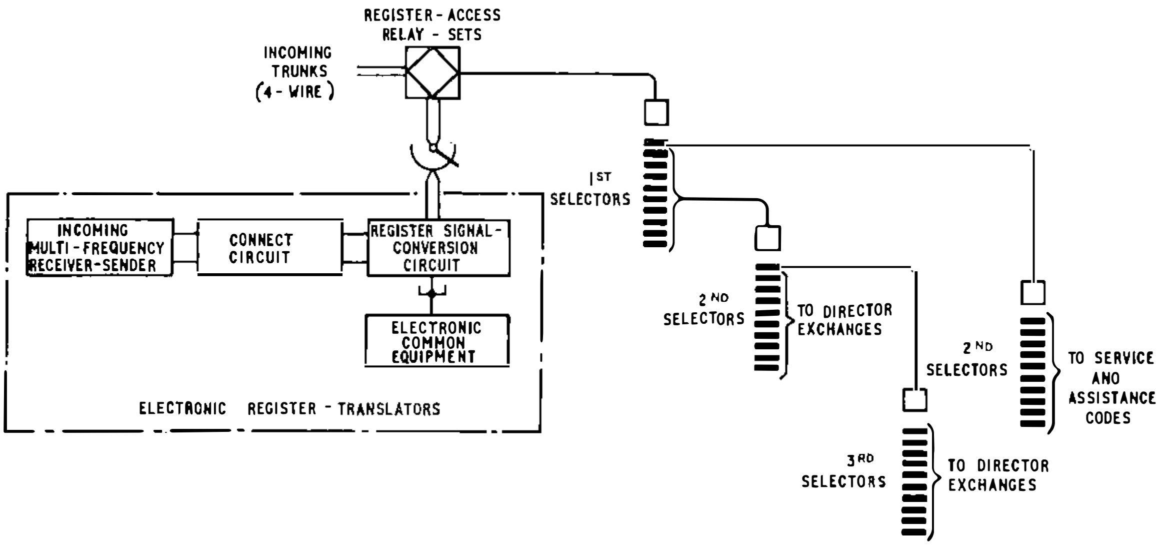


FIG. 1—Typical trunking at a terminal group switching centre in a non-director area with access from the trunk transit network



(*a*) Trunking where Electromechanical Register-Translators are Used



(*b*) Trunking where Electronic Register-Translators are Used

FIG. 2—Typical trunking at a terminal group switching centre in a director area with access from the trunk transit network

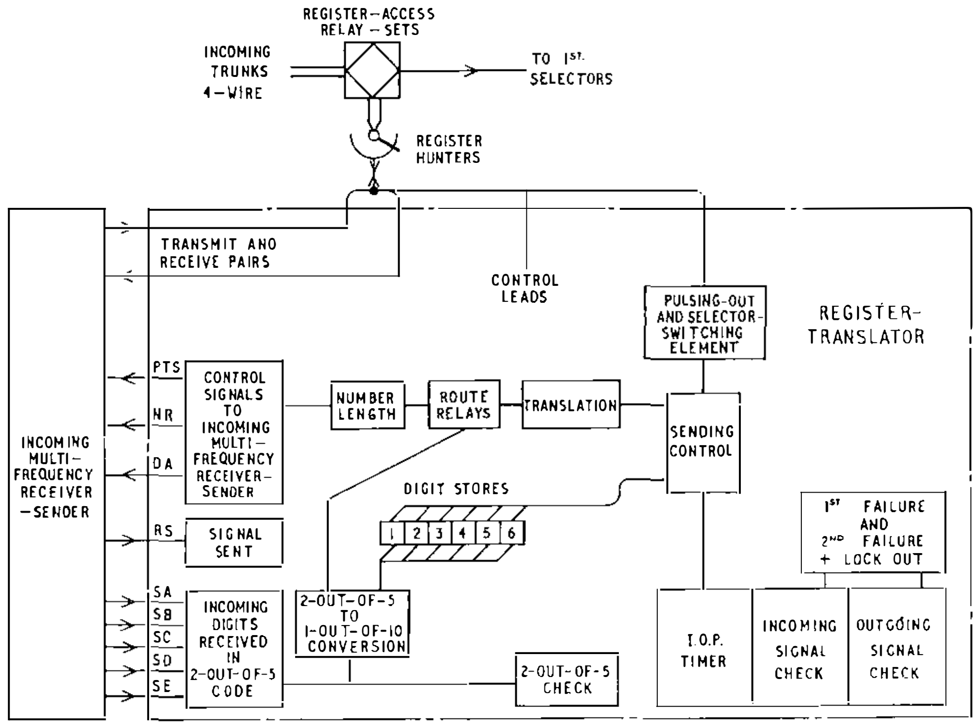


FIG. 3—Block schematic diagram of incoming register-translator equipment for non-director areas

ment to return a terminal proceed-to-send signal to the originating centre. A signal-sent condition from the m.f. equipment, on the RS lead, subsequently removes the proceed-to-send control signal.

In response to the proceed-to-send signal, the first forward digital signal is transmitted from the originating centre and received by the incoming m.f. equipment, and is marked into the register-translator in 2-out-of-5 code on the SA–SE leads. The incoming digit is checked in the register to verify a correct 2-out-of-5 combination, and is converted into decimal form. A digit-acknowledgement signal is then applied to the DA lead to cause the incoming signal marking to be removed. Subsequent digits are signalled, one at a time, from the controlling centre in response to further proceed-to-send signals, and each digit is checked and decoded as described above and taken into the appropriate digit store.

The first digit received on any call is the third digit of the called subscriber's national number, excluding the trunk prefix digit 0, i.e. the first digit received is the third digit of the required numbering-group code. This is used to operate a route relay which marks the translation routing digits, if any, to be transmitted. The need for this facility can be explained by reference to Table 1 and to Fig. 4. Fig. 4 shows

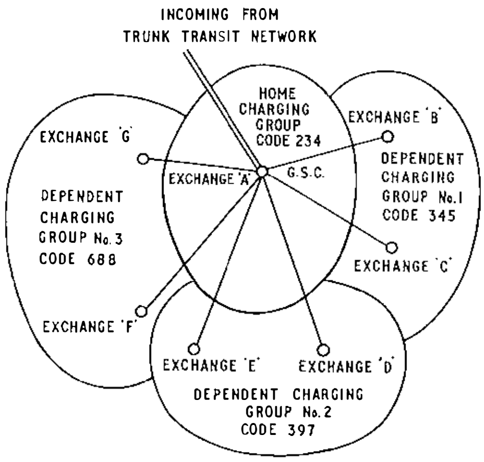


FIG. 4 -Typical example for use of the non-director area register-translator

a non-director area G.S.C. serving exchanges in dependent charging groups in addition to its own (home) charging group. Each charging group has one numbering-group code,

TABLE 1

Numbering-Group Codes and Translations for Exchanges Shown in Fig. 4

Exchange	Charging Group	National Number	C Digit	Translation	Selector Level
A	Home	0234- × × × ×	4	Nil	—
B	1	0345-2× × × ×	5	92	922
C	1	0345-4× × ×	5	92	924
D	2	0397-3× × × ×	7	94	943
E	2	0397-5× × × ×	7	94	945
F	3	0688-4× × × ×	8	96	964
G	3	0688-21× × ×	8	96	9621

and the figure indicates, for each charging group, the 3-digit numbering-group code that is dialled following the prefix digit 0, to reach an exchange in the charging group concerned.

Prior to the introduction of the transit-network scheme, the controlling register-translator at an originating G.S.C. has to transmit, by translation from the numbering-group code, the necessary routing digits to route a call through the incoming G.S.C. to a selector switching stage from which access can be obtained to the required dependent-numbering-group exchange. Under the transit-network scheme, however, a register-translator controls routing of traffic through its own exchange only. Thus, when dealing with a call via the transit network, a controlling register-translator supplies routing digits to take the call through the originating G.S.C. to an outgoing route to the next centre, which may be either a transit switching centre (T.S.C.) or, subsequently, the objective G.S.C. To facilitate onward routing, the controlling register-translator transmits forward to the register at the next exchange a part of the national number dialled by the calling subscriber.

At terminal G.S.C.s, (see Fig. 4 and Table 1) discrimination between different dependent numbering groups is made by inspection of the third digit (usually known as the C digit) of the numbering-group code, which is different for each numbering group served by the home G.S.C. Hence, this is the first digit received at a terminal G.S.C. Thus, in Fig. 4, a C digit 4 indicates a call to the home charging group, a C digit 5 indicates dependent charging group No. 1, a C digit 7 indicates dependent charging group No. 2, and so on. The received C digit is examined by the incoming register-translator, which then generates one or two translation routing digits, if required, to take the call to the appropriate switching stage for access to the required numbering group. If the call is to an exchange in the home charging group, no translation digits are required, because access is from a 1st selector.

Following the first incoming digit, the subsequent digits are received to complete the local portion of the called subscriber's national number. There may be four, five or six digits depending on the precise trunking arrangements at the G.S.C. concerned and depending also on the numbering scheme of the objective exchange.

When the last digit has been received, the incoming register-translator connects a control signal to the m.f. equipment via the NR lead to cause the return of a number received m.f. signal and thus enable the controlling register-translator and its m.f. equipment to be released from the connexion. Since the number of digits in subscribers' national numbers can vary between one exchange and another served by the same G.S.C., the incoming register-translator must determine the number length on any given call in order to decide when the number-received signal should be returned. This is done from inspection of the first digit or the first two or three digits received.

On initial seizure of the register-translator, the outgoing 2-wire line is extended from the register-access relay-set into the register, and a loop is applied within the register to seize the 1st selector associated with the register-access relay-set. Since the register-translator is designed for installation in existing step-by-step G.S.C.s, outgoing sending is in Strowger pulsing form and is controlled by a self-interacting pulsing-relay circuit. The register-translator is designed to give a standard inter-digital pause (i.d.p.) of 750 ms, controlled basically by a transistor-type timer within the register; but the i.d.p. may be curtailed, upon detection that switching of the pulsed selector has taken place, by a high-speed relay element inserted in the outgoing loop. Pulsing-out of translation digits, if any, commences as soon as the first incoming digit has been received, followed by repetition of the local-number digits when these are available, until all expected digits have been received and transmitted. To avoid difficulties when calls are routed to 11-and-over final selector groups, the penultimate digit is not transmitted until the last incoming digit is stored. When sending is completed, a signal from the register-translator causes the register-access relay-set to switch the call through and release the register-translator.

Service Safeguards

The register-translator incorporates comprehensive self-checking facilities, and fault-analysis lamps are provided to identify failures to the receiving or sending sections of the equipment. Both receiving-circuit and sending-circuit operation sequences are monitored by electronic timers, and if a circuit sequence is not completed, owing to a fault, an output from the appropriate timer causes forced release of the register-translator from the access relay-set. The occurrence of a fault, and the consequent forced-released condition, will usually inhibit the m.f. signalling sequence between the originating and terminal G.S.C.s. The m.f. equipment at the originating G.S.C. then passes a signal to the controlling register to cause it to release the trunk connexion and automatically initiate a second attempt to establish the call. If the failure occurs on a second-attempt call, the controlling register is released and number-unobtainable tone is returned to the subscriber from the register-access relay-set at the originating G.S.C.

Apart from the forced-release function, the precise action taken within the incoming register-translator under call-failure conditions depends on the type of fault. For certain failures that can be identified as actually occurring within the incoming register equipment, e.g. failure to send outgoing digits, the register-translator is locked out of service and a deferred alarm is given. For failure conditions that may have arisen either within the register-translator or in the external network, e.g. a disconnected outgoing line, the call is forcibly released and a first-failure memory is set in the register. If the next call is completed correctly, the memory is reset. If the next call fails, however, the probability is that this is due to a register-translator fault, and the equipment is locked out of service, a SECOND FAILURE lamp is lit, and a deferred alarm is given.

Circuit Principles

The circuit elements used for receipt, check and storage of incoming digits are shown in Fig. 5. The first digit is received in the m.f. receiver-sender as a 2-out-of-5 combination of signal frequencies and is marked into the register by operation of two of the SA–SE relays, in accordance with Table 2. Relay DR is permitted to operate if two, and two only, of the SA–SE relays are operated. If relay DR does not operate within 2 seconds, the register-translator is forcibly released under first-failure conditions. The arrangement of SA–SE relay contacts, associated with arcs 1NS1–6NS1 and the C-digit tags, gives conversion from 2-out-of-5 to 1-out-of-10 marking. Thus, when the first digit is marked into the register, earth potential from the RD2 arc home position is extended via the appropriate C-digit tag to operate a particular route relay (1TS, 2TS, etc.). Contacts of the operated route relay control the positioning of two Post Office Type 4 uniselectors (not shown in Fig. 5) in order to mark the translation routing digits, if any, to be transmitted. With relay DR operated, the earth potential from the RD2 arc also operates relay DS, which in turn operates relay DSR. A DSR contact returns a digit-acknowledged (DA) signal to the m.f. equipment, which then removes the incoming signal marking, thus releasing the SA–SE relays and, consequently, the DR, DS and DSR relays. During the slow release of relay DSR, a pulse is given to step the RD uniselector to contact 1. Relay DSR, on releasing, connects earth potential to the PTS lead to cause the m.f. receiver-sender to return the next proceed-to-send signal.

Subsequent digits, representing the local part of the called subscriber's national number, are stored on Post Office Type 4 uniselectors 1NS–6NS. Generally, a further four, five or six digits will be received. With the arrival of the next digit, relay DR operates as before and closes a self-drive

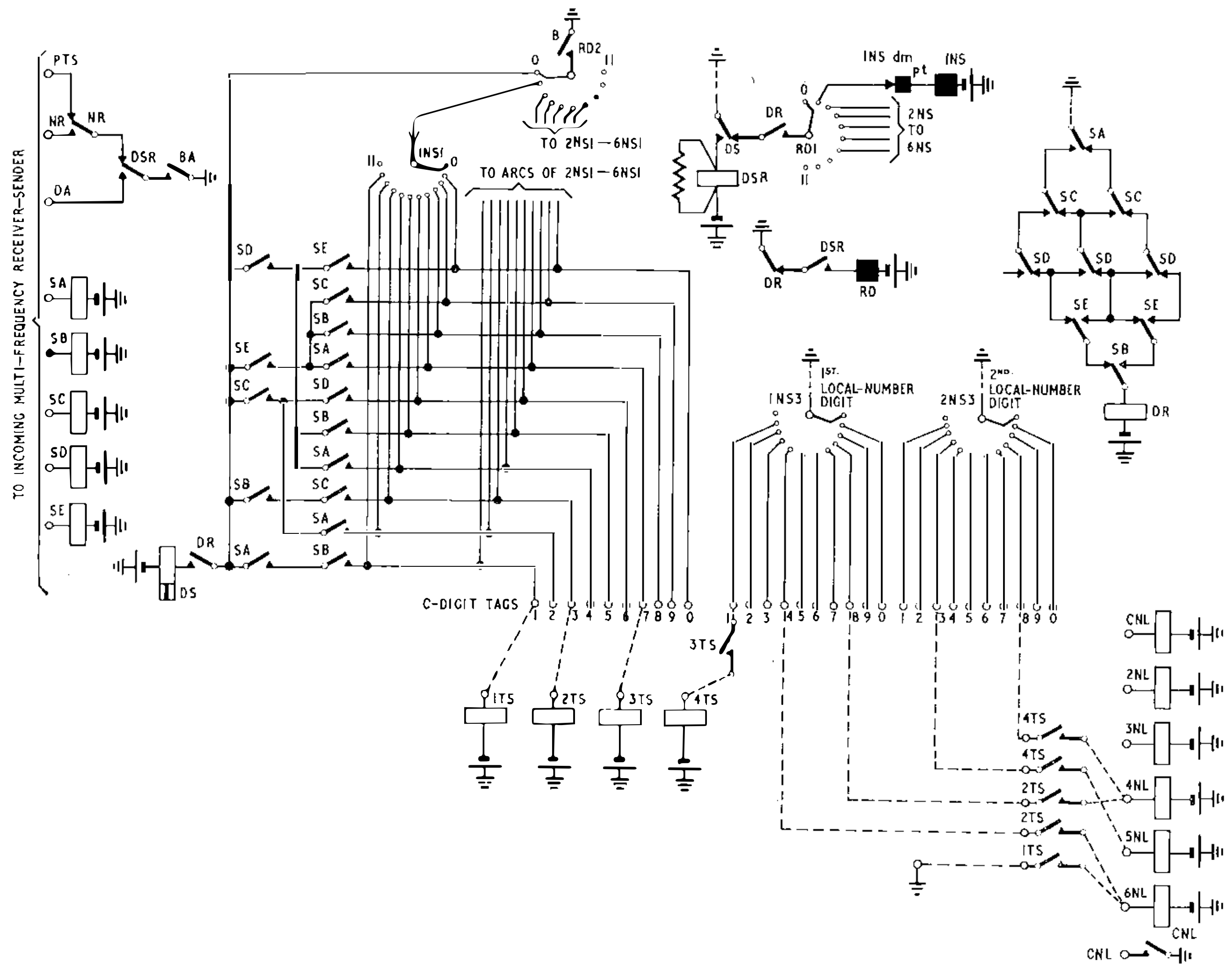


FIG. 5—Digit receipt and storage in non-director area register-translator

TABLE 2

Marking of Digits in Register

Digit	Relays Operated
1	SA, SB
2	SA, SC
3	SB, SC
4	SA, SD
5	SB, SD
6	SC, SD
7	SA, SE
8	SB, SE
9	SC, SE
10	SD, SE

TABLE 3

Number-Length Determination

Key to Typical Example Shown in Fig. 5					
Incoming Digits Required For Number-Length Determination			TS Route Relay Used	Number of Digits Required for Call	Relay Operated
C	N 1st	N 2nd			
1	—	—	1	6	6 NL
3	4	—	2	6	6 NL
3	8	—	2	4	4 NL
7	1	3	3 and 4	5	5 NL
7	1	8	3 and 4	4	4 NL

circuit for uniselector 1NS via RD1 arc. An outlet on 1NS1 arc, corresponding to the incoming digit, is marked with −50 volts via DS relay and the appropriate pair of SA–SE contacts. Uniselector 1NS steps until the marked contact is reached, when relay DS operates, cuts the drive to the 1NS uniselector and operates relay DSR. As before, relay DSR returns the digit-acknowledgement signal and, when the incoming digit marking is removed, the RD uniselector is stepped to contact 2 in preparation for receipt of the next digit. Each digit is marked on the appropriate 1NS–6NS arc as its complement with respect to 11. For example, if the incoming digit is 2 the uniselector is stepped to contact 9. Later, under sending control, the uniselector is stepped to contact 11, and digit 2 is sent out as Strowger pulses.

When the last due digit has been received, relay NR is operated so that, on release of relay DSR, a number-received signal is returned to release the controlling register-translator from the connexion. As indicated in Table 1, the number of digits in subscribers' numbers can differ from one exchange to another served by a given G.S.C., thus the incoming register-translator must determine the correct number of digits and, hence, the point in the call at which to return the number-received signal. Depending on the subscriber's number concerned, this can be determined from either the first digit, or the first and second, or the first, second and third digits received. The necessary discrimination is generally achieved by cross-connexion of TS relay contacts to operate one of five number-length relays 2NL–6NL. As indicated in Fig. 5, more than one TS relay may be used if three digits are involved in number-length determination.

It is probable that at a terminal G.S.C. one number length will be more commonly used than any other. To minimize cross-connexions and to economize in the use of TS relays a common-number-length relay, CNL, is provided. If none of the relays 2NL–6NL has operated after receipt of the third incoming digit, then the most common length of number will have been dialled, and relay CNL will be operated. A contact of relay CNL is connected to operate the appropriate relay in the group 2NL–6NL.

Timing Element

Conventional circuit principles are employed for the remaining basic functions of the register-translator, e.g. pulsing-out, cleardown, and will not be described. However, one other circuit element of interest is the transistor-type timer used to control send-fail and receive-fail conditions, and to generate the outgoing inter-digital pause. The basic circuit, which is also used in other S.T.D. equipment, is shown in Fig. 6. The timer consists essentially of two p–n–p silicon-transistor stages: a compound emitter-follower VT1 and VT2, and a relay-operating stage VT3. With the controlling contact unoperated, current drain via the potential divider is avoided, but VT1 collector–base junction is forward biased from earth via the 270-ohm and 220-ohm resistors, the transistor, the *CR* timing element, and the 500-ohm resistor chain and a 1,000-ohm resistor to −50 volts. Hence, a charging current can flow to the timing capacitor, C. The capacitor charges to only slightly less than the full 50-volt battery potential because the resistance *R* (typically, 1–2 megohms) is a high proportion of the total chain resistance. When the steady state is reached, a charging current of a few microamperes maintains the charge on capacitor C, which would otherwise discharge slowly through the high resistance of resistor R. Under these conditions transistor VT3 is in the non-conducting state and the relay normal.

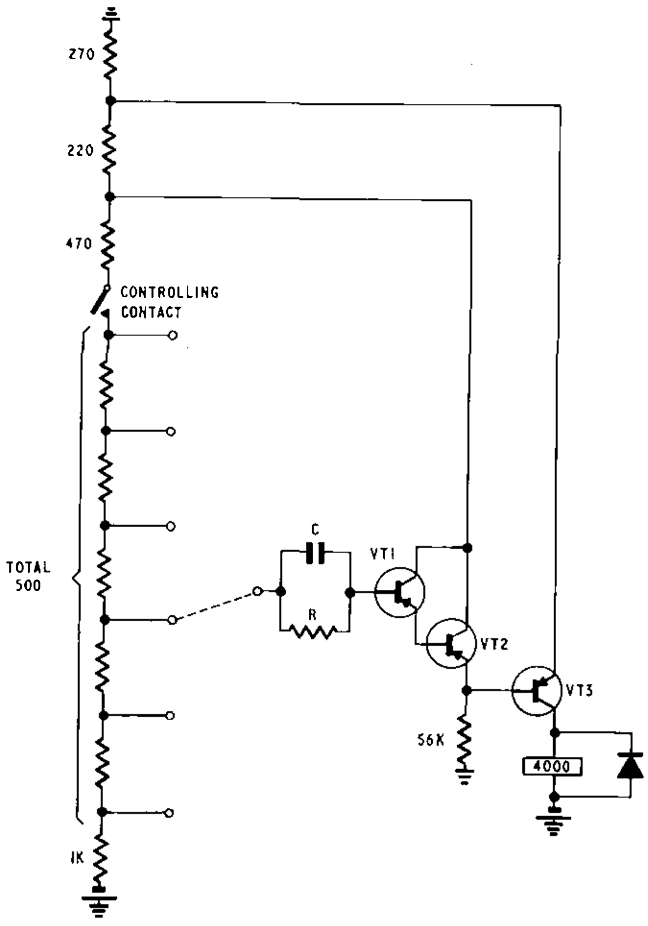


FIG. 6—Transistor-type timer circuit

When the controlling contact closes to commence the timing period, −50 volts is connected via the 470-ohm resistor to the collectors of transistors VT1 and VT2, which now assume emitter-follower configuration. At the same time, the potential at the tapping point on the 500-ohm resistor chain, which was previously near to −50 volts, rises towards earth potential due to the closure of the series-resistor circuit from earth to −50 volts. This positive-going change is coupled to the base of transistor VT1, which is thus biased off, and the potential now developed across the 270-ohm resistor is applied to transistor VT3 via the 56,000-ohm resistor so as to ensure that transistor VT3 is also biased off at this stage. Capacitor C discharges through resistor R, eventually permitting transistor VT1 base to reach a net negative bias, so that transistors VT1 and VT2 conduct. When the base drive is adequate, transistor VT3 bias is overcome and the transistor conducts sufficiently to operate the relay. Since transistors VT1 and VT2 are biased off during the timing period, the time delay is mainly determined by the timing-element *CR* product. While this product can be large, so as to give several seconds time delay, it is a feature of the circuit that when the controlling contact opens, the resetting interval is very short, governed principally by the time-constant of capacitor C in conjunction with the low resistance of the charging circuit already described. Also, the timing capacitor can be a relatively low-value non-electrolytic type, facilitating reasonably close and predictable accuracy of timing. Choice of tapping point on the 500-ohm resistor chain determines the extent to which capacitor C must discharge before VT1 conducts, and thus permits fine adjustment of timing to the nominal value required.

Physical Design

The register-translator equipment is conventionally mounted on standard 10 ft 6½ in. by 4 ft 6 in. 2,000-type racks, and each rack has capacity for eight register-translators. Five mounting plates accommodate each register-translator, including both the circuit components and the translation strapping field. The mounting plates are bolted to the rack and permanently inter-wired.

ELECTROMECHANICAL INCOMING REGISTER-TRANSLATOR FOR DIRECTOR AREAS

Outline of Facilities and Operation

The block schematic diagram, Fig. 7, shows the main elements of the register-translator. The same incoming m.f. receiver-sender equipment is used as in non-director areas, and it will be seen from Fig. 7 that the only difference at the interface with the m.f. equipment is the provision of an additional backward-signal lead (SC) to cater for return of a spare-code signal, when appropriate.

The operational sequence for initial seizure, return of proceed-to-send signals and receipt and decoding of digits is similar to that for the non-director equipment. On normal subscriber-to-subscriber calls, the digits received represent the 7-digit director-area number required, i.e. a 3-digit code portion followed by four numerical digits. The seven digits are stored on Post Office Type 4 uniselectors. When the 3-digit-code portion of the number has been received, the register applies for association with a translator to obtain the routing digits to the objective local exchange. After translator association the three digits are marked into the translator in 1-out-of-10 form and operate a translation relay, TS. The operation of this relay is signalled back to the register to remove the code-digit-store marking, and the appropriate routing digits are then returned from the translator into these same digit stores. An additional store, designated T in Fig. 7, is used for a fourth routing digit when required. Following the routing-digit transfer, the translator is released, and the routing digits and numerical digits are pulsed out from the register to route the call to the required subscriber.

When it has received seven incoming digits, the register returns a number-received signal in order to release the m.f. equipment at the originating G.S.C. and switch the connexion through. If, however, a spare code has been received, a signal from the translator causes a spare-code signal to be returned instead of a number-received signal. This prompts the release of the trunk connexion and return of number-unobtainable tone to the calling subscriber from the originating G.S.C.

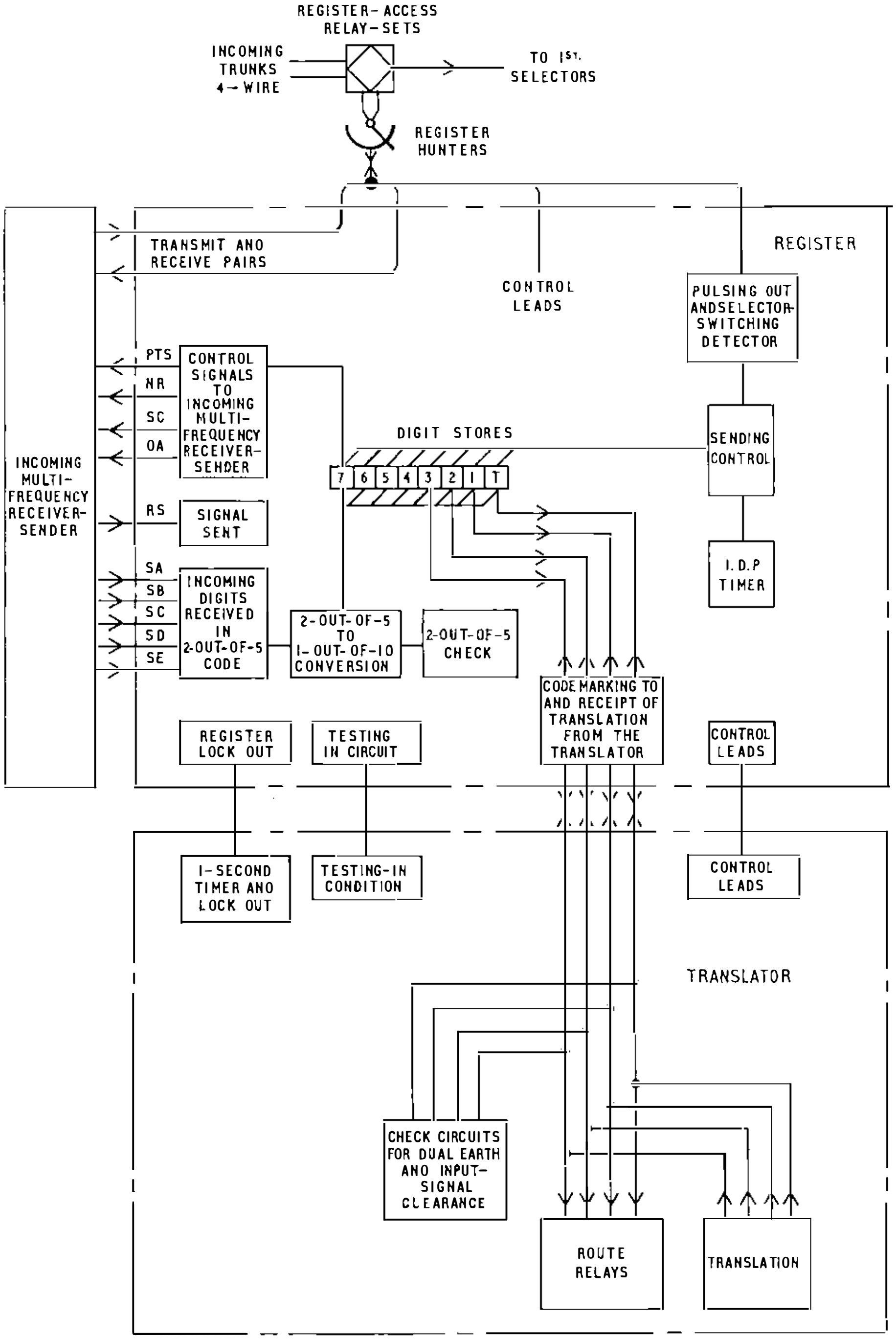


FIG. 7—Block schematic diagram of electromechanical incoming register-translator equipment for director areas

As indicated in Fig. 7, check circuits are incorporated to monitor the correct association and release of register and translator, and to verify the absence of incorrect marking conditions on input and output leads. The action taken under fault conditions, as for the non-director equipment, depends on the type of fault identified, and either the register or the translator or both may be locked out of service automatically. In the event of a translator being locked out, the registers it serves are changed over to a second translator. At any installation a minimum of two translators are provided to meet service-security requirements, and under normal conditions each translator can serve up to eight registers.

1T-4T to the digit-store arcs. Relay TF also releases relay CA in the translator to remove the 1A-9A relays from the first code-digit wires. Relay TF operates relay CR via a check circuit which verifies that the digit wires have been cleared of all potentials; the negative potentials from relays 1T-4T

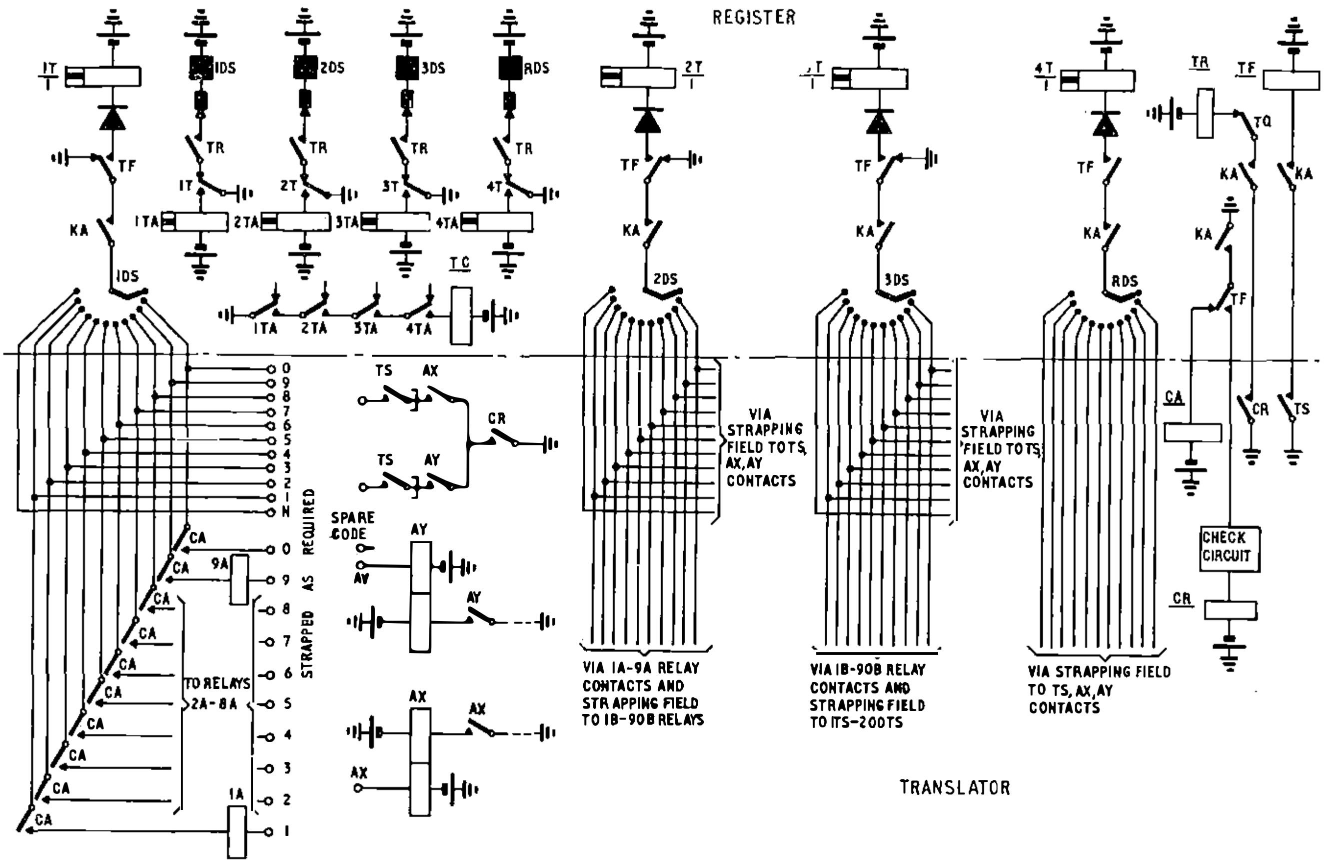


FIG. 8—Transfer of code and translation digits between register and translator

Circuit Principles

The register and translator circuit elements used for transfer of code and translation digits are shown in Fig. 8. The incoming code digits are stored on Type 4 uniselectors 1DS-3DS, and when the third code digit has been received the register applies for association with a translator. When association has taken place, relay KA in the register operates and extends an earth to operate relay CA in the translator. Contacts of relay CA permit the first code-marking condition to be extended via the 1DS arc in the register to operate one of nine first-digit selection relays, 1A-9A; the second and third digit markings from arcs 2DS and 3DS are used in conventional manner[6] to operate a relay in the group 1B-90B and, thence, the appropriate translation relay, TS.

The translator can be equipped with a maximum of 200 translation relays, 1TS-200TS, each having 10 make-contact units. One contact is required for each translation digit returned to the register, and since the register-translator design provides a maximum of four translation digits on any call, each TS relay can be arranged to cater for two translations. As indicated in Fig. 8, this facility is obtained by cross-connexion strapping so that the marking condition for the first code digit operates either relay AX or relay AY in conjunction with one relay from the group 1A-9A. Relay AX or AY contacts select the group of TS contacts used to return translation digits to the register.

The incoming code-digit stores, 1DS-3DS, with a fourth store, RDS, are also used to receive and store the translation digits returned from the translator. In order to remove the code-digit marking, a TS relay contact operates relay TF in the register, which now connects high-speed cut-drive relays being isolated by the series diodes. The operation of relay CR then operates relay TR in the register, thus closing self-drive circuits to the digit-store uniselectors, which drive and switch to the outlets corresponding to the translation digits marked by the TS relay. In each case the outlet represents the complement, with respect to 11, of the digit concerned. Each uniselector is subsequently stepped to position 11 as its stored digit is transmitted to line. If the incoming code requires less than four translation digits, the TS relay contacts for unused digits are strapped so as to mark outlet 11 of the digit-store uniselectors concerned.

Physical Design

Two 10 ft 6½ in. by 4 ft 6 in. 2,000-type racks have been designed to accommodate the register and translator equipment. Two translators can be fitted on a translator rack, and up to 12 registers on a register rack.

ELECTRONIC INCOMING REGISTER-TRANSLATOR FOR DIRECTOR AREAS

Additions to Existing Register-Translator

The electronic incoming core-type register-translator for director areas, as at present in use, only accepts incoming digits in Strowger pulsing form. As mentioned in the earlier article in this Journal,[2] however, the register-translator was designed to anticipate the future provision of incoming multi-frequency signalling, but additional equipment must be installed to enable this capability to be utilized. The most important addition is a new register signal-conversion circuit (S.C.C.) designed to pass digital signals in 2-out-of-5 code

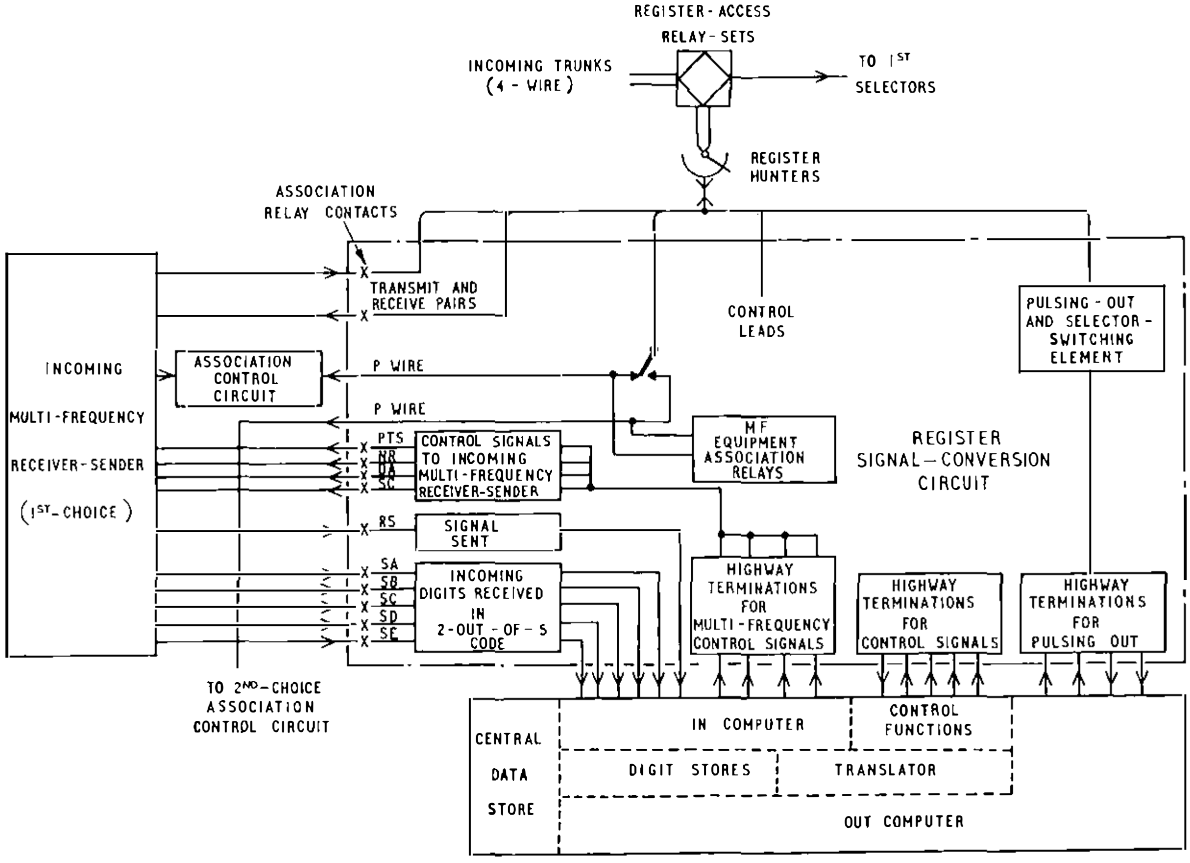


FIG. 9—Block schematic diagram of electronic incoming register-translator equipment for director areas

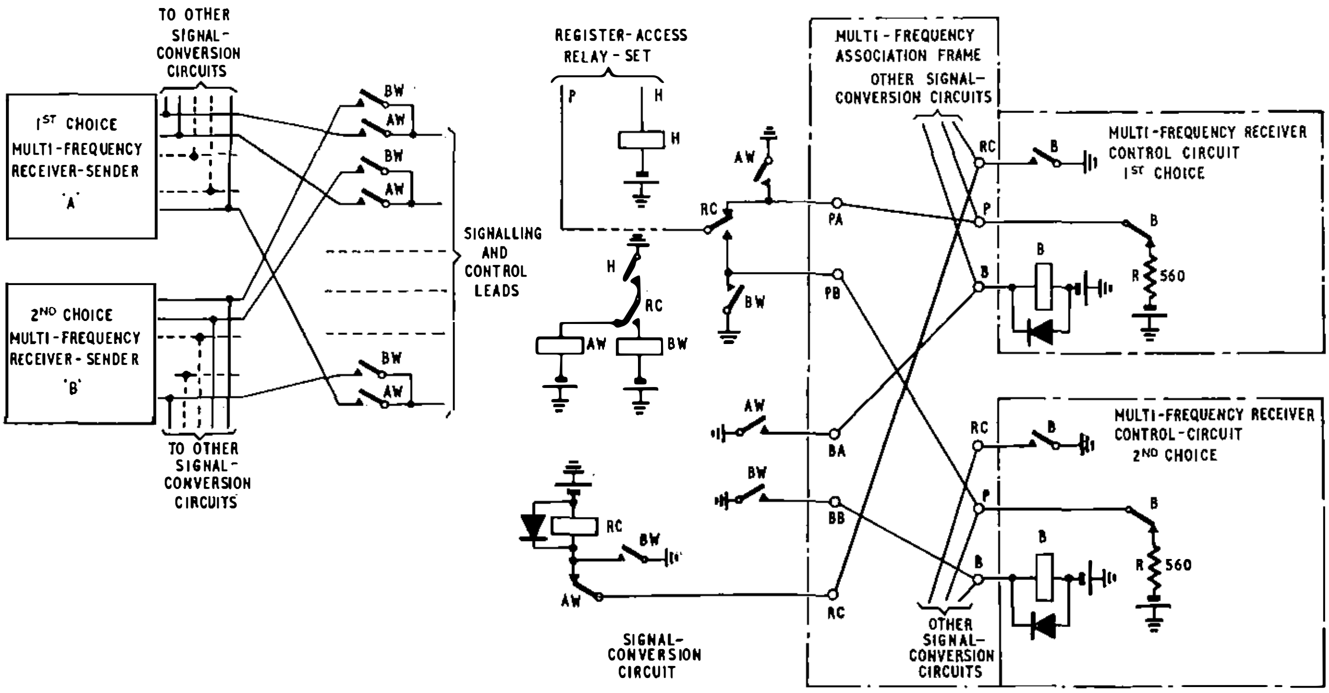


FIG. 10—Association of register with receiver-sender

from a m.f. receiver-sender to the electronic common equipment (E.C.E.), and to mark backward-control signals received from the E.C.E. into the m.f. equipment. The block schematic diagram (Fig. 9) shows the main elements of the S.C.C. and its interconnexion with the E.C.E. and m.f. equipment.

One unit of the existing register-translator equipment consists of two associated equipment cabinets known as a cabinet-pair. One cabinet of a pair contains the E.C.E. slide-in units, and the other contains the S.C.C. equipment also mounted on slide-in units. The new signal-conversion circuits for incoming m.f. signalling will be fitted in a third cabinet—thus each cabinet-pair will become a cabinet-triple. The third cabinet will house a maximum of 100 of the new type S.C.C.s. Because one E.C.E. cabinet can accommodate approximately 200 registers, half the total number of registers at any installation can carry incoming m.f. traffic, if required.

The operational facilities of this register-translator for incoming m.f. traffic are the same as those of the electromechanical register-translator, already described, and the same receiver-sender equipment is used. An important difference, as indicated in Fig. 9, is that the m.f. receiver-senders are not connected directly to the register S.C.C.s, but are arranged so that a pool of receiver-senders are shared among a number of signal-conversion circuits. This is important since the number of signal-conversion circuits provided at any one exchange is dictated partly by security considerations, which require that a satisfactory grade of service be maintained in the event of failure of two electronic common-equipment cabinets. In consequence, when all the electronic common-equipment cabinets are working, the number of S.C.C.s in service is greater than the number required to carry the busy-hour traffic, and it would be uneconomic to provide one m.f. receiver-sender for every S.C.C. With the arrangement adopted, the number of signal-conversion circuits will exceed the number of receiver-senders by a ratio of at least three to two.

Association of Registers with Receiver-Senders

The circuit principles used in the association of register signal-conversion circuits with m.f. receiver-senders are shown in Fig. 10. The signal-conversion circuits are arranged in groups of 24, dictated by the capacity of the register-hunter bank, and each group shares a common pool of, typically, 16 receiver-senders. Relay contacts are used to connect S.C.C.s to receiver-senders, each S.C.C. having access to two receiver-senders, on a first-choice and second-choice basis. Thus, in a 24 S.C.C. group, there are 48 interconnexions with m.f. receiver-senders, and so the 16 receiver-senders are each interconnected with three S.C.C.s. The interconnexions are made systematically to ensure that if one or more register-translator cabinets are out of service, the receiver-senders are distributed uniformly over the S.C.C.s that remain in service.

The circuit ensures that a signal-conversion circuit can only be seized by a register hunter if at least one of its two associated receiver-senders is free (Fig. 10). This is arranged by taking the P-wire testing-in path to a receiver-control circuit (R.C.C.), one of which is provided for every m.f. receiver-sender. Thus, each signal-conversion circuit is connected to two receiver-control circuits. As indicated in Fig. 10, if the first-choice control circuit is engaged, having been seized from another signal-conversion circuit, its B relay will be operated. Hence, relay RC will be operated in the conversion circuit to change over the P-wire to the second-choice receiver-control circuit. If both receiver-control circuits are engaged, the P-wire will be earthed and the signal-conversion circuit will test busy to the register hunter. If, however, either of the receiver-control circuits and its associated receiver-sender are free, relay B of the free receiver-control circuit will be normal, and the testing-in potential of −50 volts is extended to the incoming P-wire. The register-hunter can now switch to this free condition, and thus operate the relay H in the signal-conversion circuit. Depending on which receiver-control circuit and receiver-sender are free, the operation of relay H will operate relay AW or BW in the signal-conversion circuit to extend the signalling and control leads to the receiver-sender.

In order to reduce the resistance of the P-wire circuit to a minimum, the receiver-control circuits are mounted in the signal-conversion circuit cabinets, and the interconnexions between S.C.C.s and R.C.C.s are made on an association frame which is mounted en suite with the S.C.C. cabinets.

ACKNOWLEDGEMENTS

The development of the register-translator equipment described in this article was carried out on behalf of the British Telephone Technical Development Committee by the Post Office in conjunction with the General Electric Company, Ltd. (electromechanical register-translator equipment) and Ericsson Telephones, Ltd., of the Plessey Telecommunications Group (electronic register-translator equipment).

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Book Review

"Principles of Television Reception." W. Wharton, C.Eng., F.I.E.E., and D. Howorth, B.Sc.Tech., C.Eng., M.I.E.E. Sir Isaac Pitman and Sons, Ltd. viii + 296 pp. 154 ill. 40s.

The scope of this book is rather wider than is implied by the title. It reviews, in a simple manner, the basic principles of modern television systems for both monochrome and colour in addition to dealing at greater length with the principles of receivers.

After dealing with the principles of monochrome receivers, the circuit techniques used in the various parts of a receiver are surveyed. Both valve and transistor circuits are considered, and useful comments are made, about the advantages and disadvantages of various possible arrangements. The principles of colour television and colour display tubes are then treated and this is followed by a review of receiver circuits for the N.T.S.C., SECAM and PAL systems. A final chapter deals with propagation, and there are appendices on colorimetry and receiving acrials. A useful feature of the book is the lengthy and up-to-date bibliography (with references up to early 1967) which is included.

The treatment is essentially non-mathematical and relies on simple physical explanations of circuit operation. However, for the most part, the explanations are brief and require from the reader a reasonable familiarity with valve and transistor circuits.

Chapter 2 on "Circuit and Modulation Theory" contains the surprising statement that two methods of circuit analysis are used in television, viz. steady-state analysis for picture circuits and pulse or transient analysis for synchronization circuits. Even more surprising in the light of the lead which the U.K. has given to the rest of the world in the use of K-ratings and waveform specifications, is the appearance, four pages later, of steady-state limits for tolerances on gain and group-delay/frequency characteristics which are claimed to be appropriate to the British 625-line system. In Chapter 10, the description which is given of differential phase and gain distortions is also liable to cause some confusion to a newcomer to the subject.

Despite these criticisms the great majority of the subject matter is well presented and the book is well produced and clearly illustrated. It can be recommended for anyone who is reasonably familiar with valve-circuit and transistor-circuit techniques and who requires a survey of modern television practice with special emphasis on reception.

I. F. M.

A Field Trial of an Experimental Pulse-Code Modulation Tandem Exchange

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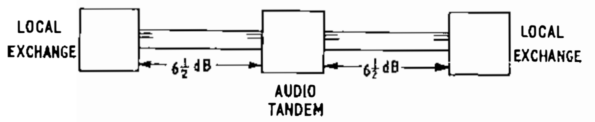
U.D.C. 621.376.56.001.41: 621.395.722

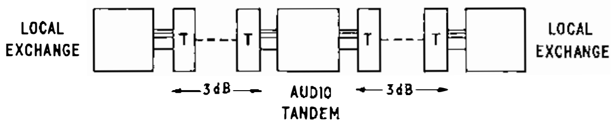
An experimental pulse-code modulation (p.c.m.) tandem exchange has been developed as the basis of a trial to test the feasibility of switching telephone traffic in p.c.m. form. Although small, the model exchange contains many of the features of a full-size exchange suitable for London tandem applications. It is now installed in Empress telephone exchange in west London where it will carry live traffic originating from three nearby exchanges.

INTRODUCTION

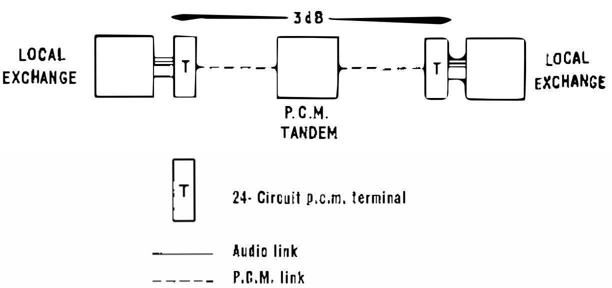
Pulse-code modulation (p.c.m.) is now widely accepted as a means of increasing the number of circuits that can be provided by existing multi-pair audio junction cables. The advantages of p.c.m. transmission have already been described:[1] by the end of 1969 it is expected that over 900 separate 24-circuit p.c.m. point-to-point systems will be installed in the United Kingdom network.[2] As such systems penetrate the network the possibility of p.c.m. switching becomes increasingly attractive, particularly to perform the tandem switching function between junctions. When a tandem exchange of conventional design is used it is necessary to decode the p.c.m. signals at the entry to the exchange and to encode them again for retransmission over another p.c.m. link. Such an arrangement is not only costly in encoding and decoding equipment but it also causes an unnecessary degradation of speech quality by repeating the sampling and coding processes. Digital switching avoids these difficulties and can be seen to be complementary to p.c.m. transmission (Fig. 1). The p.c.m. line signal is already time-divided, and the principles of t.d.m. switching by high-speed electronic gates can be applied directly; no additional peripheral modulating equipment is required. The robust digital p.c.m. signal is more tolerant of crosstalk and interference within the exchange than the signals of earlier pulse-amplitude modulation systems. Also, by the use of 4-wire digital switching in conjunction with p.c.m. transmission, significant reductions in transmission loss can be obtained, particularly for calls across large urban areas, as, for example, in the London tandem network.



(*a*) Existing Audio Circuits



(*b*) With P.C.M. Transmission only



(*c*) With P.C.M. Transmission and Switching

FIG. 1—Advantages of p.c.m. switching for tandem applications

Clearly, the economic attraction of p.c.m. in a particular switching environment will be dependent on the proportion of p.c.m. transmission systems already in service, or likely to be installed within the life of the new switching equipment, and on the relative cost of p.c.m. switching compared with switching by conventional means. In fact, the indications are that the cost of p.c.m. switching will be significantly less than that of audio switching, so that the cost saving might be used to offset the expense of meeting the net increase in peripheral p.c.m. multiplex equipment which would be necessary initially in an environment which was mainly of audio junctions.

EMPRESS EXCHANGE FIELD TRIAL

Preliminary study of the basic technical problems of p.c.m. switching indicated that there was no effective substitute for an experiment involving the detailed design and construction of an integrated p.c.m. transmission and switching system, and the installation of this system in representative Strowger surroundings where it would interwork fully with the existing network and carry live telephone traffic.

Thus, the prime purpose of the experiment was to demonstrate the technical feasibility of p.c.m. tandem switching of p.c.m. junctions serving Strowger-type local exchanges, to expose any practical problems and to find solutions to them, and to establish a firm basis for future development. The experiment should also go a long way towards indicating the technical possibilities and economics of more widespread use of fully-integrated p.c.m. line and exchange systems.

As examples of some of the practical problems, means must be devised of suppressing the effect of interfering signals when operating in the rather high level of interference generated by adjacent electromechanical equipment. Rather severe timing requirements have to be met, and timing problems are greatly affected by the actual physical layout of the equipment: production tolerances of the circuit elements used must also be taken into account. New components and techniques have to be shown to be sufficiently fault-free and to have an acceptable life for the job. System design must provide alternative paths so that, when faults do occur, the traffic can be carried until maintenance repairs have been carried out.

Three adjacent London director exchanges—Acorn, Ealing and Shepherds Bush*—were selected for the trial. These

† Electronic Switching Branch, Research Department, Telecommunication Headquarters.

* With the introduction of all-figure numbering, these exchange names together with that of Empress exchange are now no longer used.

exchanges serve an area with a community of interest, so that in the normal course much traffic passes over direct audio junctions between them. A proportion of this traffic is automatically diverted to p.c.m. equipment installed at these exchanges, where the information is converted into p.c.m. form and passed to the experimental switching unit, which, for convenience, is located at Empress exchange in the vicinity. Fig. 2 shows that each exchange is equipped with two 24-channel multiplexes. In addition, there are two p.c.m. multiplexes at Empress exchange, but these do not carry live traffic; they are used solely for tests and demonstration purposes. Thus, the experimental exchange handles only 144 live channel connexions (40 Erlangs of traffic); even so, it contains many of the features of a full-size exchange.

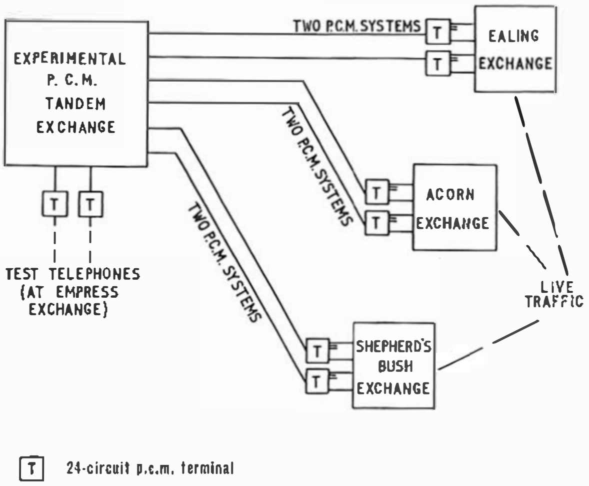


FIG. 2—Block schematic diagram of Empress exchange field trial

In early 1965, work commenced at the Post Office Research Station on the detailed design of the model exchange. Two years later, prototypes of many of the key units had been constructed and tested, and limited quantity production began; wiring and assembly of the racks commenced in June 1967. By January 1968, assembly work was almost completed, overall commissioning tests commenced, some modifications, mostly of a minor nature, were carried out, and the model was moved to its site in Empress exchange in the following April (Fig. 3).

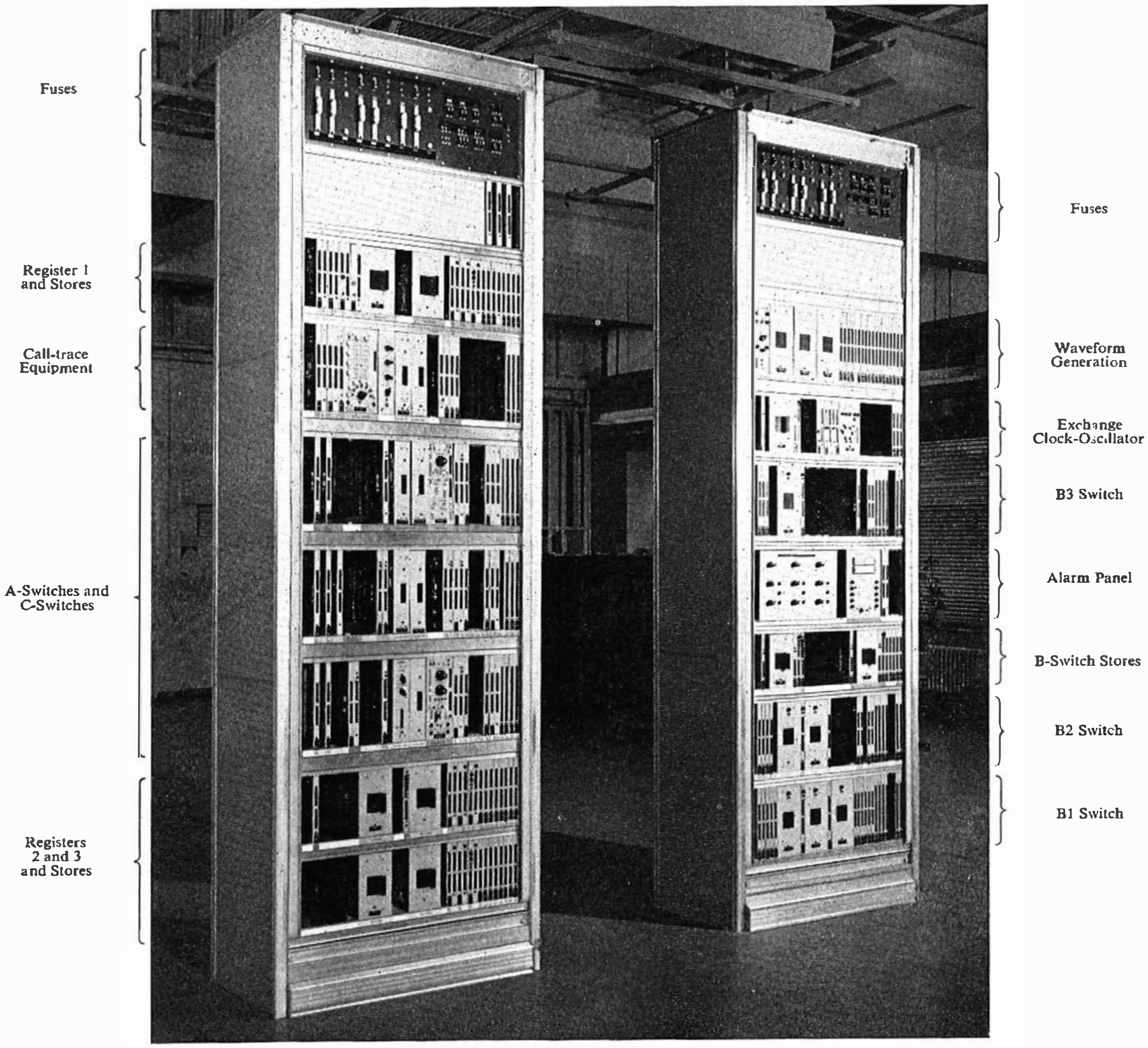
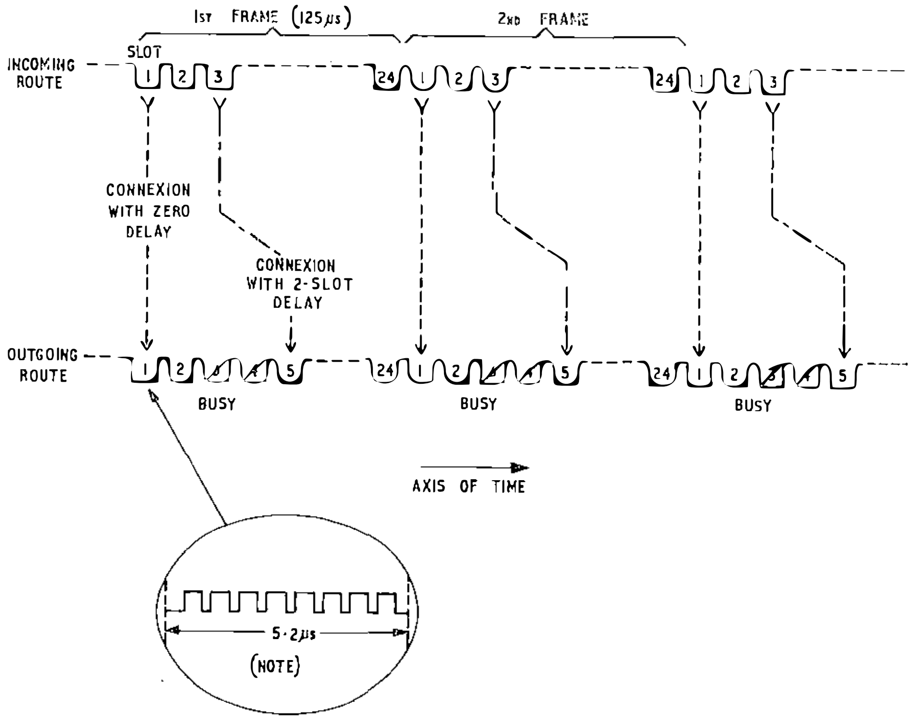


FIG. 3—Field trial p.c.m. exchange equipment

P.C.M. Line Systems Used

The 24-circuit p.c.m. line systems supplied for the trial are substantially the same as those currently being installed in the United Kingdom network for normal point-to-point working.[3] For each input channel the analogue speech waveform is sampled at 8 kHz, and the amplitude of this sample is described using a 7-digit binary code, which specifies 2^7 (128) different levels, or quantizing steps. In fact, for each channel eight digits are transmitted to line; the first digit, known as the signalling digit, specifies the signalling code, while the remaining seven digits specify the speech-waveform amplitude. The eight digits representing each channel form a time-slot; these are then interleaved with the 23 other time-slots to form a frame (Fig. 4). In fact, a 4-frame multi-



Note: Eight-digit coded signal in each time-slot

FIG. 4—Principle of time switching

frame is used; the first digit provides signalling information in odd frames only, in the second frame of the multi-frame it is at present unallocated, while in the fourth frame it provides the synchronization pattern.

Correct interpretation of signalling conditions is of course vital to the operation of the exchange; these conditions are transmitted in the form of rhythmic, or comma-less, codes (Table 1) formed by the state of the signalling digit in successive odd frames.

TABLE 1
P.C.M. Line System Signalling Codes

State of Signalling Digit Appearing Serially in Odd-Numbered Frames	Signalling Condition (Forward Direction of Signalling)	Signalling Condition (Backward Direction of Signalling)
000000	Circuit idle and dial break period	Circuit busy or called party clear
111111	Call trace	Circuit free or call-trace
010101	Circuit seized and dial make period	Called party answer

Facilities for forward and backward call-trace have also been incorporated in the line systems. After a call has been set up over the p.c.m. network, forward call-trace can be initiated by the insertion of a U-link into a test point on the appropriate channel outgoing signalling relay-set of the multiplex equipment. This causes the appropriate signalling condition to be transmitted to line, and a lamp display at the incoming signalling relay-set at the distant-end multiplex equipment indicates that call-trace has been requested. When call-trace has been established, the call cannot be released by normal clearing signals. Similar facilities exist in the reverse direction. The experimental exchange has, of course, been designed to handle call-trace signals; its supervisory equipment inhibits release in the presence of call-trace, and a lamp display provides an indication of the path taken by the call through the exchange. The experiment should illustrate the feasibility of providing these facilities in the future for exchange-maintenance purposes.

Apart from the call-trace facility, the line systems differ in certain other respects from those currently specified for point-to-point working. In order to meet the timing requirements at the exchange it is necessary to maintain a fixed relationship between all transmit and receive timing at each multiplex terminal. Also, to ensure delivery in time for the field trial (these systems were some of the first to be ordered) it was necessary to accept certain deviations from standard practice, the most important ones being the use of a straight binary line code instead of a symmetrical binary code with alternate-digit inversion, and the use of a 24-bit synchronization pattern instead of the preferred 16-bit pattern. For systems connected to an exchange the choice of line code can be important in ensuring that the line repeaters remain active under idle conditions.

Two-cable working is employed, and regenerators are fitted where necessary. The longest route requires seven regenerators; this is sufficient to demonstrate synchronization problems.

Access From Strowger Exchanges

Access equipment is required at the Acorn, Shepherds Bush and Ealing exchanges to ensure that a proportion of the traffic is diverted to the experimental p.c.m. network. For calls originating at one of these exchanges and requiring access to another of them, the first two digits of the director routing code actuate the Strowger code selectors in the normal way and, at the output of the second-code selector, a choice is made between an audio route via a third-code selector and a route incoming to the experimental p.c.m. network. Early-choice and late-choice outlets are interleaved to give a realistic traffic loading to the experimental network. If the experimental network is chosen, then the third routing digit controls the routing of the call through the experimental exchange. Thus, the register unit of the model is required to handle only one routing digit. In this respect it is simple in concept, but the principles used can be readily extended to cope with more routing digits. Outgoing routes from the experimental network have access to first numerical selectors at Acorn, Ealing and Shepherds Bush exchanges.

System Security and Change-over Arrangements

In a trial of this nature involving public traffic, security of service is of the utmost importance; during commissioning the experimental equipment was subjected to a very comprehensive set of overall tests, which included measurement of timing tolerances, behaviour under extremes of ambient temperature and performance in the presence of external interfering fields, as well as a confidence test for an extended period. The experimental unit is also equipped with comprehensive automatic routining facilities for the regular checking of all its essential parts; these routiners operate in conjunction with print-out equipment and proved to be of considerable value during commissioning and confidence testing. The system philosophy permits a variety of alternative paths to be offered for each desired connexion; path selection ensures that the use of paths involving faulty equipment is avoided, and where possible a record is provided of the paths which have been rejected. All the essential common equipment, such as the exchange timing equipment (clock oscillators) and waveform-generation equipment has been triplicated.

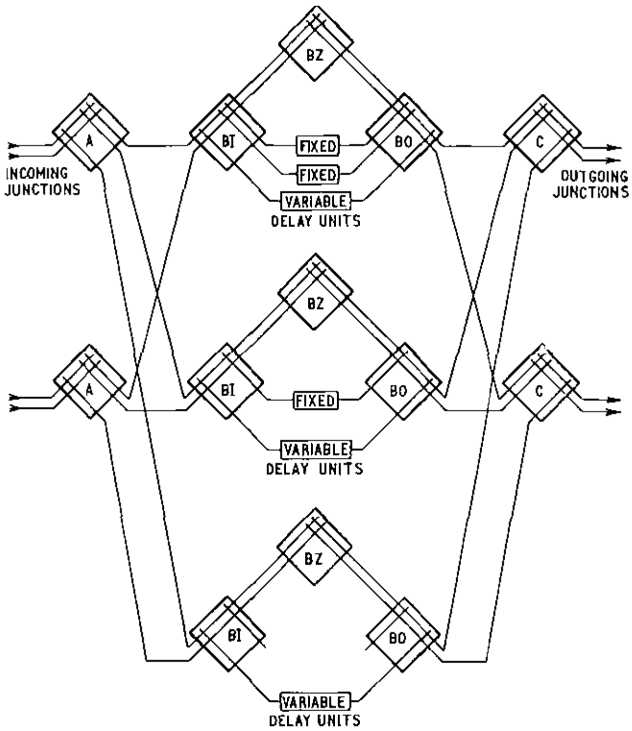
In spite of these precautions to provide adequate security and fault tolerance within the exchange, unforeseen problems must be expected, while the small size of the network imposes restrictions which would not apply in full-size exchanges. If, for example, one line system fails on one of the links between Empress exchange and an outstation, the outgoing capacity of that link is halved and congestion can occur within the experimental network. The network is therefore equipped with a manual and automatic facility for diverting new calls away from it in the event of trouble.

DESIGN OF THE EXPERIMENTAL EXCHANGE

Switching Network

The switching network forming the experimental exchange is, in effect, composed of co-ordinate switches similar in principle to those used in crossbar and reed-relay exchanges. In such switches, connexions are established through a particular co-ordinate point, known as a cross-point, between a particular row and a particular column. The p.c.m. switches differ from the more conventional co-ordinate switches, however, in one essential feature. Because the p.c.m. cross-points are time-shared, each provides the equivalent of 24 cross-points in a space-divided analogue network.

A 3-stage symmetrical switching network is used; systems employing more switching stages were rejected because they did not give sufficient cross-point economy to justify the consequent increased complexity in control, and the additional transmission-path delays produced more difficult timing problems. A full-size exchange operating on the same principle as the experimental unit would use matrices of up to about 15 × 15; the particular trunking arrangements used for the experimental exchange are shown in Fig. 5. Although the switching matrices used in the experimental unit are small, the fan-out associated with a full-size matrix is simulated in one A-switch.



The model exchange is equipped with two A-switches, three B-switches and two C-switches

FIG. 5—P.C.M. tandem exchange switching network

Incoming junctions are connected to the A-switches, and the central B-switch stage contains delay-link units, the purpose of which is described in a latter section. The C-switches give access to the outgoing junctions.

For a large exchange, up to about 15 A-switches and 15 C-switches could be provided while maintaining full interconnexion between these switches; such a unit could handle about 3,000 Erlangs of traffic. For larger exchanges, limited availability is proposed: in the B stage, connexions that do not require delay are routed via the BZ-switch cross-points.

The particular combination of paths required for all the channels that have to be connected at a particular slot time are set up by the control, and the information on the channels is passed between the appropriate exchange terminals during that slot time. At the end of the slot time all the connexions are cleared and the necessary interperipheral paths for the channels in the next time-slot are made before the slot time begins. It is, therefore, essential to use electronic devices for the cross-points, because the switches have to operate at very high speeds. Such devices should also give greater reliability and freedom from wear problems than electromechanical devices. As only 1/24th of the cross-points required for an equivalent space-division exchange are necessary, the electronic cross-point devices can be more expensive than the electromechanical ones and yet still show an overall economy.

Fig. 5 also shows how the switches and links may be organized in security layers to cope with equipment failures. For example, if part of the B1-switch or its associated links fail, the A-switches continue to have access to both C-switches via the B2-switches and B3-switches.

Fig. 6 is a simplified schematic diagram of the complete exchange.

Timing Problems

The time-divided nature of the p.c.m. line signal brings with it some rather severe timing requirements. For the

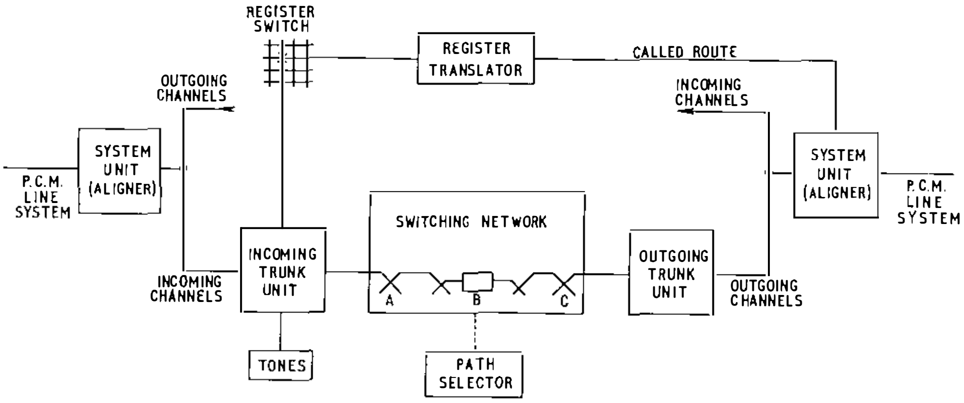


FIG. 6—Overall schematic diagram of p.c.m. tandem exchange

24-channel p.c.m. system operating at 1·536 Mbits/second, the fundamental digit-pulse period is about 650 ns; a 50 per cent duty cycle is used, giving a digit-pulse width of 325 ns.

To retain the identity of individual conversations, and to enable them to be correctly switched through the exchange, all the incoming information from the different routes is synchronized at the entry to the exchange. Thus, each system connected to the exchange requires a unit known as an aligner to compensate for delay variations due to temperature changes and repeater phase jitter etc., and to align incoming information with exchange time. For paper-core junction cables the delay variations are not likely to exceed 150 ns/mile even under extreme conditions, and the system aligners provided for the experimental exchange incorporate an 8-digit variable-delay buffer store. The experimental p.c.m. network operates on a synchronous-star principle, and the exchange clock-oscillator controls all network timing. In addition to variable storage, some fixed delay has, in general, to be provided so that the loop delay on any link is an integral number of multi-frames. For the experiment this has been provided partly by additional fixed delay in the system aligners, and partly by adjustment of the relationship between transmit and receive timing at the p.c.m. multiplex equipments at the outstations.

In handling digit pulses of 325 ns duration, the propagation delay of the electronic switching elements and, indeed, of every few feet of inter-connecting wire has to be taken into account. It is, therefore, necessary to introduce four deliberate stages of half-digit retiming of pulses during their passage through the exchange. These timing devices permit connexions of up to 50 feet in length between switching stages; such connexions would be necessary in a large exchange.

Function of Delay-Link

The switching network of A, B, and C switches enable a caller on, say, channel slot 2 of a particular incoming route to be given access to the same channel time-slot of any outgoing route. As the exchange is handling junction traffic, the choice of outgoing time-slot is, however, unimportant, for all time-slots of a particular p.c.m. system serve the same destination. Traffic studies have shown that, in a large exchange, approximately 40 per cent of calls can be set up without the need for slot changing.[4] For the remaining 60 per cent of the traffic the same time-slot will be busy in the wanted route, and it will then be necessary to introduce time-switching. For this purpose delay links are introduced which are capable of storing the p.c.m. message appearing in, say, slot 3, and releasing it in, say, slot 5 (Fig. 4). The link units are either of the fixed-delay type, introducing delays of, say, one or two slots, or of the variable-delay type —these are more complex units capable of connecting any incoming time-slot to any outgoing time-slot and of working in conjunction with a program unit. If, for example, a delay of three slots is provided in the forward direction, then it is necessary to provide a complementary delay of 21 slots in the backward direction.

Call Detection, Path Selection and Control Equipment

Each p.c.m. system is terminated in a system unit which provides synchronization-pattern detection and generation equipment and the time aligner. For each system of the experimental network, incoming and outgoing channels are interleaved alternately, so that no system serves exclusively one type of junction. Thus, at the system-unit output, incoming channels are associated with an incoming trunk unit, which includes supervisory equipment and provides access to the register switch and thence to the register-translator. Outgoing channels are associated with an outgoing trunk unit. Path-selection equipment is linked with the B-switches of the switching network. The method of setting-up calls is described in a later section.

Cross-Point Switches and Stores

In a conventional space-division exchange, a connexion. once set up, is held for the duration of the call. In the p.c.m, exchange, because of the time-division nature of the signals, a connexion is held only for the duration of a channel time-slot (5·2 μs) and then it is released so that the signals on the subsequent time-divided channels can be switched to their destinations. In the next p.c.m. frame, the incoming channel must be switched to its outlet as before, and so on.

The foregoing features make the design of the cross-point switches very different from that of switches for a more conventional exchange. Firstly, the cross-points have to operate far more rapidly than would be possible with electromechanical switches, and solid-state logic gates have to be used. Secondly, because of the necessity for rearranging the connexions for each channel, a store must be associated with the cross-points in order to memorize the switching configuration for each channel time-slot. This store is operated in a cyclic fashion so that the same switching information is presented in the corresponding channel time-slot of each frame, the only change in the cycle occurring when a new call is set up or when an existing call is cleared.

A simplified logic diagram for one 3-outlet column of a cross-point matrix and its associated core store is shown in Fig. 7. The core store is read by a pulse from the appropriate read amplifier just before the signals for that particular time-slot are expected on the highways. The store toggles T1 and T2 are thus set to a binary combination corresponding to the cross-point it is required to operate. Because it is a 3-way switch, two binary digits are required to operate it, the 00 combination being used for the free condition. Three binary digits would be necessary to control a 7-way switch and four binary digits for a 15-way switch.

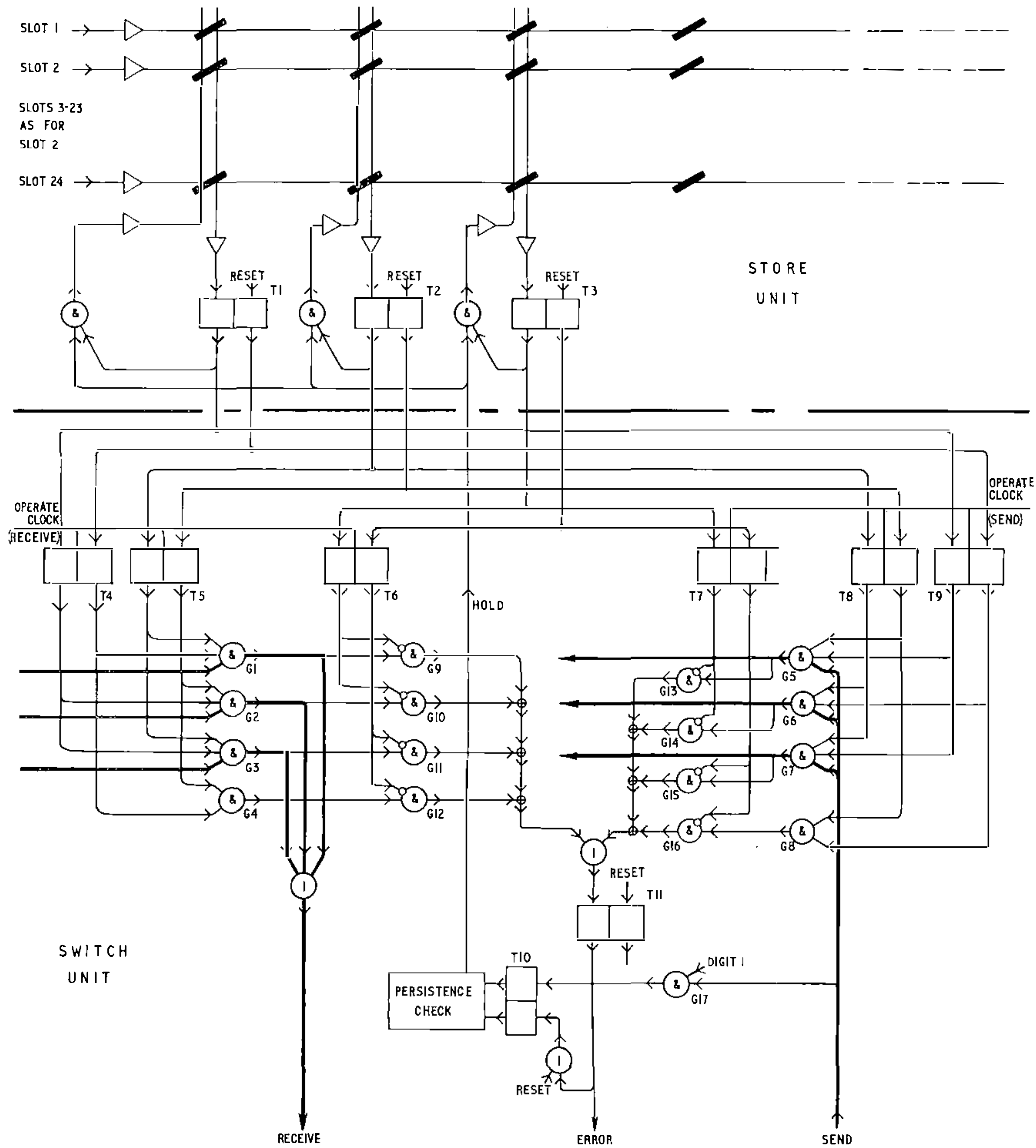


FIG. 7—Simplified logic diagram of 3-outlet column of cross-point matrix

The cross-points must be operated between digit 8 of one time-slot and digit 1 of the next, an interval of only 325 ns. This requires very precise timing, and store toggles could not control the cross-points directly. Secondary toggles, T4–T6 and T7–T9, mounted on the switch unit and operated by clock pulses, are, therefore, used for this purpose. Two sets of toggles are used, one for each direction of transmission since, owing to different propagation delays, the time-slot for one direction of transmission is not exactly coincident with that for the other direction. These toggles control the main cross-point gates G1–G3 and G5–G7, respectively. As the p.c.m. signals and the outputs from the control toggles have the same logic levels, the decoding of the control signals and the switching of the p.c.m. signals can be carried out within the same logic gates.

Error Detection

In addition to the two binary digits used to control the cross-points, a parity bit is used to check the operation of the switch; the coding is shown in Table 2.

The parity bit is stored in the same way as the control bits, and the store output is used to operate toggles T6 and T9. If the operation is correct, the output of toggle T6 will apply an inhibit condition to that gate of the group G9–G12 which corresponds to the cross-point that has been operated by the control bits. The p.c.m. signals are thus prevented from passing through to the error toggle, T11. However, if the p.c.m. signals should pass through an incorrect cross-point, as indicated by the parity bit, the inhibit condition is not present on the corresponding gate and the first 1 digit in the p.c.m. signal will pass through the gate and operate the error toggle. In the opposite direction of transmission, the output of toggle T7 is used to apply the inhibit condition to gates G13–G16, but the error toggle is common to both directions of transmission. The gates G4 and G8 are dummy cross-points used to decode the 00 combination of control bits, so that a complete parity check can be applied in accordance with Table 2. This method of parity checking not only

TABLE 2
Parity Check for Cross-Point Operation for 3-Way Switch

Cross-point Control Bits	Parity Bit
00 (free)	0
01	1
10	1
11	0

checks the store output but also the operation of the cross-point control toggles and the cross-points themselves.

The operation of the error toggle causes a print-out to be made on the fault printer and also resets the hold toggle T10. If the error condition continues for the duration of the persistence test, the call is released.

Delay-Link Stores

Both the fixed-delay and variable-delay links use a fast capacitor-diode store for storing the p.c.m. signals and releasing them after a suitable delay. Fig. 8 shows the principle of operation of the store. The column wires are each

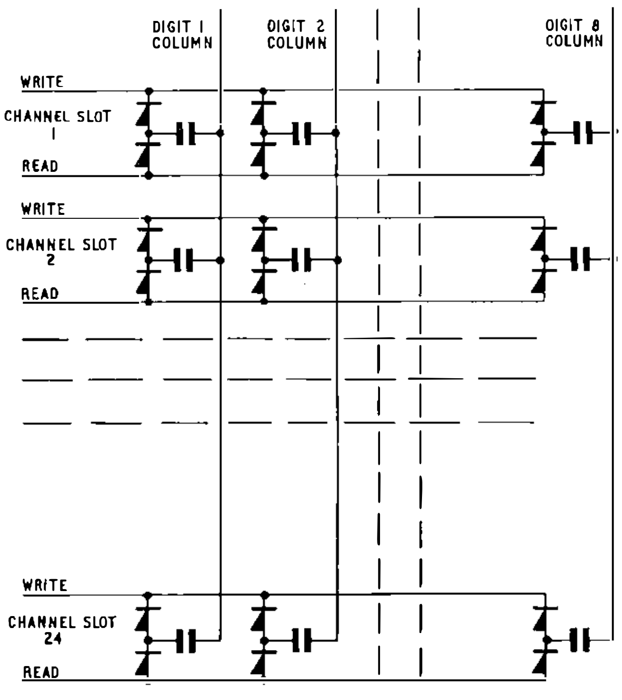


FIG. 8—Capacitor store for delay link

connected to a low-impedance d.c. supply in turn, column 1 being connected during the first digit interval of the channel time-slot, column 2 during the second digit interval, and so on. During the first channel time-slot, the p.c.m. signals are applied to the first row of the store and, if a 1 is to be written, a negative potential is applied to the write wire. The appropriate capacitor is thus charged via the row write wire and the column wire. If a 0 is to be written, zero potential is applied to the row write wire and the capacitor is not charged.

In order to read out from the store, the column wire is energized at the appropriate digit time as before and the read wire, which is normally held at a negative potential, is made positive. If the capacitor has been charged during the write cycle, the resulting discharge current is detected as a logical 1.

Supervisory Equipment

The 24-channel supervisory equipments are provided on a basis of one to each incoming trunk unit. The first function of the supervisory equipment is to detect the calling condition on a channel and, after a persistence check, to generate a register-wanted signal in order to connect the calling trunk to a free register via the register switch.

If the connexion is made successfully, a register-connected signal is returned to the supervisory equipment, which then injects a holding condition into the receive highway. This condition takes the form of a logical 1 signalling digit in the channel slot in frames 2 and 4, which are, respectively, unallocated and used for synchronizing the line-transmission system.

The supervisory equipment is also used to detect the clearance condition. Clearance is indicated by the signalling digit changing to 0 in both directions of transmission, and a 98 ms persistence check is used to detect this. The check interval is longer than the longest permitted dial-pulse break period (83 ms) from the pulse regenerator in the originating exchange and shorter than the minimum period of backward busy condition (250 ms), indicating clearance from the terminating exchange. In order to allow for the effects of noise pulses, the 98 ms interval is divided into 3·5 ms sub-intervals, and clearance is assumed unless a valid hold condition exists for the whole sub-interval. Once clearance is detected, the holding condition is removed and, after the 4-frame persistence tests in the cross-point switches, the call is cleared.

OPERATION OF REGISTER TO SET UP A CONNEXION

Register Access

When the register-wanted signal is generated in the supervisory unit, the scanning waveforms applied to the trunk unit and to the register switch ensure that the binary code corresponding to the trunk unit is written into the store associated with the first free register. Connexion is thus made from the trunk unit to the register via the register switch, and the main highways in the trunk unit are interrupted so that the register can send and receive signals in both directions.

Counting Strowger Digits

The register is shown in block schematic form in Fig. 9. The first part of the register is operated on a t.d.m. basis and detects and counts 10 pulses/second Strowger signals. This is done by sampling the p.c.m. signalling digit every 6 ms and applying suitable persistence tests to detect genuine makes and breaks. The persistence tests are necessary to overcome the effects of contact bounce in the originating electromechanical exchange and occasional errors in the p.c.m. system. The detection of a valid break condition followed by a valid make is interpreted as a Strowger pulse, which is then passed to the 24-channel pulse counter.

In a large exchange, two or more Strowger digits would have to be received and a translator employed in order to mark the required outgoing route. However, in the small experimental exchange, only four routes have to be catered for plus a dummy route for routine-test purposes. A single Strowger digit is adequate for routing information, and the register itself can be used to mark the outgoing route directly.

The make-period timer in the register is designed to recognize the inter-digital pause (i.d.p.) at the end of the first Strowger digit by counting, in conjunction with the make-persistence circuit, a total of sixteen 6 ms samples corresponding to the make condition, without the intervention of

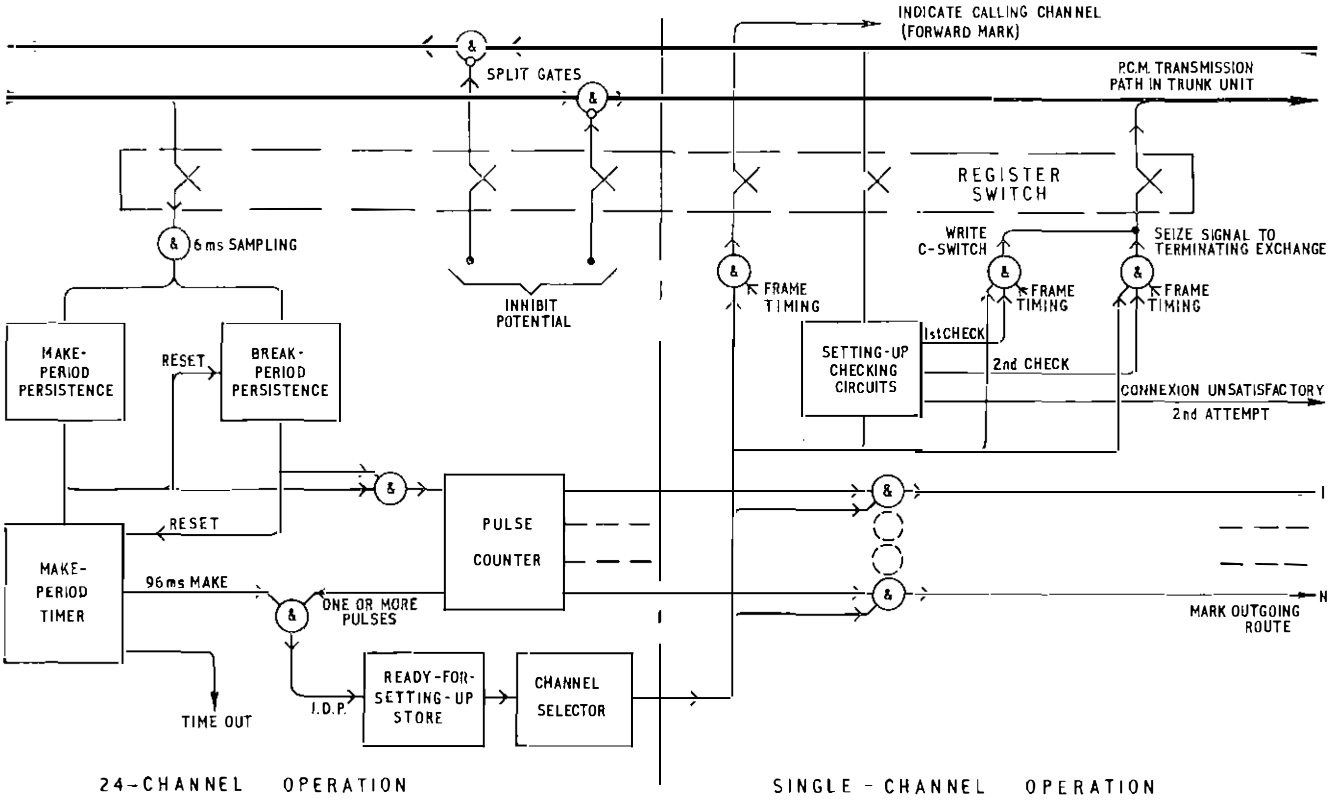


FIG. 9—Block schematic diagram of register

a break. Once the i.d.p. has been detected, the outgoing route is determined by the output of the pulse counter, and the call is ready to be set-up.

Setting-up the Connexion

Although the counting of the Strowger pulses is carried out on a 24-channel basis, only one call at a time is set up by the register. Since the i.d.p. may have been detected on more than one channel, one of the channels on which the i.d.p. has been detected for setting-up has to be selected. This is carried out by storing all the channels that have reached the i.d.p. condition in the ready-for-setting-up store and selecting one of these channels on a quasi-random basis in the channel selector.

The setting-up of the call is carried out by those portions of the register shown on the right-hand side of Fig. 9. Scanning waveforms ensure that each register in turn has exclusive access to the exchange for a period of 28 p.c.m. frames (3·5 ms). If a register has a call in the channel selector during this time, an attempt is made to set up this call through the exchange.

The register first transmits a forward mark condition or INDICATE signal in the calling channel via the trunk unit associated with the call. This signal is fed over a separate wire to the A-switch matrix. It then fans out to the B-switches unless the link between the A-switches and B-switches is already occupied by a call in that particular channel time-slot; an inhibit condition is then applied.

The destination of the call is determined by the pulses stored in the pulse counter. The output of the pulse counter is, therefore, gated with the channel selected for setting-up and fed as a backwards mark to the system units associated with the required route and thence to the outgoing trunk units. Here it is extended in duration to cover all the outgoing channels associated with the required route and fed to a gate in which the mark is inhibited for those channel time-slots that are already occupied by calls. The remaining mark pulses fan out to the B–C links, and, again, an inhibit condition is applied if the B–C link is busy in a particular channel.

The method of setting up the call in the B-switch is shown in simplified form for a fixed-delay link in Fig. 10. The indicate signal is offered to all the delay links in a B-switch and, if the link is free in the calling-channel time-slot, the indicate signal is fed through the link in the form of a 1111111 combination. In the BO-switch, an indicate signal is distinguished from a normal p.c.m. signal by the absence of 1 digits in the corresponding BO-switch store.

If the INDICATE signal, after it has been delayed in the link, should coincide with a backwards mark pulse, toggle T1 is operated via gate G1 during frame 5 of the 28-frame setting-up cycle. This shows that the delay link is potentially able to set up the call. However, several delay links within the B-switch may be available to set up the call, so that a system of wired preference has to be used to reset all the toggles except one.

The output of the toggle T1 is passed to the B-switch selector, which makes a quasi-random selection of those B-switches in which a T1 toggle has been set. It then passes a SELECTED signal to the G2 gates in the selected B-switch and, if the toggle T1 has already been set, the AND gate G2 will be operated during frame 9 of the 28-frame cycle.

Toggle T2 will be set and will then prevent any subsequent pulses from passing through gate G2. Meanwhile, some of the gates such as G3 will have been primed by the backwards mark signal with the code of the B–C link, and, when the pulse passes through gate G2, the BO-switch stores will be written with the link code at a slot time equal to the calling-channel slot plus the number of slots delay in the link. The BO cross-point switches will then switch the outgoing side of the delay link to the marked B–C link until the call is cleared.

Once toggle T2 has been set, a write signal is passed back to the BI-switch. The indicate signal, which has already primed some of the gates, such as gate G4, with the code of the A–B link, is then allowed to write the BI store.

A path involving zero time-delay is set up in a similar way, except that the initial selection is carried out during

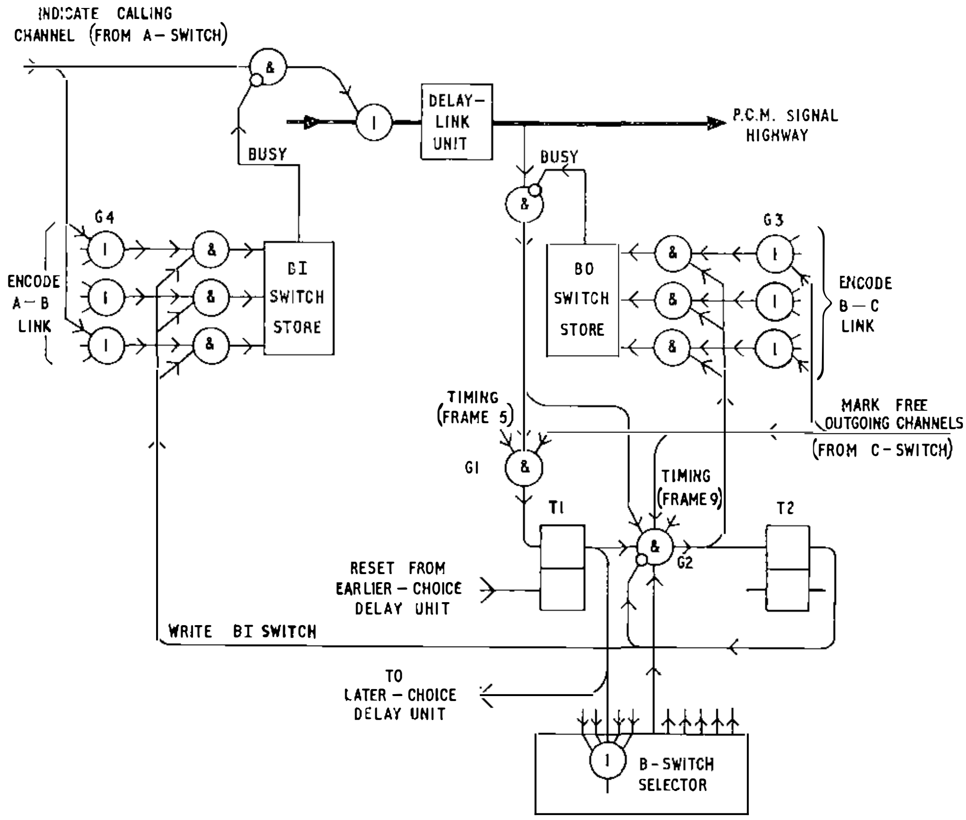


FIG. 10—Setting-up a call in the B-switch

frame 3 of the setting-up cycle, to ensure that a zero-delay path is always chosen in preference to a path involving slot changing. The exact method of setting up a call via a variable-delay cord is outside the scope of this article, but it is obviously more complicated because a separate store has to be used to control the amount of delay required for each call.

When the path through the B-switches is completed, the A-switch store receives the code of the incoming trunk so that there is a path from the register through the R, A, BI and BO switches. The register can then proceed to check that the call is being set up satisfactorily.

Checking

The checking process is carried out in three stages, as follows:

(*i*) The register checks that the signalling digit received from the originating exchange is 0 in two successive signalling frames. Since the C-switch has not been written, any 1 digit would indicate connexion to another working circuit.

(*ii*) The register sends forward a seize signal, via the A-switches and B-switches, to the C-switch and checks that 1 digits are being received from the exchange in two successive signalling frames. This indicates that a circuit-free signal is being received from the terminating exchange.

(*iii*) The register then sends forward a seize signal through the completed switch path to the terminating exchange.

After a suitable interval, a check is made for 0 digits in two successive signalling frames. This shows that the circuit-free signal has been changed to a circuit-busy signal on seizure. Owing to possible delays in the terminating exchange, this test is performed approximately 9 ms after the 28-frame setting-up cycle.

Normally, setting up a successful call through the experimental exchange is completed at this stage, and the register is released by inhibiting the hold condition to the register and register-switch stores. This releases the register switch and removes the split condition from the main highways in the trunk-unit. A through connexion is then available from the originating director to the terminating exchange, and the remaining Storwger pulses are conveyed through the tandem exchange using the p.c.m. signalling digit in the usual way.

If any of the above checks should fail, the path through the exchange is held and a second attempt is made via a different path. If both attempts fail, the number-unobtainable-tone store in the trunk unit is written and tone is returned to the subscriber.

PULSE AND POWER SUPPLIES

The main clock supply is derived from a triplicated 3·072 MHz oscillator so designed that any one oscillator can fail to any condition without affecting the output appreciably. Triplicated dividers with majority-decision outputs give secure timing waveforms, which are distributed via a system of buffer amplifiers arranged in three security layers to correspond with the security layers used in the switch network.

Power supplies of ± 24 volts and ± 12 volts are distributed to various parts of the exchange via laminated-strip transmission lines to minimize noise pick-up. The $+5$-volt supply for the integrated circuits is derived from the $+12$-volt supply by a series transistor controlled by a Zener diode on each plug-in unit. Low-voltage and over-current alarm circuits are provided on each unit.

ROUTINERS

Routining is carried out by two routiners and a special design of routiner outgoing-trunk unit, which simulates a terminating exchange. The first routiner is designed to test the register and setting-up functions. The programs of operation are controlled by up to four wired-logic cards, which can be changed if it is found desirable to alter the program at some time in the future. The basic program is one in which the routiner injects a signal into an incoming trunk unit and seizes a register. It then dials a digit, which causes the exchange to set up a connexion to the routiner outgoing trunk unit and enables the routiner to check both the transmission and the signalling. The other programs enable calls to be set up to the terminating exchanges and to check functions such as time-out and clearance.

The second routiner acts mainly to check the transmission through the delay links. This is important, since a fault in a single storage cell in a link can give rise to very poor speech quality, whilst checks on the signalling digit do not give any indication of a fault. This routiner can set up a path via a delay link, check the transmission and clear the connexion during one of the 28-frame cycles such as used by a register for setting up a call. This routiner does not, therefore, produce any increase in the traffic loading of the exchange.

COMPONENTS

Integrated circuits of the diode-transistor logic (d.t.l.) and transistor-transistor logic (t.t.l.) families[5] are used for nearly all the logic and switching functions. The main advantage of the integrated circuits has been to reduce the number of connexions on to the printed wiring board and thereby improve the reliability of the system. A secondary advantage has been to reduce the constructional effort required—an important feature since nearly all the work was carried out in the Post Office Research Department.

The main storage functions are carried out by 25 × 64 matrices of 0·03 in. ferrite cores. Integrated-circuit differential amplifiers are used as read amplifiers, but discrete transistors have to be used for driving purposes on account of the relatively high power required.

DURATION OF THE TRIAL

Good progress has been made in commissioning the exchange; difficulties encountered so far have all been mainly of a minor nature, and the experience to date has not revealed any major problems which would indicate that p.c.m. switching by the methods proposed is not a technically feasible and sound proposition. Much will be learnt during the progress of the trial with live traffic of the reliability of this type of equipment and its behaviour in a Strowger environment and of the problems of locating and replacing faulty components. It is planned that the experimental exchange will be maintained continually in service for a period of at least one year, and during this period the routining and print-out equipment and the traffic recorder will provide much valuable information on its performance.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of the London Telecommunications Region and of their colleagues in Headquarters Departments, and the pioneering work of Mr. W. T. Duerdoth and others, on which the exchange design was based.

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The Experimental P.C.M. Exchange Opens at Empress, London

U.D.C. 621.376.56.001.41: 621.395.722

An article in this issue of the Journal† describes the experimental digital tandem exchange which has been designed at the Post Office Research Station at Dollis Hill to test the feasibility of switching telephone traffic in pulse-code modulation (p.c.m.) form. The article records the installation of the switching equipment in the Empress exchange building in West London, and reports favourably on the progress made with its commissioning.

On-site testing has continued well, and on 11 September the exchange was opened for live traffic by the Postmaster General, the Rt. Hon. John Stonehouse, M.P., who formally marked the occasion with an inaugural call to the Mayor of Hammersmith, Sir Samuel Salmon, (Fig. 1). The ceremony was attended by representatives of the telecommunications industry, universities and the press and by senior members of the Post Office. In his address the Postmaster General noted the growing experience with p.c.m. transmission systems at home and abroad, and said that the particular significance of the Empress exchange was that it was the first example of switching p.c.m. signals carrying live traffic anywhere in the world.

He stressed the important part that fast microelectronic circuits had played in the design, and described the experiment as one major step towards a telecommunications system that is fast, efficient and cheap and can take any form of traffic—voice, vision or data—in its stride. He warned that "the development of itself would not change the characteristics of our system overnight", but congratulated the team of engineers at Dollis Hill on their imaginative experiment which could have important and far-reaching consequences for the future planning of the system.

FIG. 1—The Postmaster General makes the inaugural call

L. R. F. H.

† CHAPMAN, K. J., and HUGHES, C. J. A Field Trial of an Experimental Pulse-Code Modulation Tandem Exchange. *In this issue.*

The Quest for a Telegraph Relay of Greater Reliability

R. W. BIGG†

U.D.C. 621.318.562.3.004.6: 621.394.65

The cost of maintaining the conventional type of polarized telegraph relay and the ever-increasing numbers of these items in service have led to a need for a more durable replacement. The present trend of development is discussed and possible future development suggested.

INTRODUCTION

From the earliest beginnings of the art of telegraphy, the telegraph relay has formed an important link in any telegraph-transmission system. Indeed, in early systems the telegraph relay was to telegraphy what the valve amplifier was to telephony. In present-day telegraphy, as well as being used as signal repeaters on d.c. lines, telegraph relays are used as output devices on all types of telegraph-transmission equipment, an ever-increasing quantity of which is being placed in service.

The telegraph relay is required to perform a far more onerous task than its counterpart used in telephony. Whereas, in telephony, relays are required to perform relatively occasional switching functions or to repeat low-speed dial pulses, the telegraph relay is required to be capable of continuous operation at high speed for long periods. Moreover, it is required to repeat, with negligible distortion, the complex input signal. These exacting requirements have in the past been met by the electromechanical polarized relay, the design and reliability of which have been constantly improved. However, the continuous make-and-break action of the contacts, particularly when transmitting into highly-reactive loads, inevitably causes contact erosion, leading to distortion of the signals and, eventually, complete failure of the relay. Thus, regular and, in many instances, frequent attention must be given to the relay. As anyone who has been concerned with telegraph maintenance will know, relay cleaning and adjustment account for a considerable portion of the total maintenance effort.

REQUIREMENTS OF A REPLACEMENT DEVICE

The principal requirement of any device intended to replace the polarized relay for telegraph applications is the elimination of the need for regular maintenance attention. The device should be essentially neutral, i.e. it should produce no bias distortion, and no adjustment should be needed to achieve this; the output condition should be dependent upon the input condition at all times. In order to be compatible with modern equipment design, the device should be small and suitable for incorporation with other components on printed-wiring boards. It must be capable of switching ± 80 volts, the standard telegraph battery-supply voltage used by the British Post Office, and, with normal contact-protection arrangements, withstand an indefinite full short-circuit to earth on the output without suffering damage. Similarly, the connexion of positive or negative 80 volts to the output should have no adverse effect.

The above are the general requirements of a telegraph relay, but for some applications there are further special requirements, e.g. input-to-output isolation. Isolation is generally required in older-type valve-operated equipment, to avoid the possibility, under fault conditions, of the h.t. voltage being transmitted to line. Also, since the relay is usually driven from the anode of a valve, circuit design becomes simpler if the input is isolated from earth. Isolation is also required if the relay is to be used for loop working on a line as opposed to single-wire earth return.

Where new equipment is concerned the input drive to the relay can be designed to meet its requirements. When replacing a polarized relay in an existing equipment, however, it may be impossible to alter the drive circuit without a great deal of modification, and, for optimum performance, the replacement device should be at least as sensitive as the polarized relay.

Currently, two types of device meet the foregoing requirements to some extent: the reed relay with a mercury-wetted contact-unit and the fully-electronic solid-state switch.

MERCURY-WETTED CONTACT-UNIT REED RELAYS

The mercury-wetted contact-unit reed relay,[1] first perfected in the United States of America, is now being produced in quantity in this country. The heart of the relay is a sealed-glass capsule containing the relay armature, which is also the moving contact member, the fixed contact members and a pool of mercury. The capsule is filled with hydrogen under high pressure. The armature is a thin flat reed having vertical grooves up which the mercury climbs by capillary action to wet the contact area at the top. As the tongue moves away from one fixed contact area a thin filament of mercury is drawn out and breaks only after the tongue has traversed much of the gap. This gives a very rapid break action and a very short duration transit time. Since contact is made and broken by mercury, which is constantly being replenished from the pool, contact-area erosion is eliminated. Spark quenching is important with mercury-wetted contact-units since, if sparking does occur, the mercury is blown off the contact area and a deposit is formed on the metallic surface. Once this deposit has formed, wetting of the contact area ceases and contact-unit deterioration ensues.

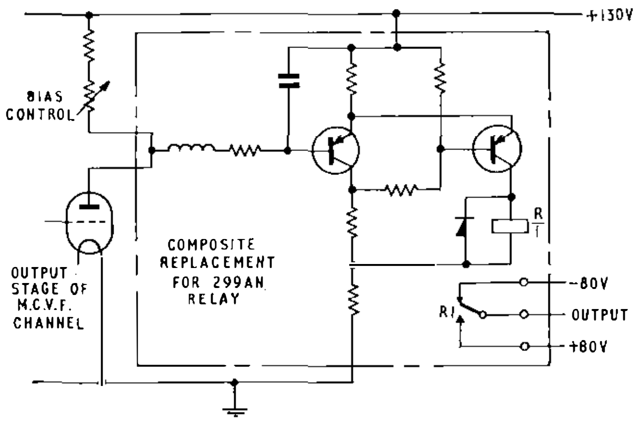
The mercury-wetted contact-unit relay has a long life expectancy when operated at the maximum specified contact rating. When lightly loaded, as in the majority of telegraph

† Telegraph and Data Systems Branch, Telecommunications Development Department, Telecommunications Headquarters.

[1] PERREAULT, G. E. New Mercury Relays for Sensitive Telephone and Telegraph Applications. I.E.E.E. International Convention Record, Vol. 13, Part 1, p. 89, 1965.

applications, the life expectancy is still further increased. Further advantages are offered by its inherent input-to-output isolation, its small size and compatibility with printed-circuit techniques, and its relatively low cost. Disadvantages of the mercury-wetted contact-unit relay lie in its lack of sensitivity compared with the conventional polarized relay, the necessity for contact protection in the form of series current-limiting resistors, and the necessity for vertical, or near vertical, operation.

The reduced sensitivity of the mercury-wetted contact-unit relay becomes a problem when such a device is required to replace a conventional polarized relay in an existing equipment in which the relay drive is fixed by other considerations. A direct replacement in these circumstances may not be possible, and an additional drive circuit of some kind is required. An example of this is shown in Fig. 1. This circuit was designed to replace the Post Office No. 299AN relay used in a type of valve-operated m.c.v.f. telegraph equipment. The No. 299AN relay is very sensitive and use is made of this fact in the m.c.v.f. equipment to obtain the required performance. Increasing the drive to the relay is impracticable, as a major modification would be required to avoid upsetting the action of the automatic gain control of the equipment. A simple Schmitt trigger circuit is, therefore, used to drive the mercury-wetted contact-unit relay.



Note: The relay in this instance is a single-side-stable type, i.e. it is magnetically biased to one side.

FIG. 1—Circuit diagram showing a Schmitt trigger circuit used to drive a mercury-wetted contact-unit relay for a particular application

Although mercury-wetted contact-units provide a true change-over action in operation, it is possible for bunching to occur occasionally, particularly after the relay has been transported or inverted. If current-limiting resistance is not included in the telegraph battery supplies to the relay, the contacts will be destroyed by the heavy current which flows if bunching occurs. For applications where the relay has to supply a load current which might intermittently be very heavy, e.g. a signal-distribution relay in a telex exchange, resistance cannot be used to limit the supply current, and, if a mercury-wetted contact-unit relay is used, there is always a danger of the relay destroying itself should bunching occur.

Small numbers of mercury-wetted contact-unit relays have been giving satisfactory service for a considerable time in broadcast units and as receive relays in m.c.v.f. telegraph equipment. All new 62-type m.c.v.f. telegraph equipment at present being brought into service uses mercury-wetted contact-unit relays.

FULLY-ELECTRONIC SOLID-STATE SWITCH

The average life expectancy of a mercury-wetted contact-unit relay in any given telegraph application is as yet unknown, but it is to be expected that failure will occur at some time. A well-designed fully-electronic switch, however, may be expected to give service for an indefinite period. Also, for higher speeds of operation, e.g. for data transmission, an electronic switch is superior to a relay.

A number of designs for an electronic switch operating with ± 80 volts have been produced. Initially, because of the lack of availability in this country of a transistor capable of withstanding the high voltage involved, designs employed a number of transistors in series sharing the voltage, or a pair of thyristors. The former approach led to complex designs using a large number of components, particularly if isolation was required, and, consequently, to high cost. Thyristors have been successfully used, but there are disadvantages associated with this device. It is relatively simple to turn the thyristor "on" by applying a suitable pulse to the gate, but, having been turned on, the device cannot be controlled through the gate in the same way as a transistor can be controlled through its base. Hence, it is difficult to make the output conditions of the switch fully dependent upon the input condition. To turn the thyristor "off," the current flowing through it must be interrupted or, at least, reduced to below the holding value. In a device equivalent to a telegraph relay this demands control from two sources: one to turn the thyristor on, and one to turn it off. If either control fails to be effective for any reason, then either both thyristors will be turned on, short-circuiting the telegraph supplies and effectively earthing the output of the device, or both thyristors will be turned off, leaving the device in an unswitched state. A further disadvantage of using thyristors is that the output current from the switch must be maintained above the holding value or the device will turn off. Due to the necessary complexity of design and the cost of the thyristors themselves, this type of electronic switch tends to be expensive, although isolation can be achieved easily.

Suitable high-voltage transistors are now available, and a number of successful designs using these have been produced.[2] Since a transistor is fully controllable through its base connexion, the output of the device can be made dependent at all times upon the input condition in such a way that when one side is in the on state, i.e. bottomed, the other side, as a consequence, is held off, and the possibility of both sides becoming switched on together is eliminated.

In an electronic switch employing transistors as the switching elements, isolation of the input circuit, whilst retaining the facility of output control by the input condition at all times, may be obtained by using the switched-oscillator technique. This method consists of using the input signal to control the output of one or more oscillators, via transformer coupling. The oscillator output is then coupled to the output switching stage to produce a control voltage for the switch itself. The transformer coupling gives the required isolation.

Several hundred electronic telegraph relays of various types are now in service and giving a satisfactory performance.

FUTURE DEVELOPMENT

At the present time the cost of an electronic switch for operation with ± 80-volt telegraph-signalling supplies is considerably higher than that of the mercury-wetted contact-unit relay; consequently, the use of the electronic switch tends to be restricted to applications requiring operation at speeds much in excess of 50 bauds. The high cost of the electronic switch is in part due to the cost of suitable semiconductor components, and also to the present tendency to package the switch in plug-in boxes of similar size and shape to existing polarized relays. This is because, in most instances, they are intended as replacements for polarized relays. If, as might be expected, the cost of suitable semiconductor devices

[2] SALLIS, R. T. G. A Device to Replace Conventional Polarized Relays. *P.O.E.E.J.*, Vol. 59, p. 181, Oct. 1966.

falls further, design and development in this field will be encouraged, and in complex telegraph-transmission equipment it is likely that the output relay as such will disappear and be replaced by an electronic switch which will form just a further stage in the overall circuit. This, in itself, will reduce the cost of the output stage. Fig. 2 illustrates an example of an integral output switch, using thyristors in this instance, incorporated in a 62-type start-stop regenerative repeater.

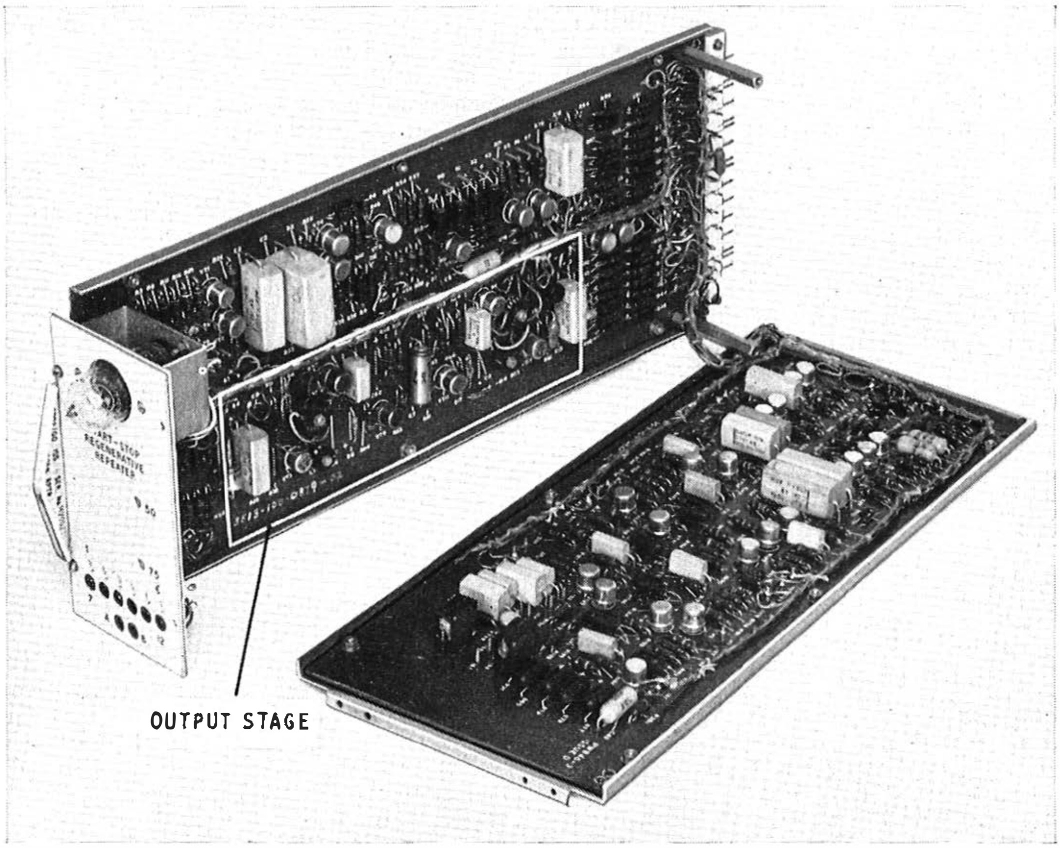


FIG. 2—A 62-type equipment unit incorporating an electronic output switch for ±80 volts

Book Review

"Digital Techniques." R. W. Sudweeks, B.Sc., M.I.E.E. Pitman and Sons Ltd. 140 pp. 141 ill. 30s.

The author states that the purpose of this book is to describe, in readable terms, some of the ideas involved in the understanding of an electronic digital computer. In this it is partially successful, but the book lacks coherence and it is not at all clear for what audience it is intended. Some of the material—especially the last two chapters—could be read and understood by intelligent sixth-formers but the first five chapters, where the meat of the work is to be found, require considerable concentration and, indeed, a certain background knowledge of the subject. For example, the reader is assumed to be familiar with the terms commutative, associative, and canonical (none of which are defined here) and, in the same breath, he is expected to absorb the statement that "If inverted inputs are required these are generally obtained from the register outputs—the bistable having two opposite outputs—without inserting inverters specially. . . ."

To be fair to the author, however, he succeeds, in the first two-thirds of the book, in giving a succinct introduction to the principles of logical design (which, of course, are not restricted to the field of digital computation). As one would expect in a work on this subject there is little redundancy and, in fact, some of the concepts are introduced rather too abruptly for smooth comprehension.

Boolean Algebra is covered quite early in the book and is used effectively throughout; the worked examples which are included in most sub-chapters are well chosen to illustrate the particular feature just introduced. Some time is spent on the Venn diagram and the use of truth tables and a chapter is set aside for a description of the Karnaugh map method of simplification. NOR and NAND logic (which is probably more common today than the original OR and AND system) is given a chapter to itself culminating in the logical design of a half-and a full-adder using each type.

At the end of chapter 5 there is an abrupt change of tempo—and even of style. Chapter 6 uses the logical ideas described earlier to build up the fundamentals of a digital computer. The author makes it clear that he is not writing a "simple guide to programming," but this chapter does, in fact, introduce most of the elementary ideas behind the art of machine-code programming.

The final short chapter describes the various forms of storage devices used in digital computers. This is rather sketchily done and one wonders if it would have been better omitted completely. It is the one part of the book which will inevitably date quite rapidly and the author admits this in his final sentence.

The overall impression left is not so much a readable introduction as a collection of useful techniques and facts. As such it would be greatly improved if it had an index.

C.A.M.

The New International Telephone Switching and Transmission Plan

S. MUNDAY and R. A. FRY†

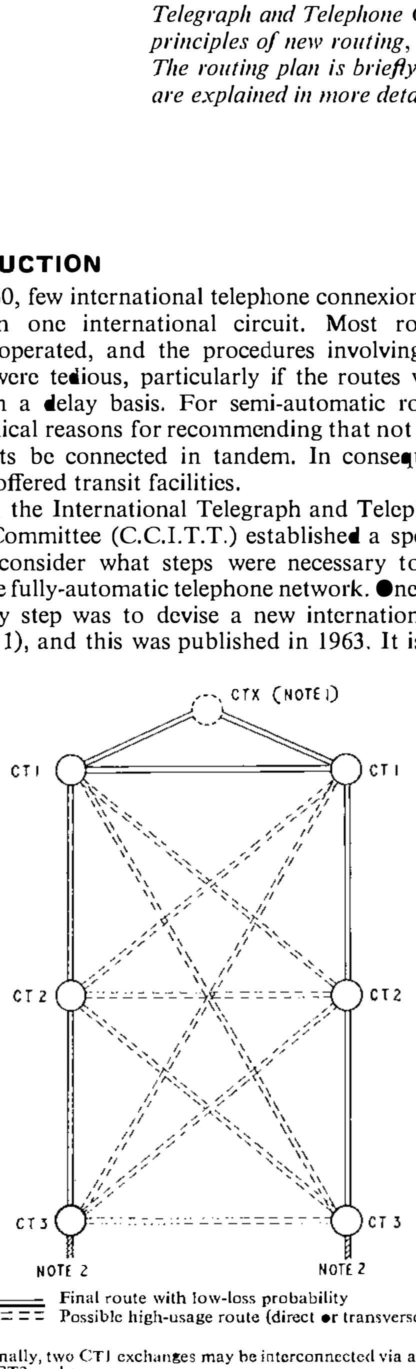
U.D.C. (100) 621.395.45: 621.395.65

In order to lay the foundation of a world-wide telephone network that will eventually provide fully-automatic international subscriber dialling between any two subscribers anywhere in the world, the International Telegraph and Telephone Consultative Committee, at its 3rd Plenary Assembly in 1964, recommended the principles of new routing, numbering, switching and transmission plans for international public telephony. The routing plan is briefly described; the switching and transmission aspects of the new recommendations are explained in more detail, and progress towards achieving the desired standards is discussed.

INTRODUCTION

Before 1960, few international telephone connexions involved more than one international circuit. Most routes were manually operated, and the procedures involving a transit operator were tedious, particularly if the routes were being worked on a delay basis. For semi-automatic routes there were technical reasons for recommending that not more than two circuits be connected in tandem. In consequence, few countries offered transit facilities.

In 1960, the International Telegraph and Telephone Consultative Committee (C.C.I.T.T.) established a special study group to consider what steps were necessary to set up a world-wide fully-automatic telephone network. One important preliminary step was to devise a new international routing plan (Fig. 1), and this was published in 1963. It is based on the well-established hierarchical principle, which is a feature of most national telephone networks, and the salient points of the plan are as follows.



══════ Final route with low-loss probability
= = = = = Possible high-usage route (direct or transverse)

Notes:
1. Exceptionally, two CT1 exchanges may be interconnected via an intermediate CT1 or CT2 exchange.
2. To national networks.
3. All international circuits are 4-wire circuits; all CT1, CT2 and CT3 exchanges are 4-wire switched.

FIG. 1—Current world routing and switching plan

(*a*) Three classes of 4-wire international exchange are envisaged, referred to as CT1, CT2 and CT3 exchanges (CT—centre du transit). A CT3 exchange normally only connects international circuits to national networks, while CT1 and CT2 exchanges, in principle, connect only international circuits together. There is no essential difference between a CT1 and a CT2 exchange; the CT1 exchanges are intended to be fully interconnected, whereas the CT2 exchanges are not.

(*b*) Every CT3 exchange is connected to at least one CT2 exchange (it may, of course, be connected to more than one). Similarly, every CT2 exchange is connected to at least one CT1 exchange. If the CT1 exchanges are fully interconnected, this arrangement would ensure that any CT3 exchange would be connected to any other CT3 exchange via no more than five circuits (CT3–CT2–CT1–CT1′–CT2′–CT3′).

However, it is recognized that, initially at least, the CT1 exchanges will not be fully interconnected, and the sub-routings CT1–CT1–CT1 or CT1–CT2–CT1 are permitted. With this relaxation the maximum number of international circuits that may figure in a connexion could thus be six.

(*c*) The network of circuits and exchanges described in (*b*) is the minimum network that must be provided if any pair of CT3 exchanges in the world are to be connected together using not more than five (or six) circuits. This is often referred to as either the basic network or the final network, and the routes in this network are basic routes or final routes. For a demand automatic telephone service the final routes between exchanges must be fully-provided, i.e. large enough to carry the traffic offered them with only a low probability of there being no circuit available.

(*d*) Exchanges can be interconnected by routes supplementary to the final routes. For example, a CT3 exchange may have direct circuits to another CT3 exchange without having to switch via a CT2 exchange. Similarly, CT2 exchanges can be directly connected and CT1 exchanges can have direct circuits to CT3 exchanges. These are examples of transversal routes which can bypass part or all of the chain of final routes. In general, the transversal routes will carry most of the traffic, the CT3–CT3 routes carrying most of all.

It is proposed that London, New York, Moscow, Sydney, Tokyo and Singapore will be CT1 exchanges. There will also be a CT1 exchange in the Indian subcontinent and also in Africa, but these have not yet been designated.

† Line and Radio Branch, Telecommunications Development Department, Telecommunications Headquarters.

The rank of an international exchange can vary from connexion to connexion. For example, for a call between subscribers in Paris and London, the Paris and London exchanges function as CT3 exchanges. For a call from a Paris subscriber to a New York one, established via London, London is a CT2 exchange, Paris and New York being CT3 exchanges. For a call routed Brussels–Paris–London–New York–Bogota–Lima (a somewhat unlikely routing, fortunately) London and New York are CT1 exchanges, Paris and Bogota are CT2 exchanges and Brussels and Lima CT3 exchanges. The corollary to this is that the same London–Paris circuit could, and most likely would, have been used for all these connexions, so that the one circuit could be CT3–CT3, CT3–CT2 or CT2–CT1, according to the class of connexion. It will be seen later that this circumstance has a profound bearing on the efforts to improve the transmission performance of the longer and more complicated connexions.

A REPRESENTATIVE MAXIMAL INTERNATIONAL CONNEXION

It is envisaged that, for most countries, the most remotely-placed national local exchange could be connected to the international exchange by four national circuits or fewer, although it is recognized that large countries such as the U.S.S.R. could require five national circuits for this purpose. Further, 4-wire switching would be employed at the international exchange and at two of the national transit exchanges. The third national transit exchange and the local exchange are assumed to be equipped with 2-wire switches.

These assumptions lead to a representative maximally-adverse international telephone connexion, illustrated in Fig. 2. The complete international telephone connexion is shown divided into three portions: an international chain interconnecting two national systems. There are assumed to be 12 4-wire circuits connected by 4-wire switching exchanges between the outgoing and incoming primary centres. The local exchange is assumed to be connected to a primary centre (equivalent to a group switching centre in the United Kingdom) by a junction circuit which is 2-wire switched at both ends.

Some of the transmission aspects of the complete connexion, or its various parts, are briefly described and explained in the following sections, and the current C.C.I.T.T. recommendations are quoted where possible.

VIRTUAL SWITCHING POINTS: THE INTERFACE BETWEEN CIRCUITS IN AN INTERNATIONAL EXCHANGE

Circuits can be connected together in a 4-wire telephone exchange at almost any relative transmission level according to national practices. For example, in a United Kingdom national transit centre[1] the switching level will be nominally −4 dBr, but at the new British Post Office international exchange (planned to open in late 1969), the switching level will be −2 dBr. Other administrations adopt other levels. The C.C.I.T.T. recommendations are devised in terms of a switching level of −3·5 dBr but, in recognition of the fact that any level can be chosen, −3·5 dBr is taken to be the send level at what are termed virtual switching points. The virtual switching points are thus points existing for the purpose of definition, enabling the C.C.I.T.T. recommendations to be uncommitted to any particular switching arrangement and hence applicable to all arrangements.

For most recommendations, except those concerning reference equivalent (a term that is explained later), only the difference between the relative levels at the virtual switching point is involved. Hence, in practice, the distinction between actual and virtual switching points is unimportant.

Fig. 3(*a*) shows the actual arrangement in a telephone exchange with a send switching level of −2 dBr. The pads shown are equivalent to the losses in the switching and transmission equipment (as indicated in Fig. 4). The send level of −16 dBr and the receive level of +7 dBr are examples only; any suitable levels could apply. Fig. 3(*b*) illustrates how the −3·5 dBr virtual switching points can be identified in such an exchange. The underlined values of relative level at any point refer to the circuit to the right of that point; those not underlined refer to the circuit to the left. The zero relative-level points for each circuit are independent, and a switched connexion has no defined point of zero relative level.

In a real switching centre, virtual switching points need not

1 TOBIN, W. J. E. The Signalling and Switching Aspects of the Trunk Transit Network. *P.O.E.E.J.*, Vol. 60, p. 63, Oct. 1967.

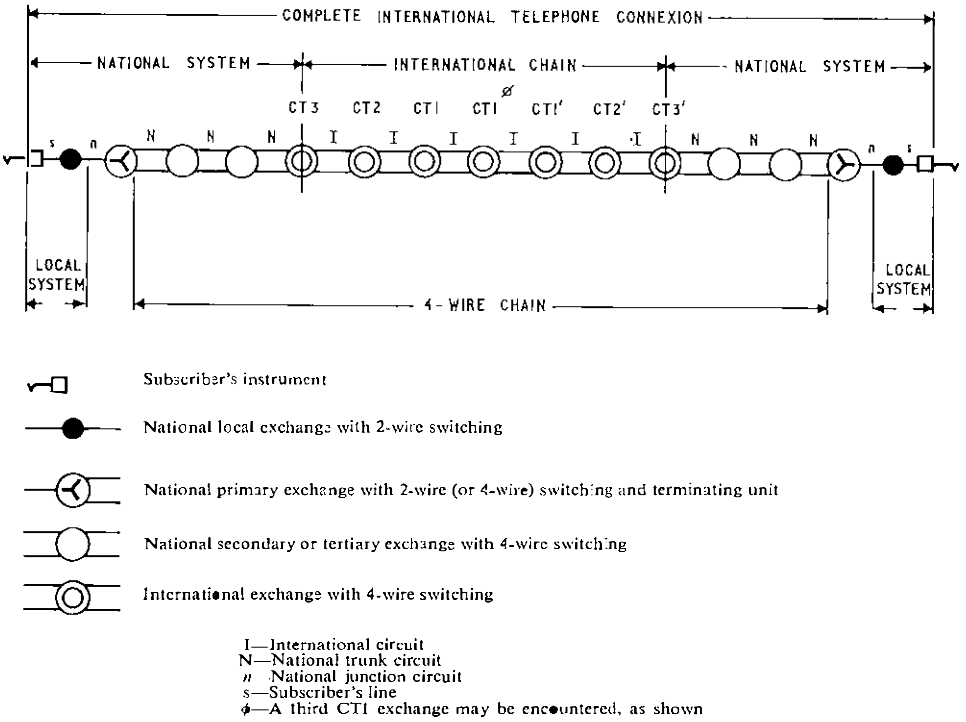
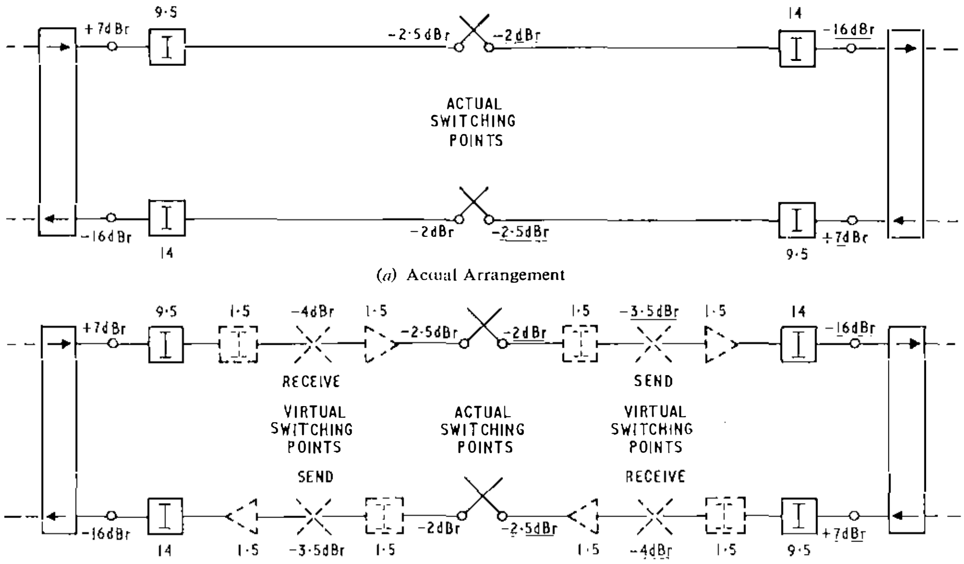


FIG. 2—A maximally adverse international connexion



(a) Actual Arrangement

(b) Hypothetical Arrangement Indicating Position of the Virtual Switching Points of the Two Circuits

FIG. 3—Virtual and actual switching points

exist, but, by introducing suitably-valued hypothetical pads and amplifiers (shown dotted in Fig. 3(b)), the total effect of which is nil, the location of the virtual switching points can be found, and they are effectively connected together without the interposition of any additional net gain or loss, i.e. the 1·5 dB pad cancels out the 1·5 dB amplifier, the actual switching points being assumed to introduce negligible loss. Incidentally, the additional pads and amplifiers in Fig. 3(b) illustrate the process, common in the transmission field, of referring a quantity from one point to another.

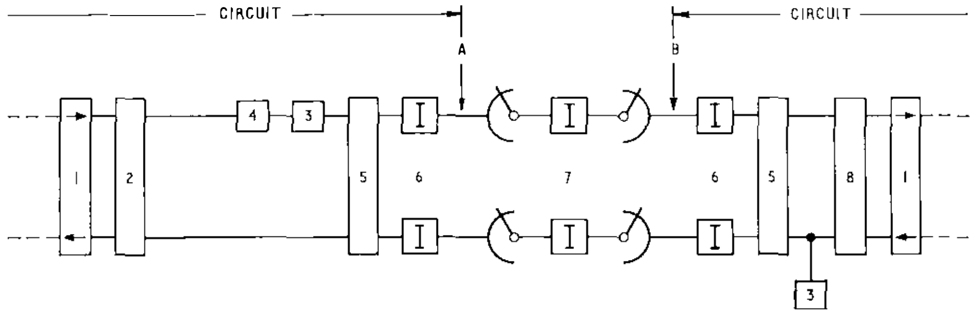
NOMINAL TRANSMISSION LOSS OF INTERNATIONAL CIRCUITS

The nominal transmission loss, at the reference frequency (800 Hz), assigned to an international circuit for stability reasons, is normally 0·5 dB, so that the relative receive level at the virtual switching points is −4 dBr, and the relative receive level at the actual switching points in the example shown in Fig. 3 is − 2·5 dBr. If an administration uses an actual switching level of x dBr, i.e. the relative level at the switch of every send channel is x dBr, a circuit can be assigned a nominal loss of 0·5 dB by arranging that the receive channel of the circuit is presented to the switch at a relative level of $x - 0{\cdot}5$ dBr. It is not at all necessary for each administration to use the same actual switching level, and the 0·5 dB loss arises from the difference imposed at a particular international centre and not, as might at first be supposed, from the differences between the switching levels at the two switching centres joined by the circuit.

Since each international circuit is operated at 0·5 dB transmission loss, the nominal transmission loss of a connexion is a function of the number of international circuits in that connexion—the more circuits the more loss. This is to help ensure the stability of the connexion. If the circuits were perfectly stable and had no attenuation/frequency distortion introducing relative gains at frequencies other than the reference frequency, they could each be operated at a nominal transmission loss of 0 dB, although more connexions might need an echo suppressor if this were done.

As described in the section on echo, circuits can sometimes be operated at somewhat higher losses if thereby the use of echo suppressors can be avoided.

The objectives for the mean value of transmission loss for an international circuit are that it should be within 0·5 dB of the nominal value and the standard deviation should not exceed 1 dB. In order to achieve this high standard, circuits will need to be routed on direct groups equipped with automatic regulation. The whole of the outgoing and incoming exchange and signalling apparatus proper to the circuit (Fig. 4) must be included in lining-up and subsequent maintenance operations, and increasing use will have to be made of automatic circuit routiners in the international network.



1—Channel-translating equipment
2—Echo suppressors
3—Line-signal receiver
4—Equalizer
5—Outgoing and incoming signalling terminations
6—Exchange pads (can be switchable)
7—Automatic switching equipment
8—Compandor

Some elements can be in a different order; e.g. the echo suppressor may be on the exchange side of the signalling receiver. An individual circuit extends from point A of one exchange to point B of the next.

FIG. 4—An international circuit includes all the permanently-connected equipment proper to the circuit

STABILITY

The stability of telephone connexions established over one or more low-loss 4-wire amplified circuits depends very largely on the degree of impedance match at the 4-wire/2-wire terminating units.

In the C.C.I.T.T. switching plan the terminating units are located in the national networks, hence the recommendations concerning stability are made in terms of the transmission loss introduced by the national chain between the receive and send virtual switching points. The proposed recommendation is that the attenuation of the path a–t–b (Fig. 5)

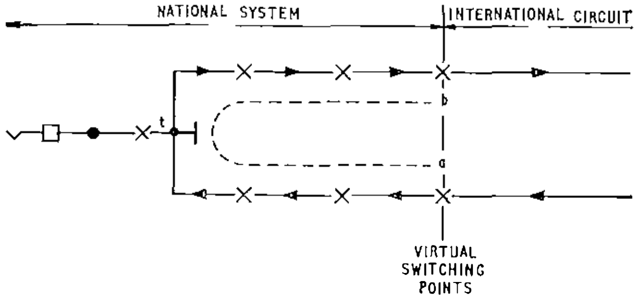


FIG. 5—The path a–t–b through the national system from the receive to the send virtual switching point

should be not less than $6 + n$ dB, where n is the number of 4-wire circuits in the national chain. This requirement should be observed at any frequency in the band 0–4 kHz. Administrations are also recommended to aim for a mean value for the attenuation of the path a–t–b of at least $10 + n$ dB, account being taken of the actual distribution of calls.

The balance return-loss exhibited at a terminating unit is that portion of the total transmission loss, introduced by the terminating unit between the receive and send channels, which is attributable to the degree of match between the impedance of the 2-wire line and the balance impedance. Hence, the loss of the path a–t–b is equal to the sum of the losses of the paths a–t and t–b plus the balance return-loss.

For connexions set up over 4-wire national circuits from the new United Kingdom international exchange, the nominal loss of each of the paths a–t and t–b is planned to be 3·5 dB. For the most complex national extension established over the transit network ($n = 3$), a minimum balance return-loss of 2 dB over the band 300–3,400 Hz must therefore be achieved, to meet the minimum requirement of $6 + n$ dB for the path a–t–b.

The risk of instability of international connexions during conversation has been estimated, and the results are displayed in Fig. 6. The proportion of connexions actually established that are likely to oscillate will, of course, be much lower, because they will, in general, be very much less complicated than the most adverse.

The calculations allowed for the effect of the variation of transmission loss with time and among circuits, the nominal transmission loss at the reference frequency of circuits, the attenuation/frequency distortion of circuits, and the distribution of stability loss of the path a–t–b.

REFERENCE EQUIVALENTS: A MEASURE OF THE LOUDNESS OF TELEPHONE SPEECH

The electro-acoustic properties of subscribers' instruments and local lines (including the transmission bridge in the local telephone exchange) are described in terms of reference equivalent. The reference equivalent of an assembly of a telephone instrument and a local line is a quantity obtained by balancing the loudness of received speech signals, and is

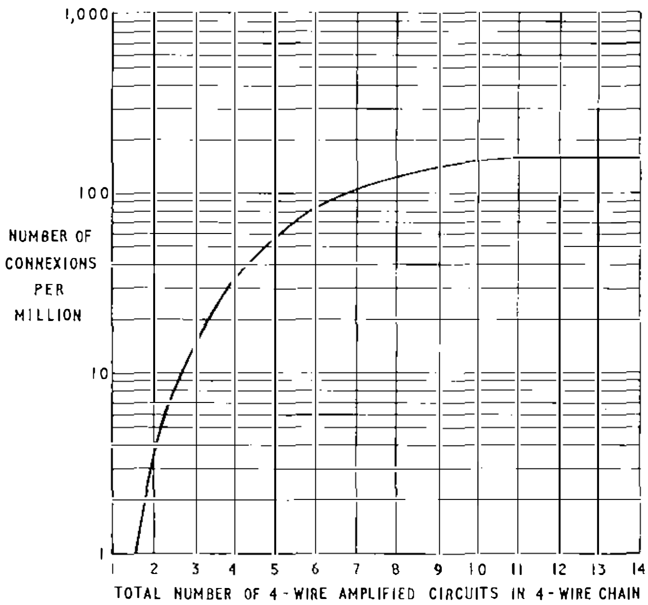


FIG. 6—Estimate of the proportion of possible connexions likely to be unstable

expressed in decibels relative to an internationally-agreed reference system. Separate figures relate to the sending and receiving directions of transmission. The higher the reference equivalent the less loud is the telephone speech.

It is more convenient, however, to plan in terms of transmission losses of circuits and exchanges. As far as the United Kingdom is concerned this is both possible and desirable, because in the British Post Office network the local, junction and trunk networks are planned separately, and the reference equivalents of the combination of subscriber's instrument, limiting line and local exchange are known. For planning purposes they are taken to be 12 dB (r.e.) sending and 1 dB (r.e.) receiving, respectively, the abbreviation (r.e.) signifying reference equivalent. The reference equivalents of the remaining items in the connexion are assumed to be numerically equal to their transmission losses and are simply added together, which is good enough for practical purposes unless there is very severe attenuation/frequency distortion.

Maximum Reference Equivalents of a National System

The C.C.I.T.T. transmission plan requires that, for 97 per cent of connexions actually established, the sending and receiving reference equivalents of the national systems should not exceed 20·8 dB (r.e.) sending and 12·2 dB (r.e.) receiving, referred, respectively, to the virtual switching points at relative levels −3·5 dBr and −4 dBr on the international circuit in the CT3 exchange.

As the limit is in terms of 97 per cent of connexions actually established, it implies having to take account of the pattern of traffic incidence. This is difficult to do, and it is preferred to plan for 100 per cent of possible connexions. For the new international exchange to be installed at Wood Street, London, the C.C.I.T.T. limits are being taken as 100 per cent targets. This objective will not be achieved initially.

Minimum Reference Equivalents of a National System

In order to reduce the risk of seriously exceeding the conventional load per channel on international transmission systems, it is recommended that the sending reference equivalent of the national system should not be allowed to be too low. A currently suggested limit (not yet recommended) is not less than 6·5 dB (r.e.), referred to the −3·5 dBr virtual switching point on the send channel of an international circuit at the CT3 exchange.

No recommendation is made or contemplated concerning minimum receiving reference equivalents of national systems, although noise and crosstalk levels become important when receiving reference equivalents are very low.

Maximum Overall Reference Equivalent of the Complete Connexion

The overall reference equivalent between subscribers can be estimated (it is not explicitly recommended) by adding to the sending and receiving reference equivalents of the two national systems the transmission loss of the chain of international circuits, each of which, as already mentioned, is recommended to be operated at a nominal transmission loss of 0·5 dB.

Combining the recommended maxima, for 97 per cent of actual calls, for the national systems and the nominal transmission loss of the six international circuits, 3 dB total, gives a nominal overall reference equivalent of 36 dB (r.e.). This is a somewhat high overall reference equivalent for a modern telephone network—the preferred one is of the order of 12 dB (r.e.); i.e. only a few subscribers would think 6 dB (r.e.) too loud or 18 dB (r.e.) too faint. However, connexions as complicated as the maximally adverse one of Fig. 2 will only rarely be established, and, in any event, the transmission quality will be very much better than that afforded by the traditional type of h.f. radio circuit which has to be used at the moment for such connexions.

Difference Between Send and Receive Reference Equivalents

The difference between the recommended maxima for the send and receive equivalents of the national sending systems is 8·6 dB. However, there is no specific recommendation that this or any other difference should be respected on every connexion, although, if all administrations adopt the same difference, the nominal overall reference equivalents of international connexions will be the same in both directions. This is not too important, however, and tests have shown that, in fact, considerable asymmetry of overall reference equivalents of the connexion can be tolerated.

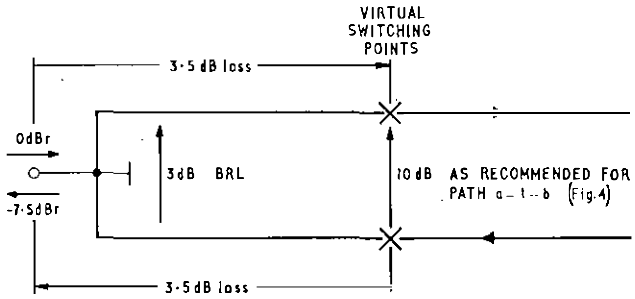
TRANSMISSION LOSS OF COMPLETE CONNEXIONS

The transmission plan recognizes that administrations are free to allocate the transmission losses in national systems as they wish, and, accordingly, the only constraints imposed by the recommendations are those detailed in the two previous sections relating to stability and reference equivalents. This circumstance gives rise to the possibility of international connexions having asymmetric loss.

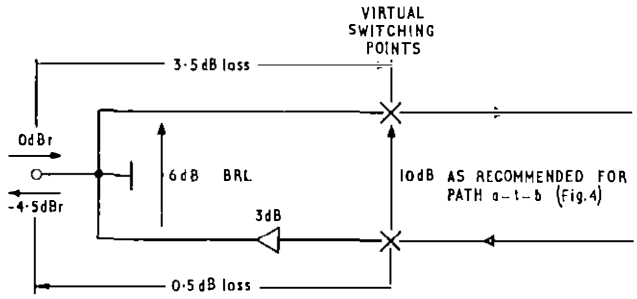
As an example of how this can arise, consider two administrations, one of which can guarantee a balance return-loss of 3 dB and the other a balance return-loss of 6 dB. These two countries may choose to arrange the losses in their national networks as indicated in Fig. 7. The diagram is drawn in terms of virtual switching points and practical 3·5 dB loss terminating units. The 10 dB minimum value of loss from the receive virtual switching point to the send virtual switching point is the mean recommended for the path a–t–b (see Fig. 5).

The country with 6 dB balance return-loss is not obliged to put all the extra gain available in the receive path as shown in Fig. 7(*b*); other arrangements are possible, of course. However, the system shown does comply with the plan, and could, if desired, be adopted. This arrangement will in fact be used for some connexions to the United Kingdom in the new British Post Office international exchange.

It is evident that a connexion between the two countries shown in Fig. 7(*a*) and (*b*) would have asymmetric nominal losses between national 2-wire points (Fig. 8). It is also



(*a*) Country with 3 dB Balance Return-Loss



(*b*) Country with 6 dB Balance Return-Loss

BRL—Balance return-loss

FIG. 7—Examples of international connexions having asymmetric loss

apparent why no limit of transmission loss can be recommended for such connexions.

ATTENUATION/FREQUENCY DISTORTION

The combined attenuation/frequency distortion of all the items of line and exchange equipment participating in an international telephone connexion between two subscribers' instruments is likely to be severe. An international call is established with lines and apparatus of varying age and design,

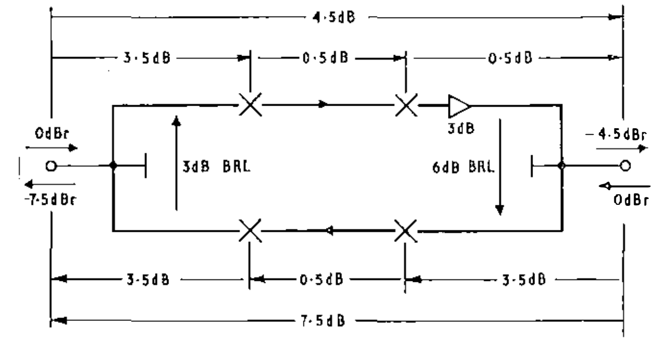


FIG. 8—Connexion between the two countries shown in Fig. 7(*a*) and (*b*)

and even the simplest international connexion comprises two subscribers' lines, two local exchanges, two terminating units, two international exchanges, and one 4-wire international circuit. For the more complicated connexion, there could be added to the above anything up to six national trunk circuits and exchanges, up to five international circuits and exchanges and one or two national junction circuits.

The difficulties of ensuring a good performance on such a complicated connexion are very great, since most of the lines and apparatus are designed to national standards to meet national needs.

Fig. 9 shows the recommended objectives for the attenuation/frequency distortion, relative to 800 Hz, for the 4-wire chain between 4-wire points in the primary centres. No allowance is made for the intermediate 11 telephone exchanges or for the two primary centres. Furthermore, the objectives

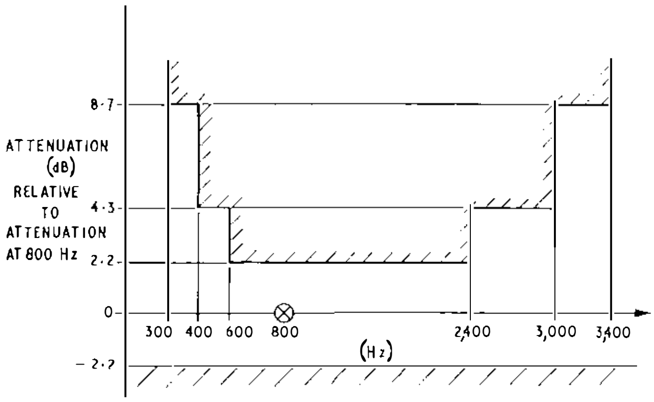


FIG. 9—Objective limits for the attenuation/frequency distortion characteristic of the 4-wire chain of 12 circuits between 4-wire points in the national primary centres

cannot be met if the channel-translating equipment used throughout only just complies with the current C.C.I.T.T. recommendations.

No explicit attenuation/frequency distortion limits are recommended for an international circuit as defined in Fig. 4, or for a national trunk circuit. The relevant recommendation states only that the characteristics of circuits should be such that the objective for the 4-wire chain is met. Neither are any limits recommended for telephone exchanges, administrations merely being urged to keep the distortions small.

The current recommendations concerning attenuation/frequency distortion are unsatisfactory, which is indicative of the difficulties of the problem, but it is hoped to produce realistic and useful recommendations concerning circuits and telephone exchanges in the future, and some progress has already been made.

PROPAGATION TIME

Limits for Connexions

It is necessary to limit the mean one-way propagation time introduced between two subscribers. An excessive propagation time introduces an unnaturally long interval between demand and response during conversation; such a delay tends to destroy rhythm. It is possible to learn to cope with a long delay between oneself and one's correspondent, but the phenomenon when encountered unexpectedly can be rather disconcerting, and there is a limit to what can be offered to the ordinary user.

The disturbing effect of very long delays is greatly aggravated when there are echo sources present on the connexion, and conversation becomes impossible if there are no echo suppressors. Echo suppressors are usually needed in practical switched telephone networks when the one-way propagation time is about 10–15 ms or more.

The C.C.I.T.T. has provisionally recommended the following limits for mean one-way propagation time for connexions with sources of echo and equipped with echo suppressors.

(*a*) 0–150 ms: acceptable without reservation.

(*b*) 150–400 ms: provisionally acceptable. In this range connexions may be permitted, in particular, when compensating advantages are obtained.

(*c*) Above 400 ms: provisionally unacceptable. Connexions with these delays should not be used except in the most exceptional circumstances.

National Networks

No limits are given for individual circuits, and the C.C.I.T.T. contents itself with recommending that high-velocity propagation transmission systems should be used for national circuits. When this is done, the one-way propagation time between the international centre, CT3, and the most remote subscriber is unlikely to greatly exceed 12 + [0·0064 × (distance in statute miles)] milliseconds.

The factor 0·0064 in the formula assumes that high-velocity plant (155 statute miles/ms), is used for the national trunk circuits, and the 12 ms is an allowance for terminal translating equipment and a certain amount of loaded cable, e.g. three pairs of channel-translating equipment, about 2 ms per pair, and 100 statute miles of trunk-cable pair loaded at 88 mH every 2,000 yd (about 16 miles/ms).

International Network

Again no propagation-time limits are given for circuits, it being recommended that high-velocity plant should be used. Appropriate values for the purposes of planning and calculation are as follows.

Terrestrial, including submarine, systems: a velocity of propagation of 100 statute miles/ms may be assumed, which includes an allowance for multiplexing equipment.

Satellite systems: for a high-altitude satellite (22,500 miles altitude) a mean one-way propagation time of 260 ms between earth stations may be assumed. This does not include any allowance for the distance from the earth station to the point where the derived circuit can be switched to other circuits. These times are usually small enough to be ignored for planning purposes.

The propagation time of one high-altitude satellite is by itself over half the upper limit of the provisionally acceptable range for connexions. Connexions involving two high-altitude satellites must therefore be avoided except in exceptional circumstances. Furthermore, there will need to be some restriction on the total length of terrestrial circuits which can be accepted for connexions involving one high-altitude satellite.

As a result of the above limitations, difficulties may arise in integrating high-altitude satellites into the world routing plan. It will, therefore, be necessary to attempt to restrict the use of satellites to direct or transverse routes, where an extension over short terrestrial circuits can be guaranteed, until some method of marking calls in the course of establishment is available.

ECHO AND ECHO SUPPRESSORS

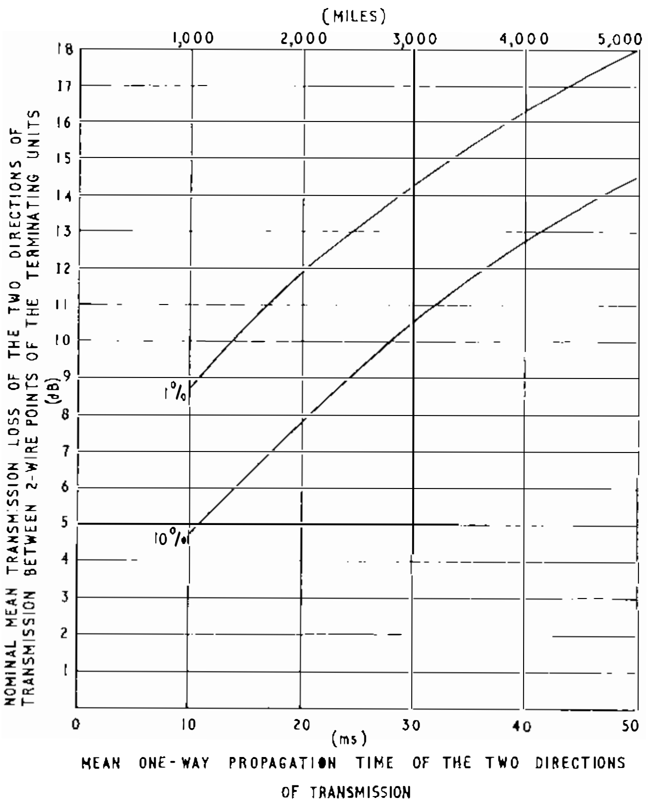
The same features of a telephone connexion that give rise to instability also operate to cause echo effects, and now propagation time is also an important factor. There is no recommended limit for echo balance return-loss. For the purpose of planning or calculation, the transmission loss of the path a–t–b for echo is provisionally assumed to have a mean value of $15 + n$ dB, with a standard deviation from the mean of $\sqrt{(15 \cdot 25 + 4n)}$ dB, where n is the number of 4-wire circuits in the national chain. The echo balance return-loss is a weighted mean-power ratio over the range 500–2,500 Hz, whereas the stability balance return-loss is the least value in the range 300–3,400 Hz.

The main circuits of modern telephone networks are high-velocity carrier circuits on unloaded symmetric pairs or coaxial-cable pairs or on radio-relay systems, so that echo suppressors are not normally used except on connexions involving very long circuits. There is often no general need for echo suppressors in national networks, but they may be required for the inland service in large countries, e.g. North America.

Echoes may be controlled in one of two ways: either the overall loss of the 4-wire chain of circuits may be adjusted so that echo currents are sufficiently attenuated (which tacitly assumes a particular value for the echo balance return-loss) or echo suppressors can be fitted.

From Fig. 10 it is possible to deduce the minimum nominal value of the overall loss of a connexion, measured or calculated between the 2-wire points, that must be introduced if no echo suppressor is to be fitted. The transmission loss is shown as a function of the mean one-way propagation time. The distance scale assumes a velocity of propagation of 100 statute miles/ms; if low-velocity plant is used in any part of the connexion the propagation-time scale of Fig. 10 should be used.

As a planning objective, the probability that an international connexion between any two subscribers will exhibit an objectionable echo, should not be greater than 1 per cent.



Percentages refer to probability of encountering objectionable echo. The distance scale is based on a velocity of propagation of 100 miles/millisecond

FIG. 10—Echo-tolerance curves

For international circuits reserved for traffic between terminal countries, i.e. CT3–CT3′ circuits, the C.C.I.T.T. recommends only a maximum nominal overall transmission loss. The minimum loss necessary to ensure freedom from intolerable echo can be found from the curves shown in Fig. 10. Should this loss be greater than the recommended maximum, an echo suppressor should be fitted.

When an international circuit is used only for comparatively short and simple international connexions, the nominal transmission loss between virtual switching points may be assigned according to the following rule, if the use of echo suppressors can thereby be avoided.

(*a*) For circuits up to 300 miles, the nominal transmission loss is 0·5 dB.

(*b*) For every additional 300 miles, or part thereof, 0·5 dB may be added, although such a circuit must not form part of multi-circuit connexions unless the nominal transmission loss is restored to 0·5 dB.

NOISE OBJECTIVES FOR CONNEXIONS

The objective for the hourly mean psophometric power of the total noise generated by a chain of six international circuits is that it should not exceed 50,000 pW referred to a point of zero relative level on the first circuit in the chain, level −43 dBmO. This objective takes into account the noise allowed for in national systems.

It has been calculated that, with such a noise limit, the percentage of connexions established over such a complex routing likely to be deemed poor or bad is about 10 per cent or less, depending on the assumptions made concerning the standard deviation of circuit losses. Naturally, lower levels of total noise are to be expected on the less complex connexions, and the percentage of dissatisfaction will be much smaller.

The objective given for connexions is based on the assumption that the following recommendations relating to circuits and international exchanges are complied with.

(*a*) Short-distance circuits, e.g. junction circuits: a maximum of 2,000 pWOp.

(*b*) Long-distance cable or radio-relay systems not exceeding 2,500 km: a maximum of 2,500 pWOp for multiplex equipment plus 3 pWOp/km.

(*c*) Long-distance cable or radio-relay systems exceeding 2,500 km: a maximum of 3 pWOp/km, including multiplex equipment.

(*d*) Long-distance submarine-cable systems: a maximum of 3 pWOp/km on the worst channel; the mean of all channels should not exceed 1 pWOp/km.

(*e*) Satellite systems: maximum of 10,000 pWOp.

(*f*) International telephone exchanges: a mean of 100 pWOp and a maximum of 200 pWOp.

These limits refer to the hourly-mean psophometric-noise power at a point of zero relative level (pWOp). The limits for circuits apply only to hypothetical reference circuits—an invention to aid system designers—and do not purport to be the limits respected by real circuits. In general, real circuits are often less complex than the hypothetical reference circuits, and, when this is so, one can reasonably expect the noise-power levels to be less than the values cited.

INTELLIGIBLE CROSSTALK

Limits for Circuits

Two classes of crosstalk are important: crosstalk between different circuits and crosstalk between the go and return channels of the same circuit.

Between any two complete circuits the near-end or far-end intelligible-crosstalk ratio measured at audio frequency at trunk exchanges should be not less than 58 dB. Considering the go-to-return crosstalk ratio, there is one aspect which is becoming increasingly important. Modern half echo-suppressors suitable for connexions with long propagation times, e.g. connexions involving a high-altitude satellite circuit, are designed to introduce, typically, at least 50 dB of suppression loss. A first conclusion is that the portion of the connexion lying between the echo suppressors must not introduce go-to-return crosstalk ratios lower than this figure, otherwise the action of the echo suppressors is nullified.

The principal path between the otherwise unconnected go and return channels of a circuit on a modern carrier system is nearly always via the channel-translating equipment, the contributions due to other stages of modulation and due to modern transmission systems usually being an order or so less significant.

The location of the principal go-to-return crosstalk path relative to that of the echo suppressor is also important. On circuits routed on direct groups, the dominant path is from the h.f. input to the h.f. output of the terminal channel-translating equipment. However, if the circuit comprises two or more circuit-sections, being reduced to audio frequencies at one or more intermediate points, e.g. at the Earth stations, the go-to-return crosstalk ratio between audio-frequency points on the channel-translating equipment also contributes to the echoes, tending to nullify the action of echo suppressors.

For circuits equipped with modern far-end operated half echo-suppressors, the near-end go-to-return crosstalk ratio should not be less than 55 dB and should preferably be somewhat higher, say 60 dB. For ordinary telephone circuits the recommended limit is that it should not be less than 43 dB; for circuits used with speech concentrations such as time assignment speech interpolation (T.A.S.I.),[2] a go-to-return crosstalk ratio at least 58 dB is recommended.

Limits for International Telephone Exchanges

A limit of 70 dB is recommended for the intelligible-crosstalk ratio between different circuits in an international exchange. The limit for go-to-return crosstalk ratio is 50 dB, and this is too low where satellite circuits and modern echo suppressors are concerned. This limit is being reviewed and may be amended, for example, to 60 dB.

GROUP-DELAY/FREQUENCY DISTORTION

The permissible differences for a world-wide chain of 12 circuits (each routed on a through group) between the minimum group delay in the effectively transmitted band, 300–3,400 Hz and the group delay at the upper and lower limits of this band are as given in the table.

Differences between Minimum Group Delay and Group Delay at Upper and Lower Limits of Frequency Band

Circuits	Lower Limit of Frequency Band (ms)	Upper Limit of Frequency Band (ms)
International chain	30	15
Each of the national 4-wire extensions	15	7·5

This aspect of the connexion is of importance when considering the transmission of data signals over the switched telephone network, e.g. as in the Datel service.

The group-delay/frequency distortion introduced by telephone exchanges is usually small compared with that introduced by the circuits. There is no currently recommended limit, but a proposal being studied is a limit of 100 μs over the range 500–3,000 Hz.

CONCLUSION

The C.C.I.T.T. has published a series of recommendations in the Blue Book, Volumes III, IV and VI, which lay the foundation of a world-wide modern telephone network capable of providing fully-automatic international subscriber dialling. Some aspects of transmission performance, e.g. attenuation/frequency distortion and go-to-return crosstalk, need and are receiving further study.

Looking towards the future, modern separate-channel signalling systems, now actively being studied by the C.C.I.T.T., may make it possible for the transmission performance of connexions to be tested and faulty circuits or exchange paths identified, a suitable indication being given to the maintenance engineers.

The future of international telephony is full of challenge, and much will depend on good transmission performance. Much has been done already. There remains yet more to do.

ACKNOWLEDGMENTS

Most of the material for the paper has been obtained from the working documents of 1964–68 study period of the C.C.I.T.T. and from the C.C.I.T.T. Blue Book, Volumes III and IV, published by the International Telecommunication Union. Acknowledgment is also made to the Institution of Electrical Engineers for permission to reprint portions of a similarly-entitled article which appeared in the *Proceedings, I.E.E.*, Vol. 114, No. 5, May 1967.

[2] CLINCH, C. E. E. Time Assignment Speech Interpolation (T.A.S.I.). *P.O.E.E.J.*, Vol. 53, p. 197, Oct. 1960.

Book Review

"Fundamental Electronics." A. S. P. Ledger, B.Sc., A.Inst.P., C.Eng., M.I.E.E., A.M.I.R.E., and N. H. Roche, B.Sc., C.Eng., F.I.E.E. Blackie and Sons, Ltd. ix + 594 pp. 273 ill. 75s. (cloth), 40s. (limp).

This book is designed to meet the requirements of students on a wide range of courses leading to B.Sc. degree, H.N.C. and H.N.D. courses in electrical and electronic engineering and the examinations leading to membership of the professional institutes. It is also suitable for students following the various telecommunication courses in the City and Guilds supplementary series.

A lot of attention is given to physical fundamentals which is aimed essentially at the electronic engineering requirements of students preparing for the graduate examinations of the Institute of Physics and Physical Society. This tends to limit the usefulness of the book to students following general telecommunications subjects.

The work is divided into two parts: basic concepts, and techniques.

Part 1 is covered by three chapters headed Physical Fundamentals, Circuit Theory and A. C. Theory. It is the author's intention that this portion of the book should cover all the basic theories of physics and electrical circuits which are necessary to enable the reader to fully understand the principles of application covered in part 2.

The material is well presented and, providing the reader uses careful discrimination in selecting the necessary material for his particular course, this part will prove ideal for reference purposes. The chapter on a.c. theory is written so that it will be extremely useful to telecommunications students in providing a sound basis for the further study of line-transmission and filter theory.

Part 2 is covered by chapters headed Diodes and Amplifying Devices, Power Supplies, The Cathode-Ray Oscilloscope, Negative Feedback, Amplification, Oscillators, Modulation and Detection, Switches and Triggers, and Light Sensitive Devices.

The subjects are generally given full coverage except in a few areas, particularly regarding some of the semiconductors such as the f.e.t. and m.o.s.t. devices. These, and the application of transistors to many of the techniques covered, are rather sketchy considering the level of student for which the book is designed.

The chapter headed switches and triggers gives a very readable description of the operation of toggle circuits and multivibrators with emphasis on hot-valve circuits and their comparison with transistor circuit operation.

Sections of the text which need to be read only by the more advanced students is presented in a smaller type. Unfortunately, the dividing line is not consistent throughout, particularly in the application sections where it is often used wrongly to discriminate between hot-valve and transistor applications. The five appendices, Relevant British Standards, Prefixes, Preferred Valves and Colour Codes, Fundamental Physical Data and Definitions, Useful Mathematical Formulae and Miscellaneous Characteristics, are all presented in small print, but much of the information is essential to students at all levels.

Altogether the book should prove useful to advanced students, but many other references will be needed to cover many of the transistor techniques and applications. A lot of effort has obviously been made to attempt to cover a large number of course syllabuses, and students should find the numerous examples at the end of each chapter particularly useful. Care should be exercised to spot the numerous errors due to poor editing and which are unexpected in a book of this nature.

B. A. E.

Press Notices

Optical-Cable Research by the Post Office

Scientists at the Post Office Research Station, Dollis Hill, are working on the development of a glass-fibre cable communication system which could eventually supersede existing coaxial cable and microwave links between cities.

The new type of cable would consist of a few hundred glass fibres in place of the copper wires in conventional telephone cables. One fibre is capable of conveying thousands of times as much information as a pair of telephone wires and several times as much as the larger coaxial metal conductors in present day television and multi-channel telephony cables or their equivalent microwave link systems. One fibre in the future glass cable would be only about 0·1 mm in outside diameter while the vital central core of the fibre would be only a few micrometres in diameter. Each fibre would carry the communication signals in the form of pulse-code modulation of an optical carrier wave. The optical wavelength which at present seems most likely to be used is that generated by a gallium-arsenide laser, i.e. in the near infra-red region of about 0·9 micrometre.

The Post Office is obtaining the assistance of industry by means of Research and Development contracts and one of these has already produced the ultra-pure raw materials required to make glasses of the very high optical transmission quality required (some 50 times better than the best glasses hitherto obtainable). Although glass fibres of a somewhat different geometry have been manufactured in the U.K. for some time, for applications such as punched card and paper-tape readers for computers, the dimensional perfection and quality control required for the new long-distance communication fibres are of a much higher order, and new techniques are being developed to meet these requirements.

The Post Office is placing other research and development contracts with London University for mathematical studies of wave-launching and propagation in the fibres, and is also collaborating with the Ministry of Technology and with Sheffield University in related glass materials studies.

The repeaters, which will be required at intervals of about a kilometre along each fibre, will make use entirely of reliable low-power solid-state devices, comprising mainly silicon avalanche photo-diode optical signal receivers, high-speed silicon integrated circuit electrical signal regenerative amplifiers, and low-power gallium-arsenide laser optical signal senders.

European Data Communication

Problems raised by the rapid spread of computers linked to telecommunication networks for on-line working were among important questions discussed by the sub-working group of the Conference of European Telecommunication Administrations (C.E.P.T.) which ended a one-week conference in London on 19 July.

The meeting, attended by representatives from 10 European telecommunications administrations, and chaired by Mr. J. Rhodes, Staff Engineer in charge of the Post Office Telegraph and Data Systems Development Branch, was called to consider the characteristics required for networks for data communications. There was a valuable exchange of views on solutions to the problems now being posed by the rapid spread in the use of computers linked to telecommunications network for on-line working.

Of particular interest and importance was the multi-access computer (especially in the form of computer bureaux) linked to remote keyboard instruments such as teleprinters. A developing need was expected to be that for high-speed data transmission, for example, at the rate of 48 kbit/s recently recommended by the Study Group Special 'A' of the C.C.I.T.T.

Characteristics which a future network should have in order to be able to cater for a wide range of facilities and types of user were discussed. These characteristics will be kept under review as information on economic factors and data traffic characteristics becomes available.

The meeting of the sub-working group arose from the study of a possible need for a special data network commissioned by the Plenary Assembly of C.E.P.T. at Rome in April 1967 in the light of the world-wide study being undertaken by the C.C.I.T.T. The outcome of the present meeting will be reported to its parent body, the Telephone/Telegraph Working Group and will eventually come before the Telecommunications Committee of C.E.P.T.

Telecommunications Vehicles to change from Dark Green to Yellow for Road Safety

As an aid to road safety, the dark green colour of the Post Office's telecommunications vehicles is to be changed to golden yellow.

The Postmaster General, the Rt. Hon. John Stonehouse, M.P., gave this information in a written answer in Parliament on 10 July.

Existing vehicles will be painted yellow only when they fall due for repainting in the normal course.

Mr. Stonehouse said that he had no intension of changing the colour of telephone kiosks.

The change of colour relates only to the 40,000 telecommunications vehicles. Mail vans and other postal vehicles will remain red.

The cost of the change will be very small in relation to the normal repainting cost. Some vehicles will need an additional coat to cover the present green. Over a five-year repainting cycle the cost is at present about £500,000. The additional cost of the yellow paint will be £30,000. There will be no additional cost for new vehicles.

The change from dark green, with its poor reflecting power and camouflaging effect in certain backgrounds and lights, is the most important Post Office safety decision of recent years.

Internationally yellow is officially recognized as a safety colour. The International Organisation for Standardization interprets yellow as giving a warning of danger, or a colour which serves to focus public attention.

The telecommunications transport fleet covers an annual mileage of 280 million. Each year there are more than 10,000 accidents involving almost 2,000 parked or stationary vehicles. By nature of their maintenance, repair and installation work, telecommunications vehicles are often stationary on roads for long periods, frequently in places where the present green merges into the background of hedges and trees.

Future of Telecommunications Data Transmission—Post Office Commissions Survey

To keep pace with rapidly expanding demand for data transmission services, the Post Office has commissioned an exhaustive independent market survey to establish likely requirements of business users for facilities to transmit digital and analogue data over the next 5, 10 and 15 years. The survey, to be carried out by a leading company of consultants, will run in parallel with the Post Office's own research and development program.

The survey is intended to produce a forecast of the total demand for data transmission facilities up to the early 1980s in terms of the number and geographical distribution of data sources, categorised by quantities and speeds of transmission required, and a provisional schedule of facilities for any public or private data transmission systems and networks that may be required.

A representative cross-section of existing and potential users of computers in all parts of Britain will be visited by a team of specialist consultants. They will interview representatives of business, industry, medical and research establishments, universities, public utilities, and Government Departments.

Computer and allied equipment manufacturers, and their trade associations, will be included, as well as professional institutions covering a broad field of science and industry and interests in accountancy, banking, insurance and management.

Factors to be taken into account include:

(*i*) growth in the number and type of computers and their diversity of usage, (*ii*) developments in computer and telecommunications technology,

(*iii*) trends in the development of business organization and general economic factors,

(*iv*) the development of international data transmission, and

(*v*) the increasing on-line use of computer bureaux.

Questions asked of potential users will be designed to establish what point-to-point facilities and public or private networks are likely to be needed and what signalling rates will be required. If the need for a data network emerges during the survey, planning information will be required on three broad categories of usage: bulk data transfer, small volume, quick response transfer (as for working into multi-access, conversational mode computers); and rapid data collection from a large number of sources.

To plan a data network, information in detail will be needed on users' requirements for data signalling rates and the devices which users would wish to connect, e.g. keyboard, paper-tape reader, card reader, line printer, magnetic-tape unit, cathode-ray tube display or telemetry equipment. Other considerations will include the format of data messages; computer alphabets to be used; message-length distribution, and the unit of data to which a response would be required at the far end. Planning parameters would depend on response time—defined as the elapse of time between the data message being offered to the network and the start of its delivery at the far end—and the proportion of connexion time used for transmission. Error-rate toleration and facilities likely to be required for correct-connexion security would need to be determined.

The survey will also aim to bring out facts and figures on present use of the telephone and telex networks for data transmission. The amount and pattern of existing data-transmission traffic will be established in relation to the time of day data is transmitted, the time occupancy of circuits and the proportion of data-transmission time to occupancy time.

The results of the survey will be referred to Post Office research and development teams who will produce systems proposals aimed at meeting most, if not all, the requirements identified by the market survey.

The Post Office and London's Schools' Television Network

The schools' television system opened in London on 12 September by the Inner London Education Authority (ILEA) uses a distribution network designed and installed by the Post Office. The system caters for the transmission of a maximum of nine 625-line television channels, in colour or monochrome each with an associated f.m. sound channel. An underground cable network of main feeders with branches to schools and colleges has been laid from a central studio. The cable is a single coaxial tube having a solid polythene dielectric for strength and a welded copper outer conductor to ensure freedom from interference.

At the end terminal, television signals from the cameras or video-tape recorders will amplitude modulate carriers in the v.h.f. band. Nine carriers are spaced so that the resulting nine television channels occupy the frequency band 40–140 MHz. The sound signals are frequency modulated so that the combined vision and sound channel is of the same form as the 625-line signals transmitted by the B.B.C.

Line repeaters are installed in telephone exchanges or manholes at 500–800 yard intervals to amplify and equalize the nine channels. The exchange repeaters also feed d.c. power over the coaxial cable to energize the manhole repeaters. In each school the underground cable is connected to a terminal repeater which also amplifies and equalises the received signals. An internal distribution network has been installed in each school and college to feed the nine television channels to receiver sockets in the classrooms.

A 24-hour watch is maintained on the system by transmitting a pilot signal from the send terminal throughout the network. School repeaters at the end of the network pick up the pilot signal and send a supervisory tone back to the nearest telephone exchange. If the pilot fails, the supervisory tone is not returned and an alarm is given.

All the equipment uses solid-state devices, has been developed by the Post Office and is manufactured to their specifications.

A similar Post Office designed schools' television scheme is to be opened in Plymouth also in September.

The Post Office is also providing a network for the London Stock Exchange Price-Dissemination Service which will provide twenty 625-lines television channels on a single coaxial cable between the Stock Exchange and 200 member firms in the City of London. A somewhat simpler scheme is the system provided for Welcome Television for distributing tourist information to eleven leading West End hotels.

Analysis of the Sick by Distant Computer

The day when computers take over the routine medical analysis of sick people, may have come a step closer. The Post Office has agreed to conduct a feasibility study in conjunction with the Research Department of Anaesthetics in the Royal College of Surgeons of England to determine whether complex information about a patient's condition can be transmitted in analogue data form, over the public telephone network, for analysis by a distant computer.

Preliminary experiments have already established that it is feasible to send physiological information, such as blood-pressure or respiration patterns, over long distances. The next step is to establish the feasibility of sending such parameters simultaneously. If the experiments prove successful, information about heart-rate and function, respiration, blood pressures and temperatures available from patient-monitoring devices at the bedside could be transmitted simultaneously to a computer centre over considerable distances. Here, a specially-programmed computer could analyse the different analogue waveforms after suitable processing, comparing and contrasting them with broadly accepted norms to furnish a dependable indication of the patient's condition.

The Post Office is now exploring the possibility of developing a system capable of transmitting three channels of analogue data simultaneously along a single telephone line.

The main problem has been to modify the established G.P.O. digital modulator-demodulator system to handle analogue waveforms and provide multiple channels of restricted but sufficient bandwidth. The waveshape must be transmitted without distortion, to be presented at the computer precisely in the form indicated at the patient-monitoring end.

Notes and Comments

C. F. Davidson, C.Eng., F.I.E.E.

Frank Davidson, like a number of senior engineers, came into the Post Office after serving an apprenticeship at H.M. Dockyard, Portsmouth. Thus, although most of his subsequent work has been in the radio field, he has a solid groundwork in practical mechanical engineering and he has even served as a part-time lecturer on Theory of Machines and Machine Design to 5th year National Certificate students. He is also a very competent mathematician, and the combination of high technical ability with an exceptionally pleasant personality makes him an excellent leader of a research and development team.

His association with satellite communication dates back to a time when Goonhilly Down was a lonely area noted primarily for heather, adders and "piskies," and during 1961–2 he made major contributions to the design, construction and commissioning of the Post Office Earth Station which has made Goonhilly a name of world renown. He was Controller for many of the early experiments on the Telstar and Relay satellites, and since then he has played an important part in the continuing development of communication satellite systems and techniques. Recently his field of work has widened and, under his friendly guidance, the success of the Microwave Radio Relay and Satellite Systems Branch of the Research Department is assured. R. W. W.

Board of Editors

Mr. A. G. Leighton is resigning from the post of Managing Editor of the Journal having served as an Assistant and Managing Editor since February 1958. Mr. J. Martin has been appointed acting Managing Editor pending the formal appointment of a new Managing Editor. The new Deputy Managing Editor is Mr. N. J. H. Ninnim and the new Assistant Editors are Mr. P. G. Steele and Mr. D. Waldie.

Mr. W. J. E. Tobin has also resigned from the Board of Editors having served the Board since February 1957.

The Board takes this opportunity of thanking Mr. Tobin and Mr. Leighton for their long and valuable service.

Mr. A. C. Croisdale has joined the Board in place of Mr. L. F. Scantlebury, whose retirement was announced in the last Issue, and Mr. A. J. Barnard will replace Mr. Tobin.

10-Year Index

An index to volumes 51–60 (1959–68) is being prepared and it is planned to publish it during January 1969. The index will contain approximately 30 pages, cross-indexing articles published over the last 10 years in title keyword and authors' names order. A separate section will be included to index the Regional Notes. The price of the index will be 2s. 6d. (post free).

Any reader who wishes to purchase a copy of the index should complete the order form enclosed with this issue and return it with his remittance to the Managing Editor (Index) forthwith. The print order for the index will be determined from the orders received by 31 December.

Post-Graduate Awards, 1968

The Post Office is making a number of post-graduate awards each year to selected staff. These awards will be tenable at universities that have facilities for research or for advanced studies relevant to Post Office problems, initially in telecommunication science and engineering. In appropriate cases the awards will enable the holders to qualify for M.Sc. or Ph.D. degrees. The primary object is to further research and to develop expertise of special value to the Post Office.

The Post Office awards were first made in 1966; the officers selected for the 1968 awards, and the awards, are listed below.

Mr. A. R. Peacock, Grad.I.E.R.E., Assistant Executive Engineer, Project Engineering Branch, Planning and Mechanization Department, Postal Headquarters has been awarded a 1-year M.Sc. course in Systems Engineering at the University of Surrey.

Mr. T. W. Adam, M.I.E.E., Executive Engineer, Technical Support Unit has been awarded a 1-year M.Sc. course in Systems Engineering at the University of Surrey.

Mr. R. H. Benton, B.Sc., Executive Engineer, Transmission Systems Branch, Research Department, Telecommunications Headquarters has been awarded a 1-year M.Sc. course in Telecommunication Systems at the University of Essex.

Mr. W. J. Newman, B.Sc., Executive Engineer, Major Projects Division, Management Services Department, Telecommunications Headquarters, has been awarded a 1-year M.Sc. course in Telecommunication Systems at the University of Essex.

Mr. M. Bennett, B.Sc., Executive Engineer, North-West Area, London Telecommunications Region has been awarded a 1-year M.Sc. course in Telecommunication Systems at the University of Essex.

Mr. P. G. Steele, B.Sc., Executive Engineer, Exchange-Facilities Division, Telecommunications Development Department, Telecommunications Headquarters has been awarded a 1-year M.Sc. course in Telecommunication Systems at the University of Essex.

Mr. P. A. Kidd, B.Sc., Scientific Officer, External Plant and Research Services Branch, Research Department, Telecommunications Headquarters has been awarded a 3-year Ph.D. course in Optical Character Recognition at the University of Essex.

Mr. A. F. Heaton, B.Sc., Waveguide and Optical Systems Branch, Research Department, Telecommunications Headquarters has been awarded a 3-year Ph.D. course in Mathematics at the University College of North Wales, Bangor.

Mr. A. E. Pullin, M.Sc., Grad.I.E.R.E., Executive Engineer, Technical Support Unit, has been awarded a 1-year Computer Science course at the Institute of Computer Science.

Press Notices

This Issue contains a new feature, "Press Notices." The subject matter of these notices will usually be covered by a full article when the development foreshadowed by the notice reaches an appropriate stage. The object of publishing the notices is to give readers news and short notes on important topics of interest at the earliest time.

Institution of Post Office Electrical Engineers

Essay Competition 1967–68

The Council of the Institution is indebted to Mr. W. A. Humphries, Chairman of the Judging Committee, for the following report on the essay winning the first prize in the 1967–68 Essay Competition.

Mr. I. M. Hogg, Technical Officer, Aberdeen, the author of the essay entitled "Maintenance of Custom Service in a Growing Telephone Network," has produced an eminently readable review of many of the new practices and expedients that have been introduced during the last few years—a period when the telephone system has been expanding at an unprecedented rate.

After a brief look at the growth of the system since the end of World War I, the author examines in more detail the expansion in the nineteen-sixties and the problems faced by internal and external planners in their efforts to make the best possible use of available resources.

In the local service field the author notes the problem presented by the low calling rate residential subscriber, and the use of shared service and line connectors. He surveys the advantages derived from the introduction of polythene cable, together with cable pressurization and long-length cabling methods. He then turns his attention to automatic exchanges, and to the multiplicity of expedients and new techniques which have been adopted, such as composite racks, over-ceiling and grid cabling, wire wrapping, and crossbar and electronic exchanges.

A further section deals with the methods used to expand the trunk and junction network to cope with the growth in traffic. Reference is made to the difficulty which can be caused by a faulty link on an S.T.D. call, and to current methods of dealing with it, and this leads him to examine benefits to be expected from the transit network. Mention is made of the radio link network, and a brief explanation of the basic principles of p.c.m. working is included.

On the maintenance aspect the author reviews a number of recently introduced aids, particularly in automatic exchanges, and notes their importance in reducing the time spent on manual routining. The value of print-out facilities, and their particular importance in electronic and crossbar exchanges is not overlooked.

Liberal use is made throughout the essay of simple graphs and diagrams to illustrate those points the author wishes to emphasize, and in the final section he indulges in some interesting speculations on possible new services the Post Office may be able to offer. He also touches on the advantages to be derived from increasing computerization of engineering records.

This essay (and other prize-winning essays), which will be kept in the Institution Central Library and which will be available to borrowers, can be confidently recommended to anyone who requires a concise review of many of the significant developments in telephone engineering over the last decade.

Essay Competition 1968–69

To further interest in the performance of engineering duties and to encourage the expression of thought given to day-to-day departmental activities, the Council of the Institution of Post Office Electrical Engineers offers five prizes, a first prize of six guineas and four prizes of three guineas, for the five most meritorious essays submitted by Post Office engineers below the rank of Inspector. In addition to the five prizes, the Council awards five certificates of merit. Awards of prizes and certificates made by the Institution are recorded on the staff dockets of the recipients.

An essay submitted for consideration of an award in the essay competition and also submitted in connexion with the Associate Section I.P.O.E.E. prizes will not be eligible to receive both awards.

In judging the merits of an essay, consideration will be given to clearness of expression, correct use of words, neatness and arrangement, and, although technical accuracy is essential, a high technical standard is not absolutely necessary to qualify for an award. The Council hopes that this assurance will encourage a larger number to enter. Marks will be awarded for originality of essays submitted.

Copies of previous prize-winning essays have been bound and placed in the Institution Central Library. Members of the Associate Section can borrow these copies from the Librarian, I.P.O.E.E., 2–12 Gresham Street, London, E.C.2.

Competitors may choose any subject relevant to current telephone, telegraph or radio practice. Foolscap or quarto paper should be used, and the essay should be between 2,000 and 5,000 words. An inch margin should be left on each page. A certificate is required to be given by each competitor, at the end of the essay, in the following terms:

"*In forwarding the foregoing essay of*.....................*words, I certify that the work is my own unaided effort both in regard to composition and drawing.*"

Name (in block capitals)..

Signature ....

Official Address..

The essays must reach:

The Secretary,
The Institution of Post Office Electrical Engineers,
2–12 Gresham Street,
London, E.C.2.

by 15 January, 1969.

The Council reserves the right to refrain from awarding the full number of prizes and certificates if in its opinion the essays submitted do not attain a sufficiently high standard.

Institution Field Medal Awards, 1966–67 Session

Details of the medals awarded for the best papers read at meetings of the Institution in field subjects primarily of Regional interest were published in the July 1968 issue of the Journal.

The Council of the Institution is indebted to Mr. E. C. Swain, Chairman of the Papers Selection Committee of Council, for the following précis of the medal-winning papers:

"*The Elements of Automatic Control as applied to a Large Heating Installation,*" *by A. Ness*

Central heating is the major accommodation service in most Post Office buildings. The complexity of a large modern heating installation is not always realized, particularly the extent to which its operation is automatically controlled.

This paper describes the heating installation for Churchill House, the Belfast Telephone Manager's Office which, the author states, is the tallest building in Ireland. The installation has a number of novel and interesting features and these are brought out in the paper which concentrates mainly on the control systems, as it is the author's intention to give an insight into the subject of automatic control. He describes various types of control system elements as they are applied in this particular installation.

Firstly the general arrangement of the installation is outlined. A conventional radiator system is used and the heating load is divided into four zones each of which is a separate low-pressure hot water system fed from a calorifier in the boiler room. The four zone calorifiers along with two domestic hot water calorifiers are connected to three oil fired boilers by means of a medium-pressure hot water circuit. A detailed explanation is then given of the boiler control system. The author shows how the number of oil burners running and their firing rate is automatically regulated to meet the load demand on the calorifiers. In this installation only one boiler at a time is meeting variations in load while other boilers, if running, will be at their full output. This arrangement differs from the more usual method of modulating the firing rate of all burners together and gives, in the author's view, advantages in overall efficiency.

The secondary zone controls are separate independent systems which provide facilities for different modes of operation to suit varying weather conditions throughout the year. Outside compensation, night set-back and morning boost facilities are all available. Whereas the primary boiler controls use electric and electronic system elements, the zone controls operate on a pneumatic system. It is believed that this is the first Post Office installation to have pneumatic controls and the author devotes some time to the operational principles of valve actuators and thermostats which use compressed air as a control medium.

Miscellaneous controls, boiler auxiliaries and the fuel oil system are also described and the author concludes by indicating that the control system elements he has mentioned are used in various forms for all heating, ventilation and air-conditioning applications.

"A Review of Post Office A.C. Signalling Systems," by W. Sheldon

With the growth, one almost might say proliferation, of a.c. signalling systems at present in use, or planned to be introduced in the near future in the Post Office network, a review of these systems appears to be timely.

The systems are numbered consecutively from 1 to 13 and, with the exception of number 2, are all in current or prospective use. It will be apparent that there must be good reasons why such a considerable number of a.c. signalling systems have been developed and introduced and in the first part of the paper the author enumerates some of the principal factors which must be borne in mind in designing an a.c. signalling system. Starting with the limitations of d.c. methods there is mention of one or two early uses of a.c. signalling followed by a discussion of the factors to be considered in the design of new systems. In the early days the choice of signalling frequency was influenced by those available from existing v.f. generators. Later C.C.I.T.T. investigations have shown the advantages of using frequencies higher in the speech range. The number of different frequencies used, and whether signalling is carried in or outside the speech band have great significance in the design of systems, particularly that of v.f. receivers. The merits of the type of signalling code, continuous, pulse or acknowledged, are discussed. The choices open on calls involving more than one link are covered by comparing end-to-end with link-by-link working. The problems of line splitting and spill-over receive attention and there is a section on v.f. receiver guard circuits.

Having thus established the background, the author continues with information on each of the a.c. signalling systems including the reasons for its adoption, frequencies used, type of code, flow charts of signals in each direction and circuit elements where these are of value in illustrating the text.

The author describes the systems used on the national, continental and international networks, leading to a discussion on the methods of passing digital information between registers. The continental systems use either a binary or an arythmic code and the national transit network employs multi-frequency a.c. methods. The important point about multi-frequency systems is the speed with which digital information may be passed. The relationship between line and inter-register signalling is brought out.

To make the paper comprehensive the author includes the v.f. signalling system devised for the emergency telephones on motorways. The system provides selective signalling on a multi-frequency basis for up to ten telephones connected to one pair of wires.

"Norwich Telephones—The Early Days," by E. G. Clayton

This paper is in two parts; the first deals with the history of telephone development and usage, and the second deals with the working life and conditions of the men who made that history.

The writer starts by giving details of the first long-distance telephone call (from Norwich) made by a representative of Edison in 1878. The call took place over the Great Eastern Railway's telegraph route from Norwich to London, a distance of 115 miles.

Mention is made of the first telephone lines erected around Norwich leading up to the opening of the first telephone exchange in Norwich in 1883 hy the United Telephone Company which was operated by one man and a boy for several years.

The story continues through the take-over of the telephone exchange by the South of England Telephone Company followed by the National Telephone Company take-over in 1890.

There follows an account of the wayleave difficulties imposed on the National Telephone Company (N.T.C.) by the Telegraph Act of 1892, and how the Norwich Corporation was the second local authority in the country to grant a wayleave to the N.T.C. to open the streets and lay ducts and cable in the highways. A copy of this wayleave map is given in the appendices and is dated 2 November 1894.

The Telegraph Act of 1899 caused further trouble to the National Telephone Company as it now permitted other telephone companies to be set up in direct competition with the N.T.C. In Norwich, the Norwich Mutual Telephone Company was formed in 1900. Three years later the N.T.C. was alone in the field again, the Norwich Corporation having declined to extend the period for the Norwich Mutual Telephone Company to start operations.

An analysis of the population and telephone penetration in 1901 and 1906 in Norwich gives two interesting pie charts. Maps of this period show the territories of both the N.T.C. and the P.O. with their respective exchanges marked. One interesting point is that there was only one through telephone line from Norwich to London prior to 1907, and none as far south as Ipswich in the south-eastern direction from Norwich.

The transfer of the N.T.C. system to the Post Office in 1912 is explained and duties of the newly formed District Manager and Superintending Engineer are given. Staff trees of the N.T.C. and the Post Office illustrate the difficulties of a quick transfer from the N.T.C. with its practice of comparing the expenditure and revenue of each sub-division, to the Post Office with its central control and accounting procedure. Wayleave difficulties arose when the Post Office took over the N.T.C. system since the permissive nature of the N.T.C. was different from the wayleave powers of the P.M.G.

The history continues up to the Regionalization period which forms a natural break in telephone development.

The second part of the paper traces the social conditions existing for the telephone staff. In 1904 a Board of Trade enquiry examined conditions in Norwich and provides much information on the cost of living, rent, pay, etc.; one of the appendices includes details of the cost of living for wage earners in the telephone staff bracket.

On 2 February 1905 the National Telephone Company entered into an agreement to sell its telephone system to the Postmaster General and when the conditions of staff transfer were made public (clause 8 of the agreement) great disatisfaction was felt by the National Telephone Company staff. As a result the "National Staff Transfer Association" was formed with its objective to improve their future prospects. After a great struggle transfer conditions were improved but the writer points out that the Post Office staff now became deeply concerned at the preferential treatment the N.T.C. staff were getting and the Post Office staff formed the "Engineering and Stores Association" members of which formed the "Post Office Defence Committee."

The work done by the Inventory Staff is mentioned together with their working conditions.

After 1912 the story is continued up to Regionalization with many most interesting examples of the life and times of the men who made this history.

A. B. Wherry,
General Secretary.

Additions to the Library

Library requisition forms are available from Honorary Local Secretaries, from Associate Section Centre Secretaries and representatives, and from the Librarian, I.P.O.E.E., G.P.O., 2–12 Gresham Street, London, E.C.2.

Members are reminded that Prize Essays, Associate Section Prize Papers, and various unpublished papers are held in the library for loan, and that a list will be sent on request. Field Medal award-winning papers are also held for loan and are listed in the Supplement to the Library Catalogue.

2956 *Principles of Electrical Transmission Lines in Power and Communication.* J. H. Gridley (Brit. 1967).
An introductory study in the transmission of electricity with emphasis on principles common to all electrical transmission links, whether their functions be bulk power transfer or communication. Useful for students preparing for B.Sc.(Eng.) and Part III of the examination of the Institution of Electrical Engineers or for Higher National Certificate in Electrical Engineering.

2957 *Electronic Circuit Packaging.* W. J. Prise (Amer. 1967).
Describes a methodical, systematic approach to the integration of all clements of electronic circuits into optimum, reliable, and economically feasible electronic equipment.

2958 *101 Ways to Use Your Square-Wave Pulse Generators.* R. G. Middleton (Amer. 1967).
Describes basic tests for *RC* circuits, audio amplifiers, vidio amplifiers, inductive circuits, television-i.f. amplifiers, r.f.-i.f. amplifiers, stereo f.m. units, and *RC*-coupled amplifiers.

2959 *Principles of Television Reception.* D. Howarth and W. Wharton (Brit. 1967).
The introduction of 625-line ultra-high-frequency transmissions, the advent of colour television, and the impact of transistors are all fully incorporated in this book. Suitable for electrical technicians of all grades.

1214 *Intermediate Engineering Drawing (New Edition).* A. C. Parkinson (Brit. 1967).
Includes a course in plane and solid geometry and an introduction to design.

2830 *Planning by Network (New Edition).* H. S. Woodgate (Brit. 1967).
Extensively revised and brought up-to-date, this new edition describes the fundamental principles involved in the various systems—including P.E.R.T. and C.P.M., and examines in detail the managerial implications of network planning methods.

2960 *MOSFET in Circuit Design.* R. H. Crawford (Amer. 1967).
Geared to the needs of the practicing engineer and designer, this book provides the basic principles and background required in MOSFET device and circuit engineering.

2961 *Cold-Cathode Tubes.* J. B. Dance (Brit. 1967).
This book is an introduction to cold-cathode tubes and the circuits in which they are commonly used. The approach is practical rather than theoretical, and should be useful to technical college students taking engineering courses.

2962 *Audio Amplifier Design.* F. J. Waters (Amer. 1967).
Written for the audio enthusiast who wishes to design his own amplifiers, whether a single-stage or a complete many-stage stereo system.

E. DOHERTY,
Librarian.

Regional Notes

Eastern Region

Leighton Buzzard Electronic Exchange (TXE 1)

On Thursday 23 May 1968 the electronic exchange at Leighton Buzzard, which is the prototype design for larger exchange areas, was successfully brought into public service by the transfer of 1,998 subscribers formerly served by the Leighton Buzzard U.A.X. No. 7 and Linslade M.N.D.X. exchanges.

The occasion was marked by an informal buffet lunch arranged by the local staff and the guests included the Regional Director and supporting staff from Region and Area together with a number of representatives from both Telecommunications Headquarters and the manufacturers who had been concerned with the development of the exchange. During the proceedings the visitors had a unique experience when the skirl of the bagpipes was heard and the piper, maintenance engineer of the old U.A.X. exchange, paraded through the new exchange playing an air that was understood to be a lament for the closing of the old.

Subscribers do not share these sentiments, however, as they are appreciative of the improved service now given and of the introduction of S.T.D. facilities. Extended service observations have confirmed that the performance of the exchange is very satisfactory.

S.H.S.

South East Region

For Sale—Ingrams Green Telephone Exchange in Working Order

The photograph shows the Ingrams Green U.A.X. No. 5, near Midhurst, Sussex, in the Portsmouth Telephone Area. The exchange started life as an R.A.X. on 1 September 1930, and was then intended to cater for some ten subscribers and one public call office.

It was the last surviving U.A.X. No. 5 in the Portsmouth Area and has thus served this rural Sussex community very faithfully over nearly 38 years, although for the last year or two arrangements had to be made to connect new customers in the Ingrams Green area to Midhurst C.B. 10 exchange. On conversion to non-director working on 3 April 1968, Midhurst exchange took over the majority of the old Ingrams Green subscribers and rendered the "old faithful" obsolete.

The photograph was taken a few hours before Midhurst exchange was opened and when Ingrams Green U.A.X. was connecting some of the last calls it was ever to make.

C.F.B. and D.R.F.D.

London Telecommunications Region

New Television Switching Equipment

A new television switching equipment, described in the October 1967 issue of the Journal, came into service at Network Switching Centre, Post Office Tower, London (L/NSC) on 3 December 1967. At this centre the Post Office provides a switching service for Independent Television (I.T.V.) to route vision and sound programs to the Independent Television Authority (I.T.A.) transmitters throughout the United Kingdom, at times scheduled by I.T.A.

This service has been given for the past nine years by an equipment which has given faithful service but had to be replaced to cope with the increased switching demands, and the need to switch vision channels to the new 625-line colour standards.

The superseded equipment was limited in size to a 15 × 16 crossbar used to connect 15 sources of program to 16 destinations on any arrangement required by the I.T.A. The new equipment is a 30 × 40 crossbar with fully transistorized transmission paths and a logic system operated from a push-button control console, which stores three program patterns and their respective program times.

Acceptance testing this equipment presented a formidable task in that the vision and sound transmission paths had to be lined up on site and many of the 1,520 recorded measurements repeated several times before final acceptance. The most difficult parameter to bring within the specification was the vision-matrix crosstalk at the colour sub-carrier frequency of 4·43 MHz. With the switches destined to carry the future I.T.V. colour service, it is essential that no crosstalk occurs which could cause detectable interference between the many possible colour signals carried at any one time.

Bringing the switch into use was a Centre Area responsibility and a Sunday was chosen for the opening day. The later start to programs gave maximum time for over-night changeover, followed by the minimum demand for switching during the day. From this cautious start the equipment has performed over 18,000 vision and sound switching operations during the first 7 months' service. Only 2 faults affecting radiated programs have occurred.

On Friday 2 August 1968 the switch took on a new role when the new television companies, Thames Television and Week-end Television took over the program responsibilities for the I.T.A. London transmitter. The change-over from the weekday to the weekend company will be at 1900 hours each Friday instead of after programs on Friday night, as at present. Normally all Post Office network switching is done in a 15-second period when a studio announcer gives viewers details of the next program to be screened. Masking of this 1900 hours change by the broadcasting authority is not possible and Post Office staff at the L/NSC were responsible for carrying out live program switching on and from the above date.

D.H.A.

Outside Broadcast of the Return of Sir Alec Rose to Portsmouth

The Post Office was approached by the British Broadcasting Corporation to provide the facilities for the sound and television coverage of Sir Alex Rose's arrival on the sea front at Southsea, and the motorcade route afterwards to the Guildhall in Portsmouth.

The sound lines were provided by the local Portsmouth engineers and the vision circuits by the London Outside Broadcast teams, assisted by a team from Birmingham. The Outside Broadcast Group was made up of 18 staff and eight vehicles. The equipment used comprised eight send amplifiers, 10 video repeaters and three one-hop microwave radio-links.

The circuits were provided and working in time for the rehearsal on Sunday 23 June. Then came the period of waiting until the actual arrival of *Lively Lady* on 4 July. During this period the circuits were used for inserts into news items and other programs on no less than 30 occasions.

The final broadcast of Sir Alex Rose's triumphant return made full use of all the Post Office facilities, and the overall coverage was a complete technical success.

R.G.W.

Associate Section Notes

Salisbury Centre

The annual general meeting, held in May, concluded the 1967–8 session.

It was rather a quiet session but two interesting visits were made. Thirty members were the guests of the British Aircraft Corporation at Hurn Airport, Bournemouth, for a tour of the BAC 1–11 production line and this was voted a very worthwhile evening visit.

The second trip was to the Post Office Tower for a tour of the technical floors including the television switching centre. The visit proved to be very informative and was well received.

R.H.

Gloucester Centre

The 1968 program of visits has been very varied.

The April visit was an evening trip to the cellars of John Harvey & Sons, Ltd, Bristol, which included a tour of the wine museum, a talk and a film on the making of sherry and finally a tasting of six different sherries.

In May we travelled to Crewe to visit the Motor Car Division of Rolls Royce, Ltd. Here we witnessed the hand-built, precise assembly of one of today's finest cars.

A party visited the Naval Dockyard at Portsmouth in June and beside a boat trip round the harbour, looked over H.M.S. *Victory*, the *Victory* Museum. We ended a very interesting day viewing a Frigate H.M.S. *Sirius* which was in for its routine overhaul.

The July visit was to R.A.F. Lyncham. Future visits, we hope, will include the new signal box at Gloucester, the Concorde at Filton and, by popular request, the B.B.C. Television Centre and B.O.A.C. (London Airport).

Forthcoming lectures during the winter months include "Pulse-Code Modulation," "Basic Transmission Principles and Practice," and "Cine Photography," all given by our own members.

P.G.W.

Exeter Centre

The summer has been a comparatively quiet time for the centre and activities have been confined to visits.

Members paid a visit to Exeter City water works on the evening of 29 May 1968. The weather was kind and the event was enjoyed by all. The party were conducted around the site by the resident engineer who had an intimate knowledge of water purification.

In spite of a great deal of effort, our Assistant Secretary has been unable to arrange a visit to B.A.C. Bristol this year. We have hopes of arranging a visit sometime in 1969; this, however, depends entirely on the success and timing of events in the Concorde program. In place of this, arrangements have been made to visit Pirelli Cable Works, Southampton, in September.

T.F.K.

Swindon Centre

In February the centre continued its program for 1967–8 with a talk by Mr. J. Wilcox on "The work of a Probation Officer." This proved to be very interesting and made the meeting realize that to carry out work of this nature requires a certain amount of dedication.

The month of March once again saw the joint meeting with the Gloucester centre at Cirencester. This year Dr. J. E. Smith gave a talk, illustrated with slides and film on "The Search for North Sea Oil and Gas" to approximately 50 members. This was an outstanding success, favourable comments coming from all ranks.

In April, a party of 16 members paid a visit to the Westinghouse Brake and Signal Co. Ltd., Chippenham, for a conducted tour of the section concerned with assembling and wiring Post Office testers and the semiconductor division.

The 1968 annual general meeting was held on Thursday 9 May and the following officers were elected: *Chairman:* Mr. P. E. King; *Secretary:* Mr. W. H. Baker; *Treasurer:* Mr. W. J. Waldron; *Vice-Chairman:* Mr. J. G. Butt; *Librarian:* Mr. A. Zrinyi; *Committee:* Messrs. Gill, Peyton and Sandell.

At the moment our membership stands at 97, and it is hoped to reach the 100 mark soon. It is encouraging to see that apprentices are now joining the centre.

W. H. B.

Ayr Centre

In April a talk entitled "The Crossbar System" was given by Mr. Thunder of Messrs. S.T. & C. Many exhibits, including a crossbar switch, were on view and the talk was very well received, the attendance on this occasion being particularly gratifying.

A visit was made to the S.T. & C. crossbar factory at East Kilbride in May, where our members were shown the manufacture and testing of crossbar equipment, the test laboratory being of particular interest.

The session closed with the annual general meeting in June.

A.B.

Dundee Centre

The annual general meeting of the centre was held in the Royal Hotel on Tuesday 7 May 1968.

The office bearers were re-elected as follows: *Chairman.* R. L. Topping; *Vice Chairman:* R. C. Smith; *Secretary:* R. T. Lumsden; *Treasurer:* D. L. Miller; *Committee:* Messrs. W. Bell, W. Hennesey, J. McNeill, I. Morrison, I. Smith, G. Stephen, and M. Williamson.

A keen sense of enthusiasm was evident from those present and an all-out effort is to be made to encourage more members to attend meetings.

Mr. I. Morrison has been successful in the Essay Competition and will receive his prize at a later date. The meeting ended with an excellent buffet supper.

R. T. L.

Cambridge Centre

The annual general meeting was held at Cambridge on 26 June 1968.

The following members were elected to office: *President:* Mr. A. E. Paterson (unchanged); *Vice-President:* Mr. G. C. Greenwood; *Chairman:* Mr. L. Salmon (unchanged); *Vice-Chairman:* Mr. R. Halls (unchanged); *Secretary:* Mr. R. S. King; *Asst. Secretary:* Mr. E. A. Burry; *Treasurer:* Mr. C. F. Nunn (unchanged); *Committee Members:* Messrs. I. Smith, R. J. Farrington, S. J. Hurt, and J. Acker.

An eventful program is in the making with visits to: Marshalls Airport Works, British Rail Diesel Depot, Whitbread Brewery, Fleet Building, *Daily Express* and the *Daily Mirror*, P.O. Tower, I.T.V., Nailstone Colliery, an oil rig and Hawker Siddeley.

Among the lectures that are planned are: "Telephone Network Planning" and "Electronic Exchanges."

R. S. K.

Edinburgh Centre

The 1968–9 Session which started in September has been planned as follows; certain details have yet to be finalized.

September: A talk by Mr. E. N. Davies, S.S.E.B., on the "National Grid."
October: A half-day visit to the National Engineering Laboratory (Ministry of Technology) East Kilbride.
November: Mr. Robb, Area Engineer, Edinburgh Telephone Area will give a talk on "Transatlantic Communications," similar to that given to G.W. Centre.
December: A visit to the recently opened Post Office Computer Centre in Edinburgh.
January: A talk on Postal Mechanization by Dr. A. W. Coombs, P.O. Research Station, Dollis Hill.
February: A visit to Melrose Electronic Exchange—The first TXE2 in the Edinburgh Area.
March: A proposed talk by a member of the R.A.F. Aerospace Briefing Team on "Project Apollo."
April: A visit to the British Rail marshalling yard at Millerhill.

The session is to close with our Annual General Meeting and Dinner.

G.A.K.R.

London Centre

Our traditional season of inactivity that follows the conference was this year clouded by the unfortunate death of Ron Harper. His passing was especially saddening for the suddenness with which it occurred. As Assistant Secretary to London Centre he was a valuable member of the committee and had the onerous task of writing the minutes. Before this he had taken an active part in Centre Area work. He will be missed by his colleagues at Victoria, all those at London Centre and by all others who knew him at all. He will be a difficult person to replace. Our condolences go out to his wife and family for their loss.

The Annual Conference was held as usual in the imposing I.E.E. building in Savoy Place. The President, Dr. P. R. Bray, was there and among his remarks in the opening address he said that the Associate Section was the foundation stone of the I.P.O.E.E. He also hinted at the possible changes that will be taking place in the structure of the main Institution.

After the annual report, the propositions were taken. There were more of them this year than usual but discussion on most was quite brief. Certain alterations to our constitution were accepted but a more revolutionary move to change the electoral arrangements was withdrawn after much discussion.

One resolution that was passed concerned the setting up of a National Associate Section (N.A.S.). Early in this session a steering committee will be set up, and one of its tasks will be to communicate with other centres with a view to promoting the N.A.S. It is London Centre's opinion that this is a necessary next step in the light of the changing circumstances in which we find ourselves.

About now one of the most ambitious projects tackled by any centre is under way. Some seventy members and their families have been or are enjoying the hospitality of the New World. They were able to take advantage of the extremely favourable terms that we were able to obtain. Norman Clark of the North West Area, who organized the trip, cannot receive enough credit for the success of the venture. The January edition of our own *New Quarterly Journal* will carry a full coverage of the event.

The *New Quarterly Journal* continues to flourish and the Editor has the heartening task of sifting through a considerable amount of copy rather than scouring around for material.

B.E.B.

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Model Answer Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Details of the books available are given at the end of the Supplement to the Journal.

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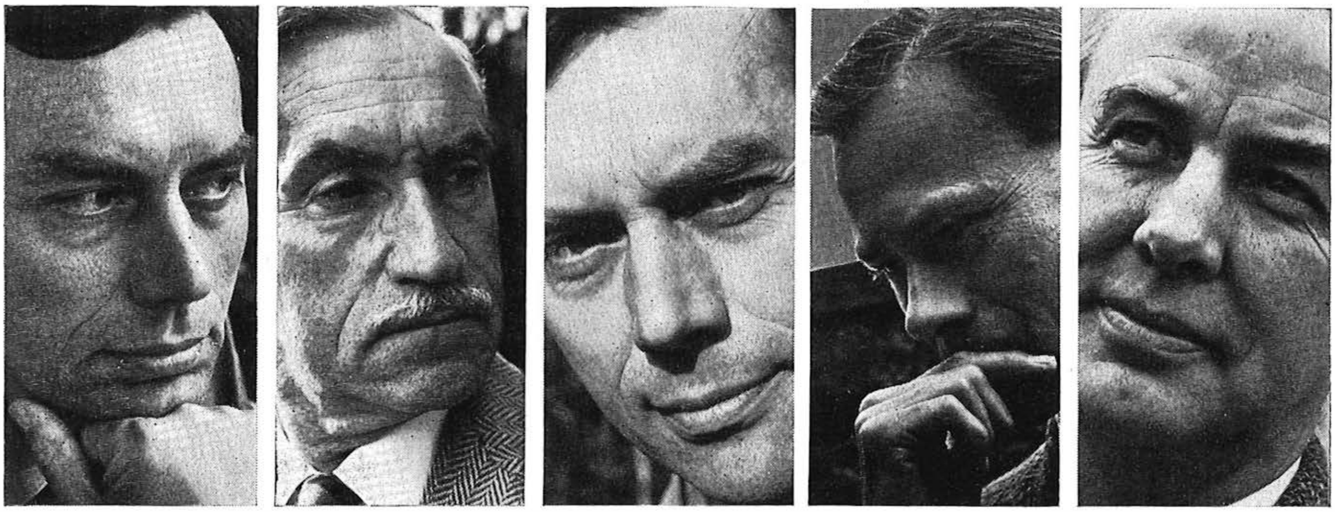

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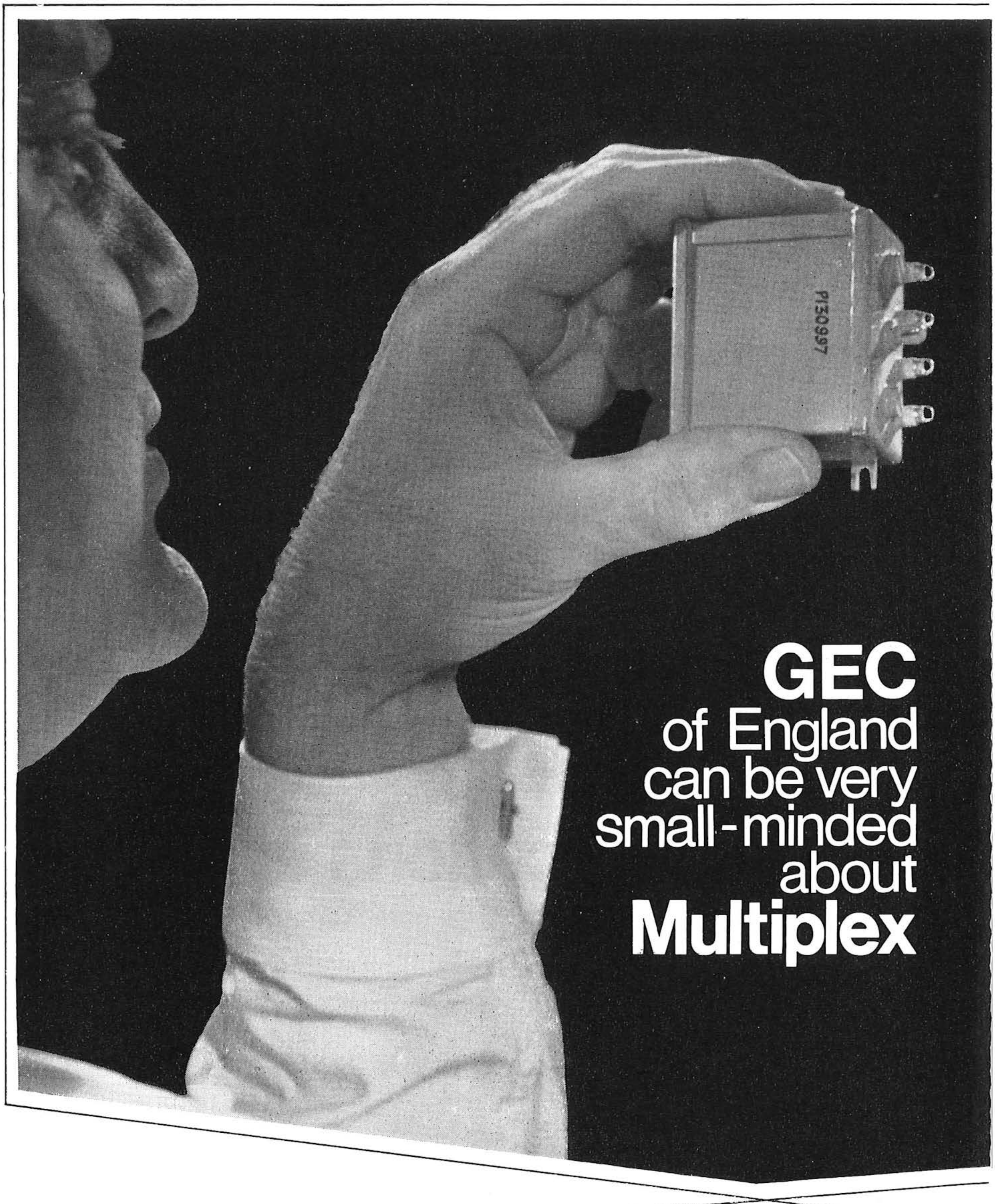

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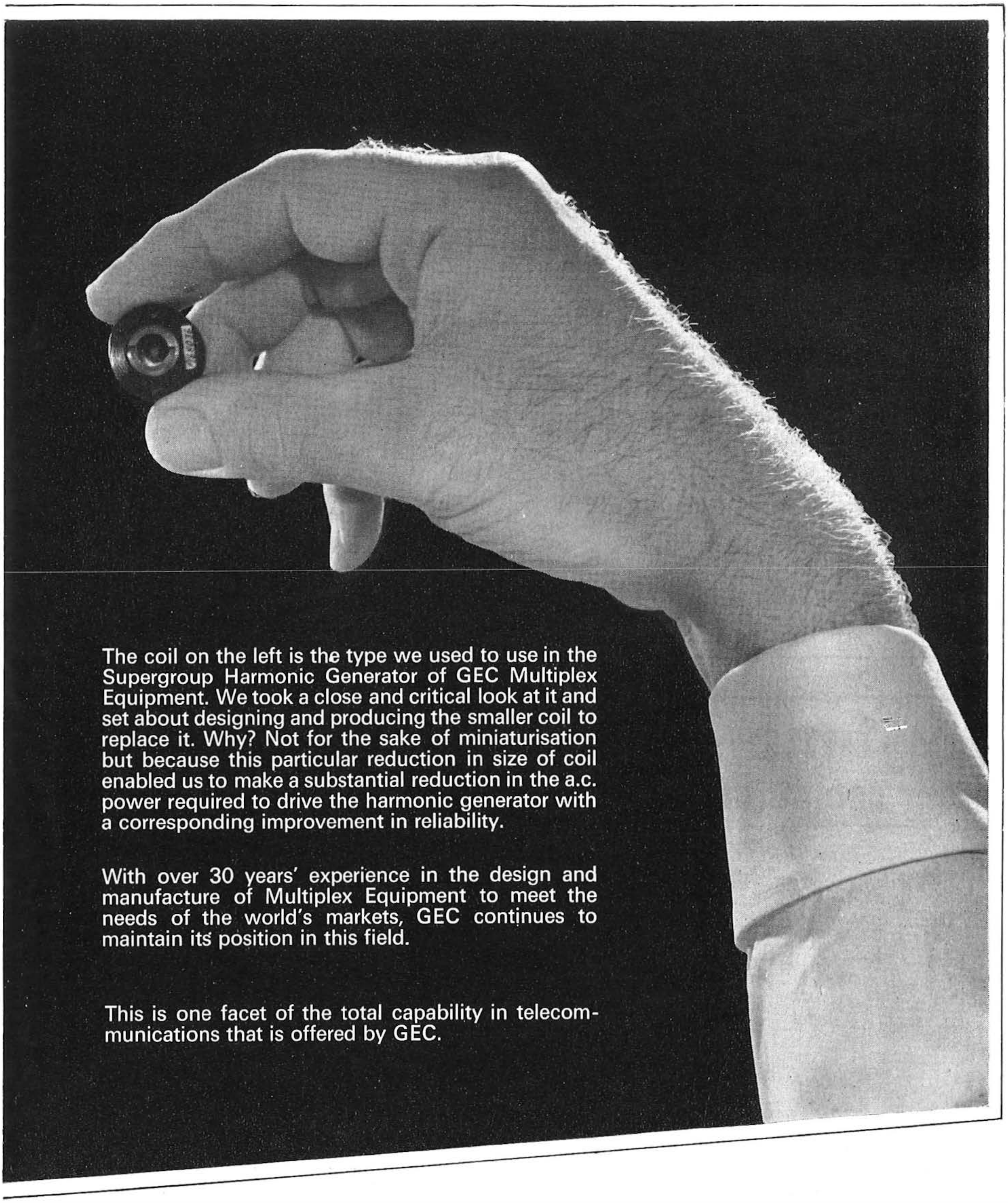

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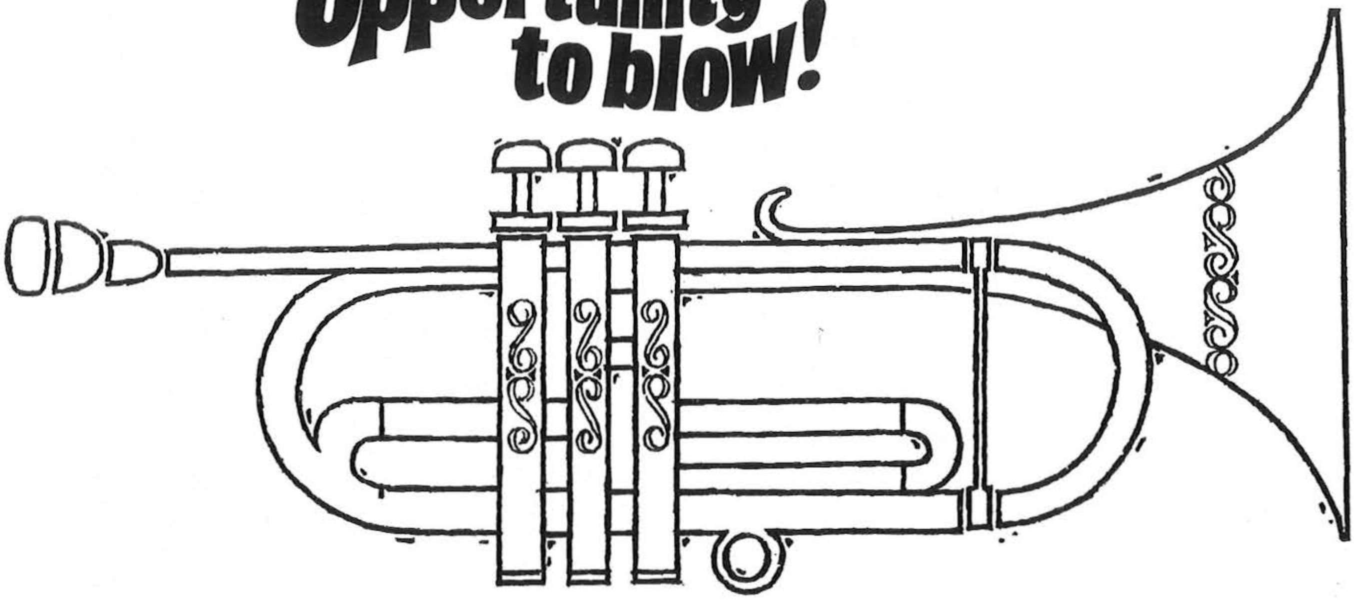

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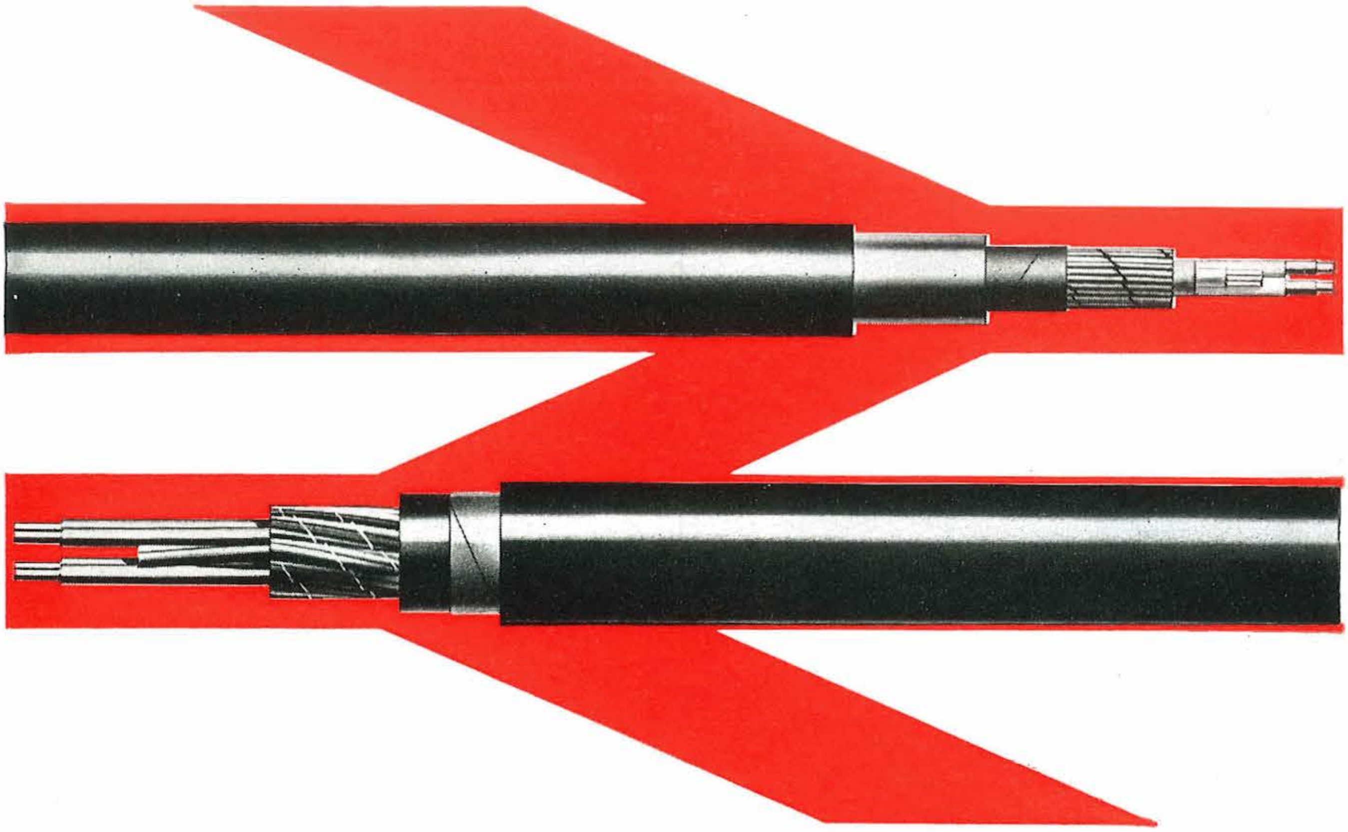

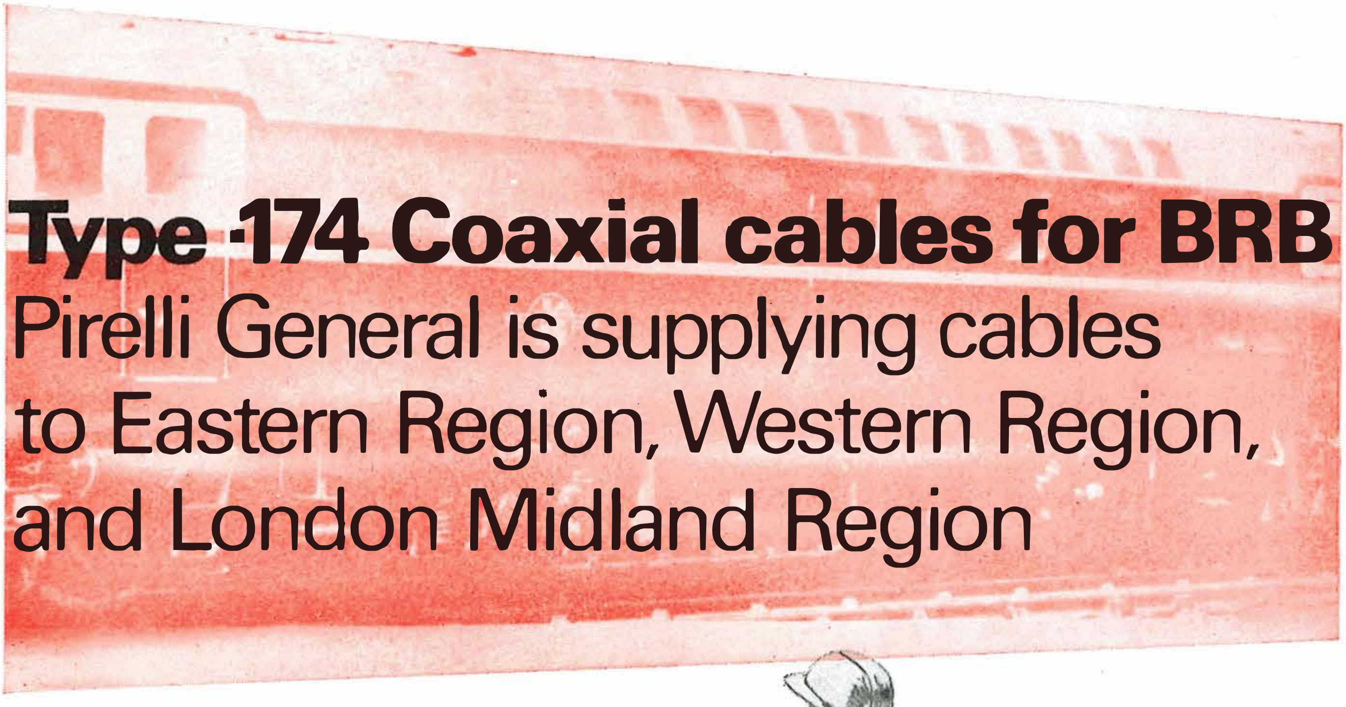

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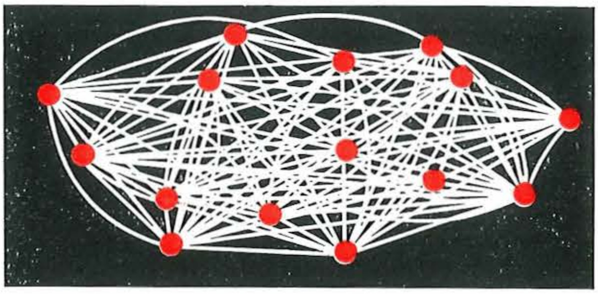

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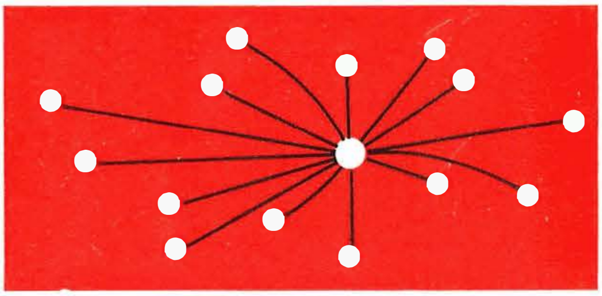

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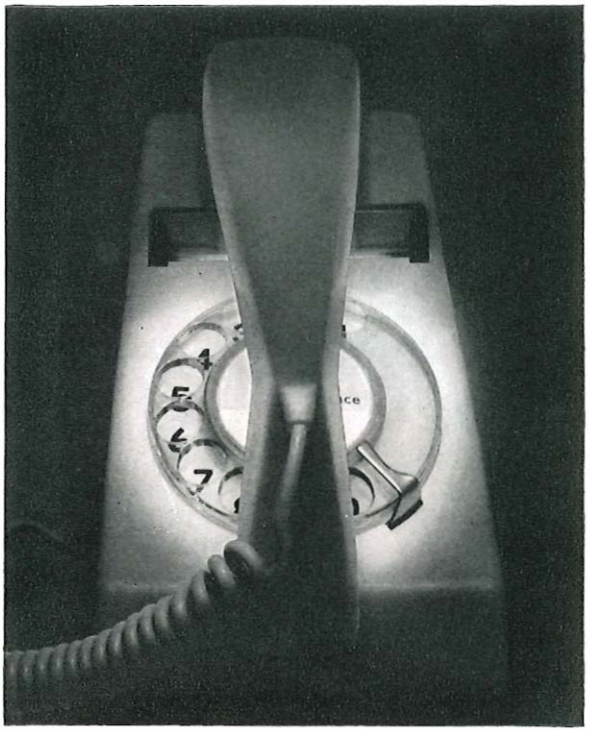

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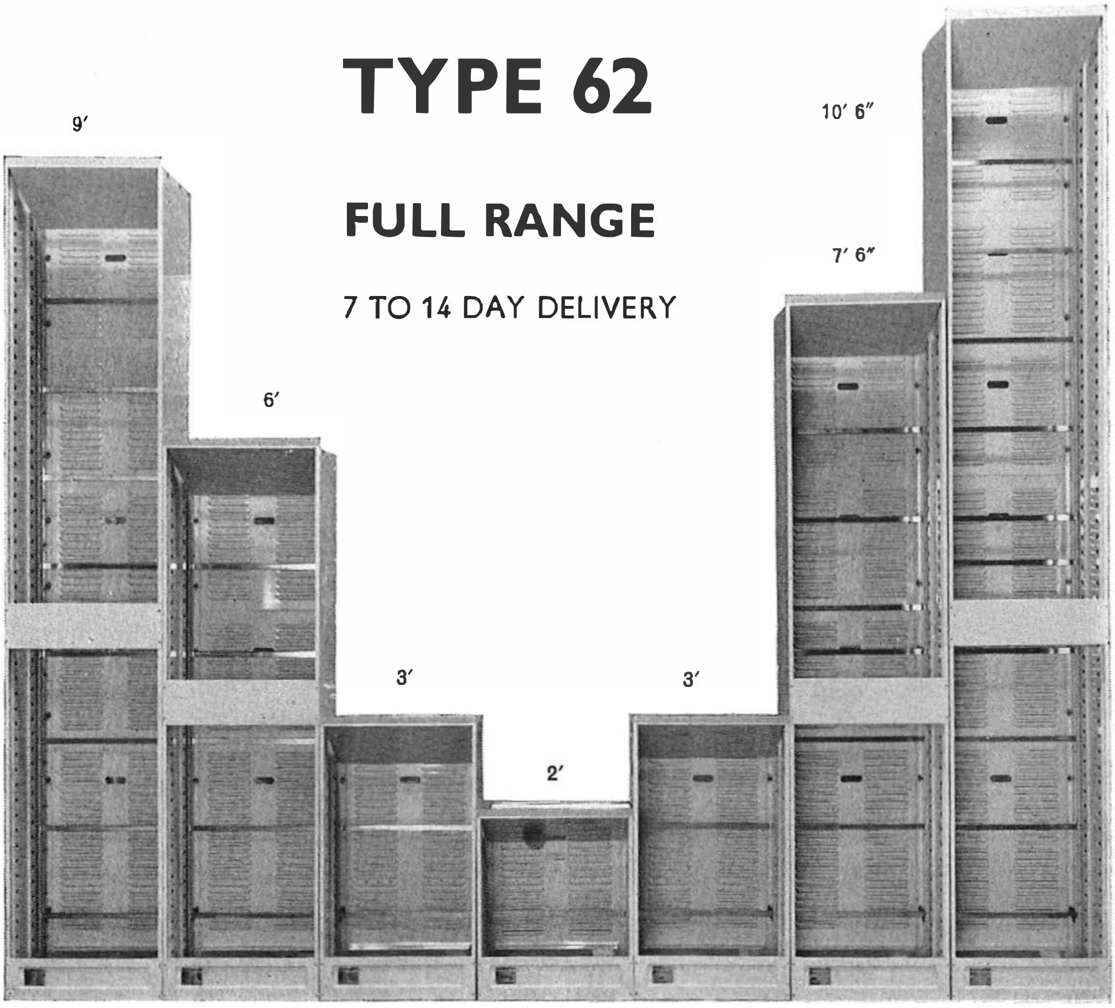

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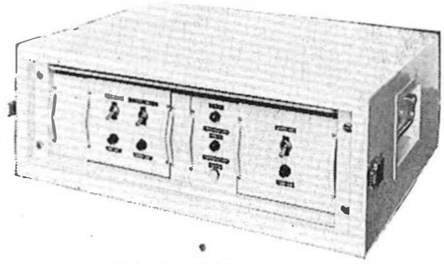

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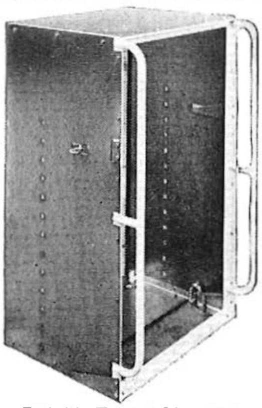

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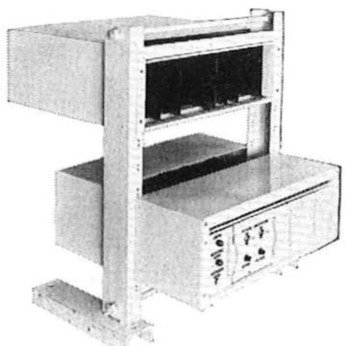

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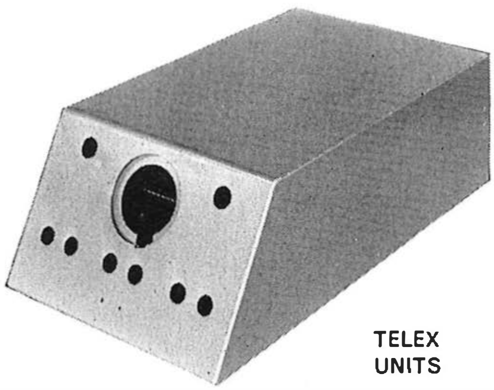

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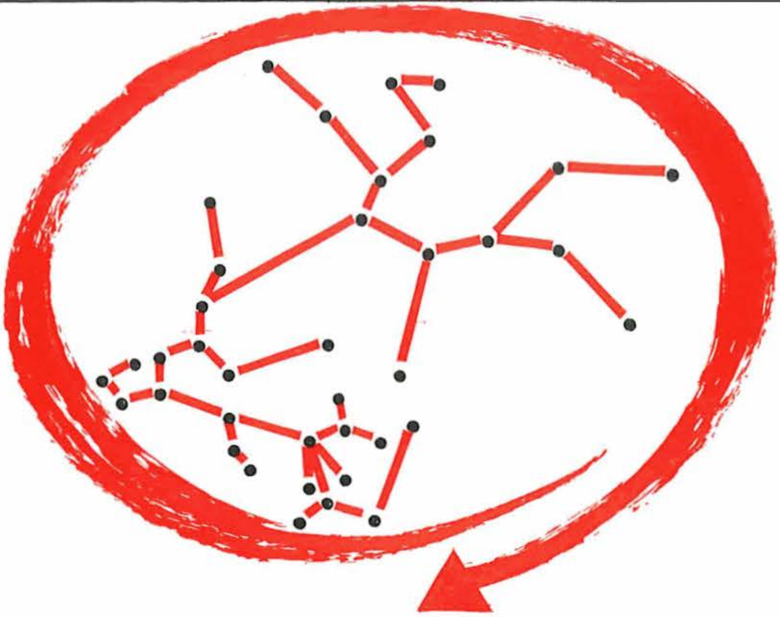

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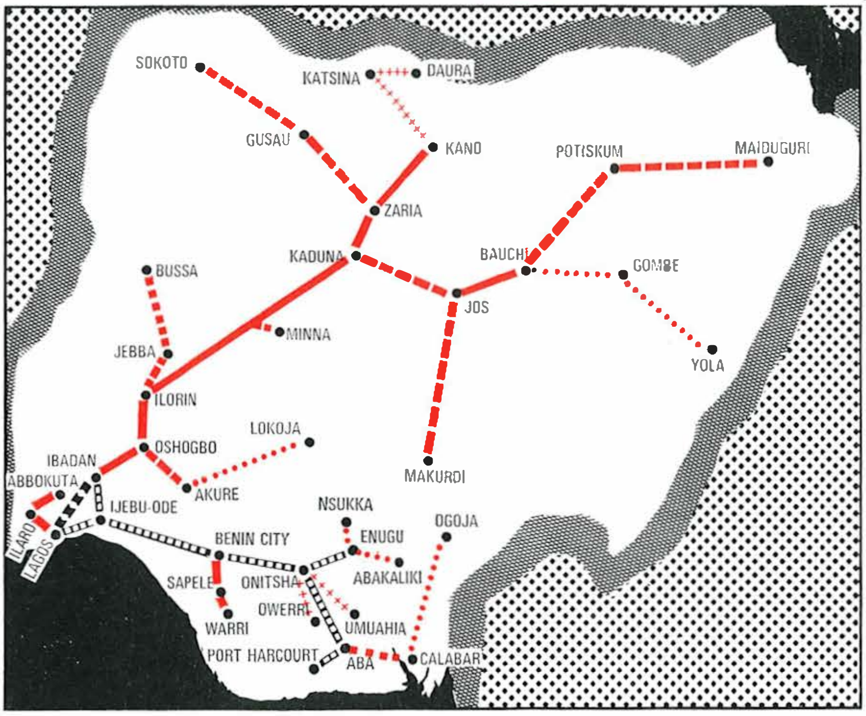

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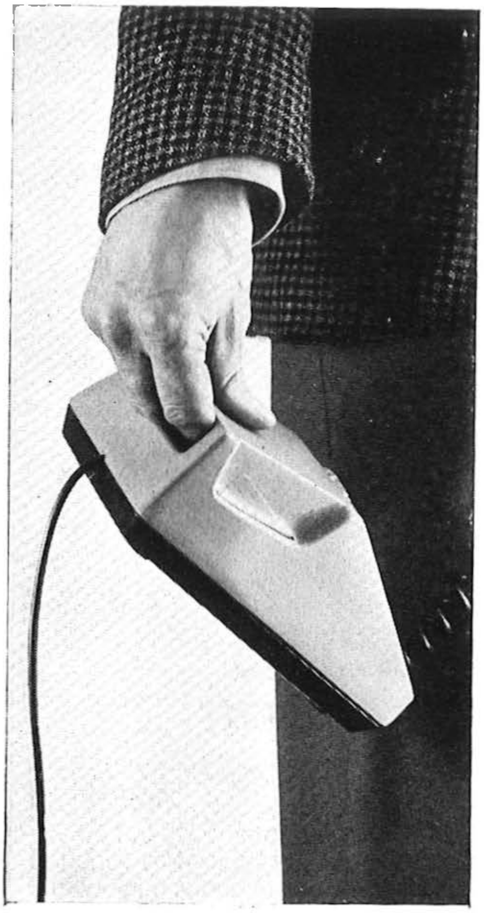

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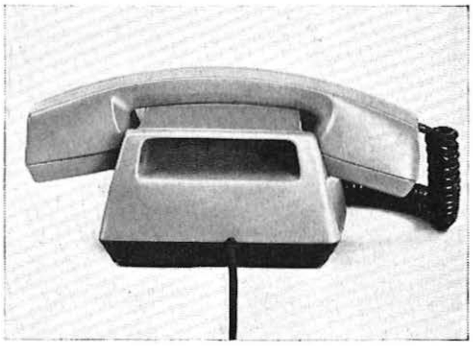

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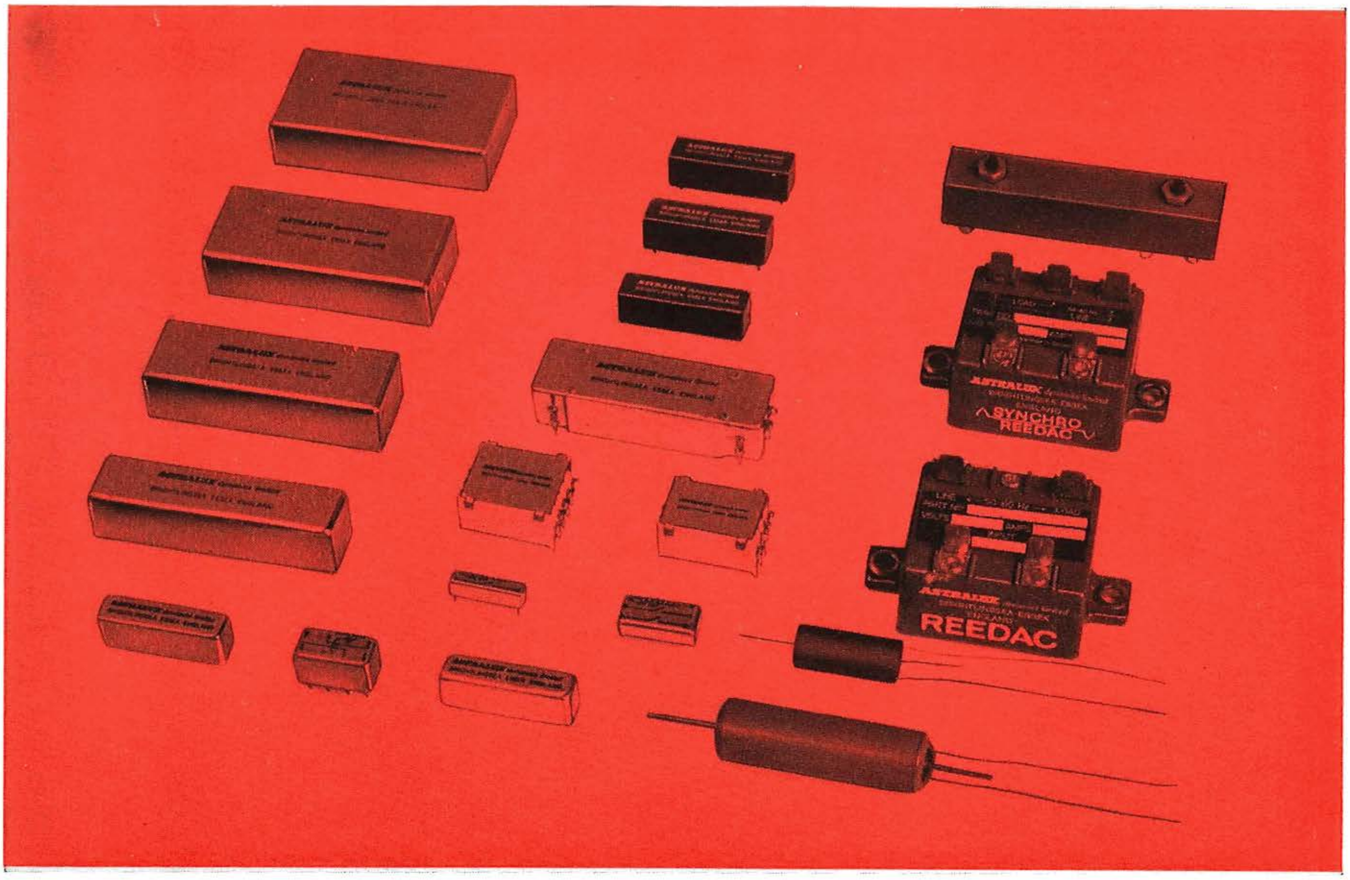

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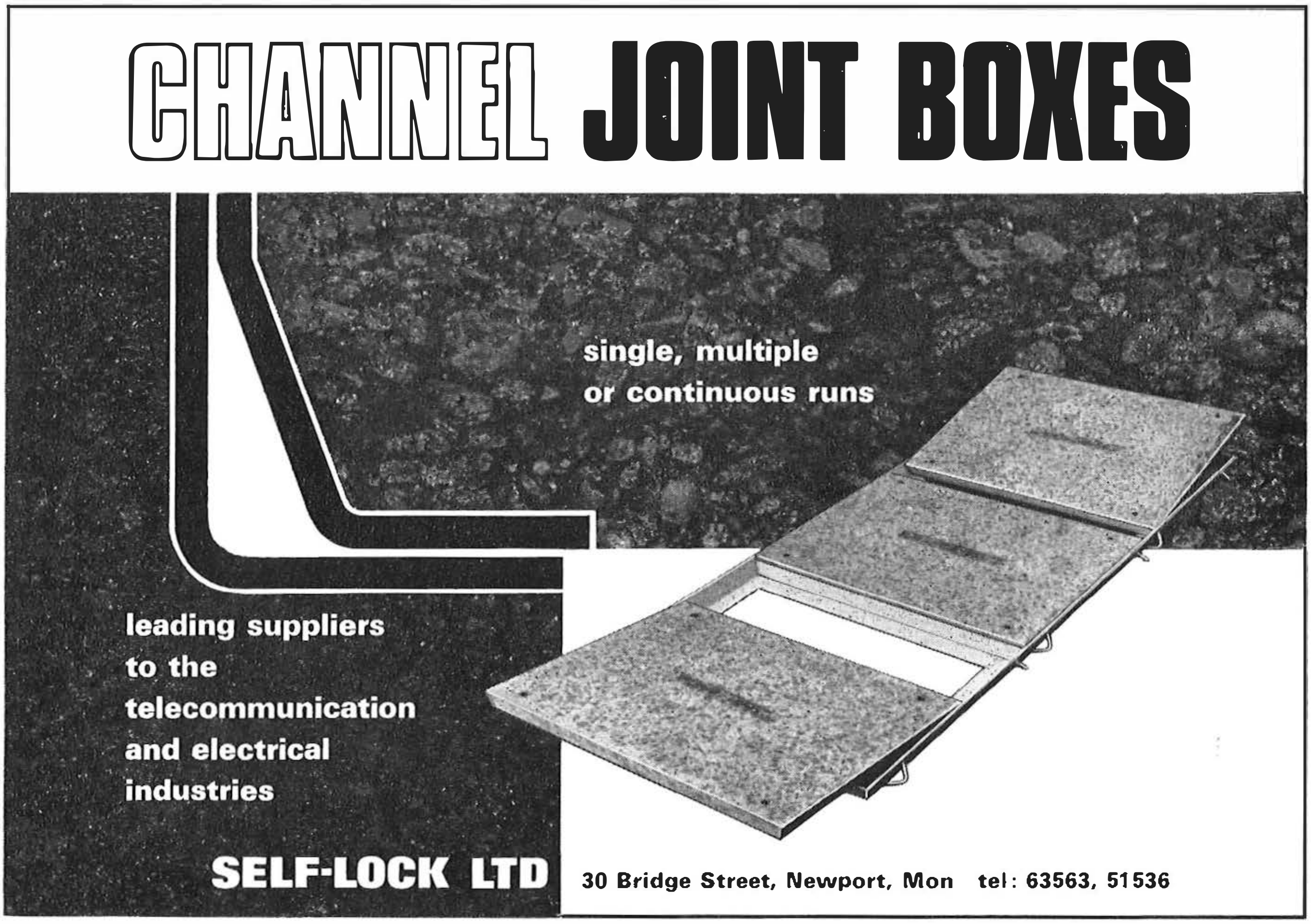

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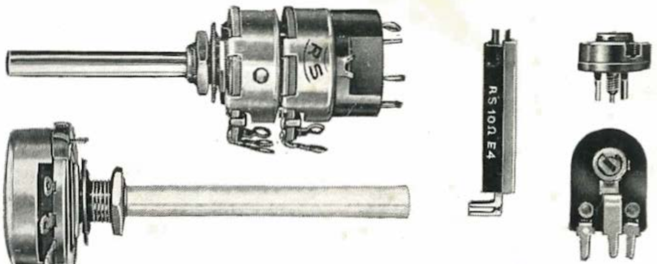

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