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Contents

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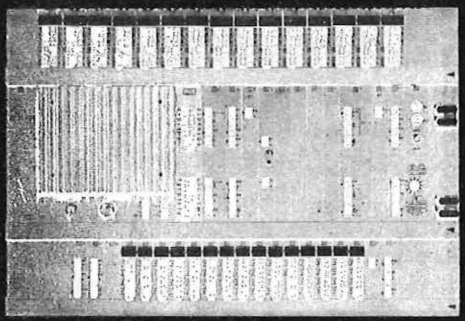

30 CHANNELS PCM MULTIPLEX

CCITT–CEPT specification

E/M signalling units or built in signalling converters for different switching techniques

Facility for data transmission

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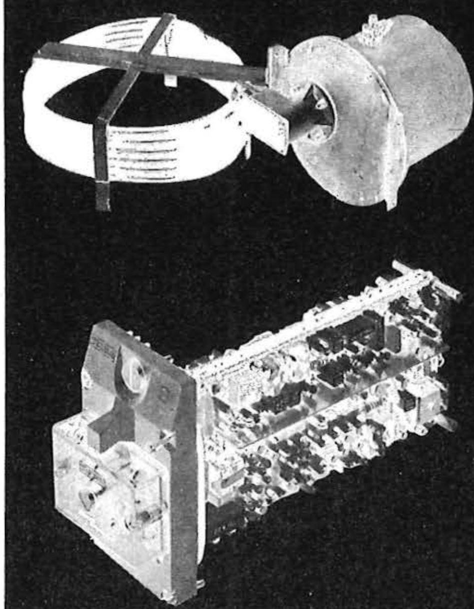

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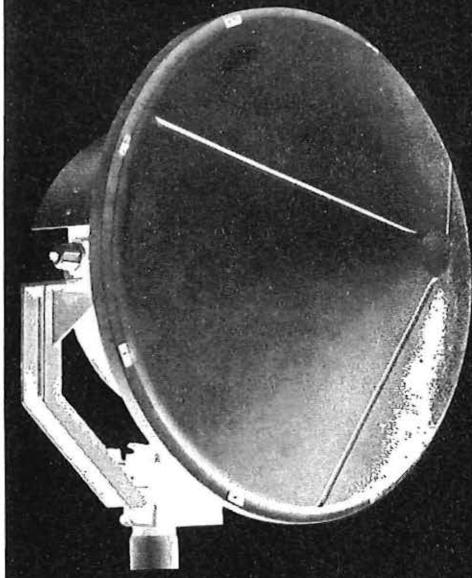
14 stations remotely supervised from each line terminal

Housings in manholes, directly buried underground or pole mounting

H17/30



30 CHANNELS DIGITAL RADIO LINK

13 GHz pole mounting radio equipment with AM/ON–OFF modulation

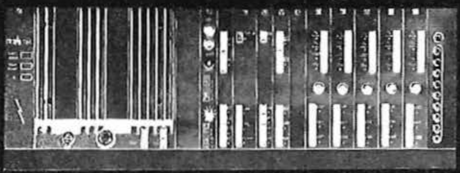
Radio installation up to 2 km apart from multiplex station with remote feeding

20 km typical hop

TELETTRA DIGITAL EQUIPMENTS

UPT 005/74

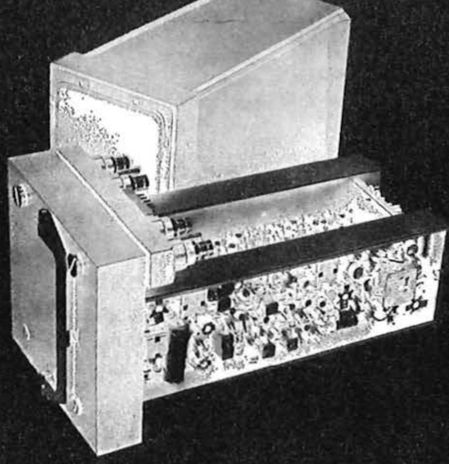
DT2/8-TM
DT8/17-TM
DT8/35-TM



**8.448; 17.152; 34.304 Mbit/s
DIGITAL MULTIPLEXERS**

Digital multiplexers for 2 and 8 Mbit/s digital lines (120, 240 and 480 chs.)

DT8



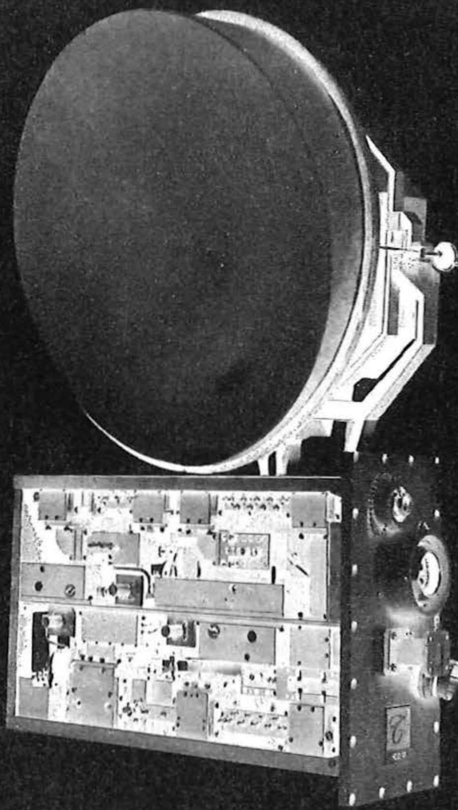
8.448 Mbit/s DIGITAL LINE

4 km regenerative section over microcoaxial (0.65–2.8) or screened symmetrical–pair cable

100 km remote feeding span

Range of application extendable to 34 Mbit lines with 2 km repeater spacing

HD2
HG



**DIGITAL RADIO SYSTEMS
UP TO 34 Mbit**

2– or 4–phase digital modulation

Heterodyne scheme

8, 17, 34 Mbit/s transmission

HD2: operating in the 13 GHz range

HG: operating within FDM CCIR frequency arrangement

over 10 years experience in PCM plant in domestic and foreign market

Telettra VIMERCATE MILANO ITALY

Mullard components for Post Office electronics

Mullard's wide range of optical isolators

Optically coupled isolators are ideal interface components because they provide complete electrical isolation between the input and output circuits, and yet give very effective signal coupling over a broad frequency spectrum.

Eight isolators are now available from Mullard — types CNY22, CNY23, CNY42, CNY43, CNY44, CNY46, CNY47 and CNY47A — the last two meeting most of the parameters of Post Office specification PO18. Each isolator contains a GaAs light emitting diode and a silicon photodetector sealed into an encapsulation.

Mullard isolators do not need to incorporate amplifiers because they have transfer ratios of up to 50%, according to type. In fact, type CNY48, which is still in development, has a photo Darlington receiver with a minimum transfer ratio of 600%. This is in a DIL-6 plastic encapsulation and has an isolation voltage of 2kV.

An exclusive method of assembly ensures that the spacing between the emitter and detector is very closely controlled. This feature provides the high signal-transfer ratio and high input-to-output breakdown voltage rating. All devices are given a high voltage test before leaving the factory.

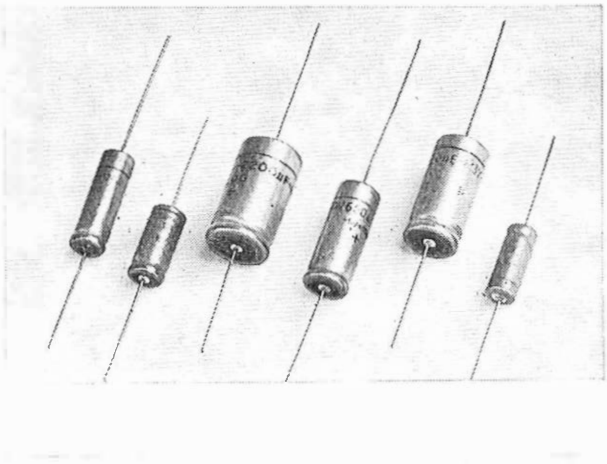
Six of the isolators are in economical plastic encapsulations, while the others are in hermetically sealed encapsulations suitable for applications in severe environmental conditions. In four of the plastic devices connections are 'brought out', while the other two have the photodetector base floating to forward bias the base-emitter junction. A similar arrangement is used for the TO-12 encapsulation. Forward biasing increases the collector-emitter current and makes it substantially greater than the photogenerated current.

Type No.	CNY22	CNY23	CNY42	CNY43	CNY44/46	CNY47	CNY47A
Encapsulation	5-pin plastic	5-pin plastic	4-pin plastic	4-pin plastic	4-lead TO-12 hermetically sealed	DIL-6 plastic	DIL-6 plastic
Min. breakdown voltage (peak)	4kV	2.8kV	4kV	2.8kV	1.5kV	4kV	4kV
Min. transfer ratio	25%	50%	25%	50%	30%	20%	40%
V_{CEO} max.	30V	50V	30V	50V	50V	30V	30V
Turn-on time	5μs	5μs	5μs	5μs	2μs	5μs	5μs

Long life 108 series meets with approval

Everybody approves of Mullard's 108 series of professional electrolytic capacitors. With individual values selected in accordance with the IEC E6 series, the full range now covers 2.2 to 2200μF. The typical lifetime at 85°C of 10000 hours more than satisfies IEC specification 103 (type 1), which only calls for 2000 hours. What's more the requirement of Post Office specification D2186 for a lifetime of 20 years at 40°C is also satisfied.

All connections inside the capacitor can are cold-welded for improved reliability. This method of construction also contributes to the low equivalent series resistance achieved. So does the low ohmic resistance of the electrolyte itself, and the result is that the total reduction in series resistance cuts down the amount of heat generated for any given ripple current. This extends the effective life of the electrolyte—and therefore the capacitor—and gives significantly improved ripple current ratings. Can sizes are kept to a minimum by using special etched foil techniques.



SWITCHED-MODE POWER SUPPLIES NEW LITERATURE

Following the release of the new Mullard FX3700 series of ferrite transformer cores for switched-mode power supplies, a special publication is now available on the various design factors to be considered. Two design examples are given, the first a push-pull transformer in a converter operating from 300V d.c. and giving 5V d.c. at 40A, and the second a similar transformer operating from 50V —the level typically available in telephone applications.

The new publication examines the different winding factors in high-frequency transformer design. Practical aspects of winding and assembly are also considered. A copy of this publication is available from Mullard Limited (quote Ref: CPS/512).

M.012

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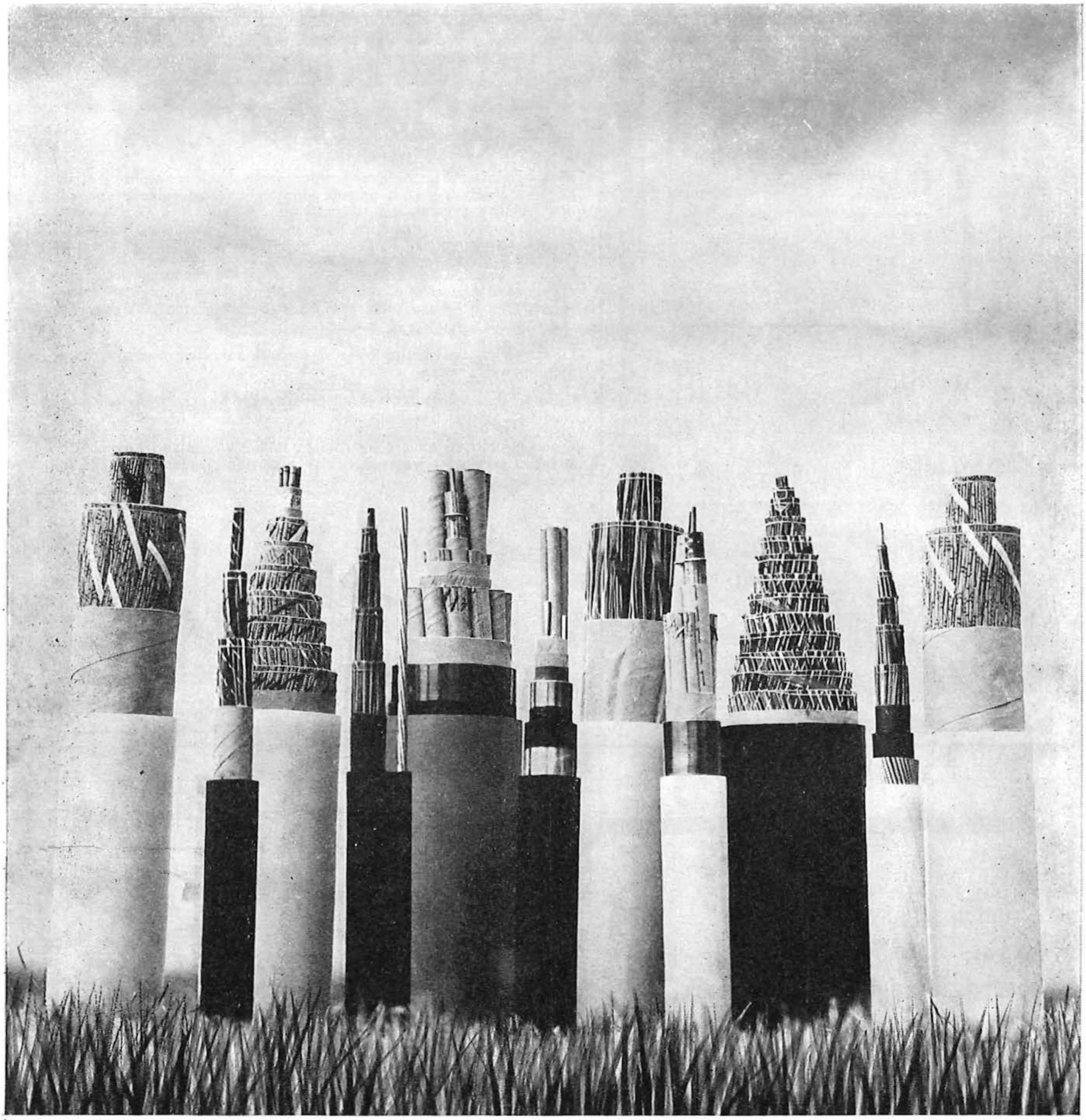

The Post Office Electrical Engineers' Journal

EDITORIAL

The CANTAT 2 submarine cable system was officially opened on 21 June 1974, the inaugural call being made by the Prime Minister, the Rt. Hon. Harold Wilson, M.P., speaking from Huyton, Liverpool, to the Canadian Prime Minister, M. Pierre Trudeau at Deer Lake, Newfoundland. This £30M cable system, which is designed to carry communications between Europe and North America at least until the year 2000 and which was completed two weeks before the contract completion date, represents a major achievement for British technology and British industry. A series of three articles in this issue of the *Journal* describes CANTAT 2, covering such topics as the design of the system, the laying of the cable and some technical details of the terminal equipment. A fourth article describes the principles of satellite navigation, which was used in laying the CANTAT 2 cable.

This issue of the *Journal* also features the first two articles of a series describing some of the studies undertaken by the British Post Office in formulating a strategy for the renewal of local exchanges in the U.K. An introduction to this important subject is given by the Director of Operational Programming, Mr. J. S. Whyte, and the first two articles describe some of the work involved in formulating a future strategy and the principles and facilities of the computer model used to assist in determining the strategy.

Local-Exchange Renewal Strategy: Foreword

For a number of years, the British Post Office (B.P.O.) has been moving progressively towards new switching policies. In the middle 1960s, crossbar systems were introduced into local exchanges and, subsequently, main-network exchanges. About the same time, TXE2, the small reed-relay electronic exchange, was introduced. This is now standard provision in its size range, and over 500 are in service in the U.K.

Further steps forward were taken last year. The first was the decision to introduce TXE4 electronic exchanges on a large scale. A series of articles in the *Journal* in 1972–73 described the technical features of the TXE4 exchange, the steps in its evolution, and the procedures used for the strict control of its development and early production.† Large orders for the system have now been placed, and preparations for mass production by three manufacturers are well advanced.

The second decision was to adopt a policy of accelerated Strowger replacement at local exchanges. These, at present, serve about 12-million customers, and will be replaced over a period of about 20 years by crossbar and electronic exchanges.

Although the evolution of policy is a continuous process, and many more steps remain to be taken in the future, decisions of a magnitude comparable to this one are taken by telecommunications administrations very infrequently. Perhaps, only the change from manual to automatic switching and the introduction of s.t.d. were of comparable significance. Both of these decisions were, however, taken at a time when the system was much smaller, and, in consequence, the capital implications were of a different order of magnitude. Recognizing not only the economic significance of the decisions they would have to take, but also their commercial, industrial, and service importance, the B.P.O. Board insisted that the issues involved be subjected to the most detailed scrutiny. The investigations covered a range and depth greater than for any previous decision taken by the B.P.O.

Of the many studies that were undertaken, those concerned with the economic consequences of alternative strategies were of particular importance, and will be described in a series of articles in the *Journal*, the first two appearing in this issue. The appearance of these articles gives me the opportunity to thank not only the authors of the articles, but also their many colleagues in several parts of the B.P.O., and the U.K. telecommunications industry, who contributed in various ways to the success of the work.

J. S. WHYTE
Director of Operational Programming

† MAY, C. A. Electronic Exchanges: The Steps Leading to TXE4. *P.O.E.E.J.*, Vol. 65, p. 133, Oct. 1972.

DAVIES, E. Management of the TXE4 Electronic Exchange Project. *P.O.E.E.J.*, Vol. 65, p. 247, Jan. 1973.

Local-Exchange Renewal Strategy: Formulating a Strategy

D. L. BENSON, C.ENG., M.I.E.E.†

U.D.C. 621.395.34: 658.15: 332.67

Renewal of Strowger local exchanges with modern equipment raises important issues of policy. The decision by the British Post Office Board to adopt a policy of accelerated replacement followed detailed study of very many relevant factors. Of particular importance were the economic consequences of various potential renewal strategies. This article describes some of the work involved in formulating future strategy, and concentrates primarily on economic studies. The methodology adopted to contain the magnitude of the cost calculations and to achieve reliable results whilst calculating costs up to 30 years ahead are described.

INTRODUCTION

Telephone exchanges are enlarged perodically to provide for growth. As a consequence, there comes a time when the earliest equipment has worn out, but a large part of the exchange, often the majority, is still quite serviceable. The worn-out equipment may be replaced by equipment of the same design, old Strowger racks being replaced by new, but the introduction of modern switching systems has provided a range of alternative options. For example, as Strowger equipment wears out, it may be replaced by starting new exchanges in modern equipment. An old exchange may then be withdrawn from service piece-meal over a period of many years, as each section of the exchange wears out.

Modern exchange systems offer advantages both to customers and to the operating administration. The replacement of Strowger exchange equipment as it wears out involves a process that will stretch over a very long period, extending well into the next century. During this period, some measure of confusion and inefficiency will occur. Another approach, therefore, is to embark on a program for the planned replacement of all Strowger plant within a specified period. This would involve scrapping some equipment before it has worn out. It would also involve higher capital expenditure for

† Operational Programming Department, Telecommunications Headquarters.

many years. However, such a plan would reduce operating costs. It would also enable exchanges to be replaced completely in modern equipment when circumstances are opportune, and it would advance the time when the benefits of modern exchanges are available to all. Clearly, many variations are possible from these examples of options.

Exchange-renewal plans have far-reaching consequences because, in the U.K., they involve fixed assets currently worth some £1,000M, and will affect the financial performance of the telecommunications business for many years ahead. Detailed cost studies are, therefore, an essential ingredient in the process of deciding which, of many potential renewal strategies, is the best one to pursue. This article describes the economic study methods which were used to investigate renewal strategy for large local exchanges.

THE GENERAL APPROACH TO ECONOMIC STUDIES

Cost studies have been based on the well-established *discounted-cash-flow* (d.c.f.) method.[1, 2] This is a method of bringing to account the fact that the real value of money, after adjustment to eliminate the effects of inflation, increases with time. For example, it can be invested and earn interest. Items of cash flow occurring in different years may not, therefore, be added together without an adjustment to reflect this change in value. In the d.c.f. method, this adjustment is effected by *discounting* future cash flows at an agreed *test-discount rate* to bring them to a common base date—the present time. Discounted cash flows may then be aggregated to show the *present value* of a scheme. If two alternative schemes are costed by this method, each produces a present value, and the difference between these is the *net present value* (n.p.v.), this being the conclusion which is usually quoted. A costing period of 30 years has been used, because this is, roughly, the normal life of telephone-exchange equipment.

Normally, all items of cash flow are brought to account in d.c.f. calculations. However, in comparative studies, any item which is unchanged appears on both sides of the comparison and, therefore, cancels out in the n.p.v. Revenue is regarded as such an item, and has, therefore, been excluded from the studies. This flows from the assumption that, whichever strategy is adopted, the telephone service will provide for the needs of customers, and receipts will be unaffected. This simplifying assumption normally operates to the advantage of an existing system, and may, therefore, give an element of protection against over-optimistic forecasts of the benefits of change.

The economics of exchange renewal strategy are complex, and costings are on a very large scale. Over 6,000 exchanges are involved, and they differ greatly in size, rate of growth and local characteristics. An economic study of individual exchanges would be an enormous undertaking. The size of this problem might be contained by studying a range of typical exchanges, but an important consideration is that decisions at individual exchanges interact with each other. They cannot all be renewed at the same time. What is required is a national study, based on an orderly program of renewal, spread over a period of many years, reflecting changes in costs which will flow from implementation of the renewal program.

The scale of a national economic study was contained by using two simple devices. The first device is to use a method of costing which enables a large number of exchanges to be costed in bulk. The second device is to sort exchanges into a few natural groupings.

The idea of bulk costing is not new, but it has not received the widespread recognition that the method deserves. In essence, the method expresses the cost of an exchange in the form of a simple linear formula. The formula brings to account the two main variables that influence the cost of an exchange. These are the number of customers' lines (or connexions) served by the exchange, and the traffic-carrying capacity of the exchange. Traffic capacity may be defined in several ways, and total originated traffic has been adopted as the most useful and convenient definition. Originated traffic is, of course, the number of lines multiplied by the average calling-rate/line. Therefore, originated traffic and average calling-rate are terms which may be interchanged.

The simple linear formula takes the form of

$$\text{cost} = aL + bE + c, \quad \text{for one exchange,}$$

where L is the number of lines provided, and E is the originated traffic, measured in erlangs. The constants a, b and c describe the cost characteristics of a switching system. The per-exchange constant c, for example, is small for a dispersed-control system such as Strowger, and very large for a common-control system such as TXE4.

Many other factors contribute to the cost of an exchange; for example, the proportion of calls which are completed to other customers on the same exchange, but all these factors are assumed to have average values. This assumption could produce a relatively large error for an individual exchange, but, as exchanges are bulked together, errors must progressively diminish.

This formula is used to cost a large number of exchanges in bulk, and so the total cost is a times the total number of lines provided, plus b times the total originated erlang switching capacity provided, plus c times the number of new exchanges started.[3]

The value of this very simple approach to bulk costing lies in the fact that it is not necessary to know the exact location of new equipment. It does not matter whether lines are provided at a new exchange or added to an existing one, nor whether they are small exchanges or large ones. Taking lines, for example, only the total number provided must be known. Basic forecasts for growth are expressed in terms of total national growth, not in the form of 6,000 or so individual exchange growth forecasts, and costs may, therefore, be derived directly from overall growth forecasts.

The fact that secondary cost factors are assumed to have average values does not give rise to serious errors, but greater accuracy can be obtained by segregating exchanges which have fundamental differences. The most important difference is that between director exchanges and non-director exchanges. Other divisions are useful; non-director exchanges may be separated into large, small and very small exchanges: director exchanges may be separated into those located in London and those located in provincial areas. However, each split involves additional data problems. Factors, such as growth forecasts, have to be apportioned to each division, and there are other considerations which are inter-dependent. Experience has shown that three divisions—director, large non-director and smaller non-director—are sufficient to formulate a sound strategy. More detailed divisions can be used in refining a strategy, but introduce unnecessary complexity at the stage when all conceivable strategies are being explored.

Crossbar and TXE4 equipment are involved in two of the three divisions adopted. Economic studies have concentrated on these two divisions, namely director and large non-director. They cover about 80 per cent of all lines, or about 9-million lines at the present time, and these lines are served by some 1,500 exchanges.

BASIC COSTS

Very many factors contribute to telephone-exchange costs. These may be divided into items of capital expenditure and operating costs. The key items of capital expenditure are contract payments and British Post Office (B.P.O.) contract costs. These costs vary with time, even at constant money values, general inflation being excluded from d.c.f. calculations.

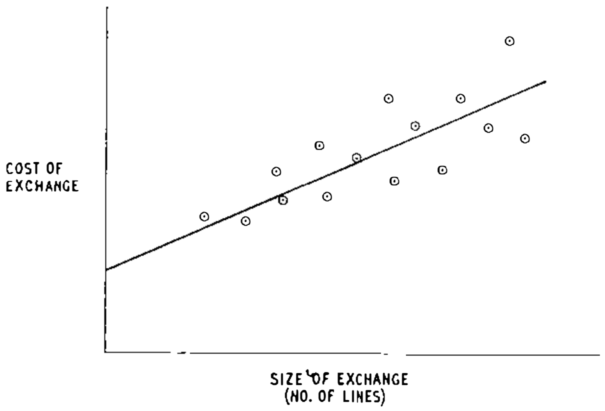

FIG. 1—Cost of a range of exchanges against size

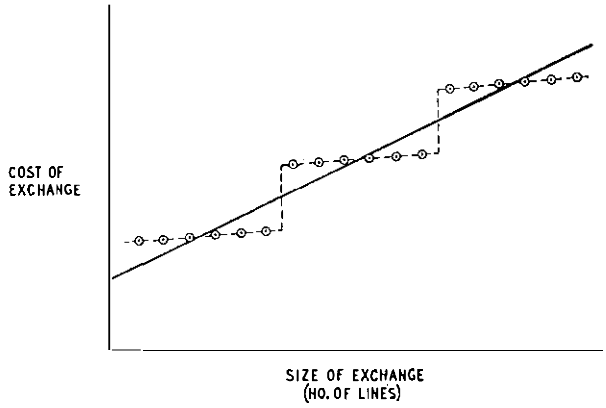

FIG. 2—Change in cost of a particular exchange as size is gradually increased

Moreover, prices are influenced by changing production volumes. Operating costs may be subdivided into maintenance charges and miscellaneous expenditure. These costs are also expected to vary with time, even at constant money values. Each of these key cost factors is discussed in the following sections.

Contract Payments

The cost of buying telephone-exchange equipment is calculated, in bulk, for each year's purchasing program, using the cost formula method referred to earlier. Two methods have been used to establish reliable cost formulae.

The first method is to obtain a large number of actual exchange costs, and to deduce a formula which gives a best fit to these data. Fig. 1 shows a simple example. A number of exchanges are selected which are virtually identical in respect of one of the two variables. Assume that, in Fig. 1, all exchanges have virtually the same average calling-rate, so that *size of exchange* in the diagram means number of lines. Each point on the diagram indicates the cost/size relationship of one exchange. By drawing a best-fit line, a partial solution is obtained. Repetition of this process for several calling rates enables a complete solution to be derived. This is a simple form of regression analysis. In practice, extensive use has been made of the more sophisticated approach of using a computer to carry out multiple regression analysis on all the exchange costs available. This produces a complete formula directly, together with statistical data defining the accuracy of fit. It can be seen from Fig. 1 that individual exchange costs cannot be expected to be represented exactly by the formula; there is a spread on each side of the line because of local differences. It may also be seen that, when a random selection of exchanges is bulked together, these local differences average out.

The alternative method is to explore systematically the way the cost of an exchange changes, as its size changes. Computer programs are available which calculate the cost of a particular exchange against a specification. Typical values can be specified for all minor parameters. One of the two main variables, say, the average calling rate, maybefixed arbitrarily: the other, the number of lines, is then advanced in discreet steps. At each step, the exchange is costed by the computer program. Such a series is illustrated in Fig. 2. The slope is not smooth, steps occurring at intervals. This is typical of a common-control exchange. Usually, these steps can be identified by a knowledge of the system design. It is also usual that the steps occur in different places for different calling rates. Putting a line through the mean of these steps is, therefore, not only convenient, but more accurate for the generality of exchanges. For Strowger exchanges, the steps are very small in amplitude, the plotted points being very close to a straight line. The full formula can be derived by repeating the process for other calling rates, or by fixing the number of lines and varying the calling rate.

Each of these methods has its advantages and disadvantages. Between them, and the many variations that are possible, formulae have been generated which have more than adequate accuracy for their purpose, namely to cost exchanges and extensions in bulk.

B.P.O. Contract Costs

These costs are the administration's costs associated with contract work. The main items are acceptance-testing and clerk-of-works' costs. These costs could be defined by formulae in the same way as contract payments. In practice, they have been applied as an overhead, or percentage addition, to contract payments. A formula would increase precision, but, so far, the added accuracy that this might yield has not justified the extensive cost analysis that would be required.

Capital Cost Trends

Costs are expected to change with time, even when the effect of changing money values is excluded, and the cost of different systems will change at different rates because they have different proportions of raw materials, labour, etc. Much effort has been spent on assessing what these trends might be. Since forecasts of this sort must inevitably be highly subjective, it is important that, whatever the standards chosen, they are applied equally to each strategy when two strategies are being compared. This equality of application eliminates a lot of potential error in comparative studies.

In considering capital costs, informed opinion was obtained from consultations with economists, experts in commercial contracts and manufacturers of telecommunications equipment. The procedure adopted was to analyse the total cost into component parts. At first, many component parts were considered, but, as the debate continued, it was agreed that as few as five would be adequate. These were

(*a*) raw materials,
(*b*) manufactured materials (resistors, transistors, etc.),
(*c*) special items (for example, reed-relay inserts),
(*d*) labour, and
(*e*) short-term fixed costs (for example, buildings).

Each of these components was then allocated a future trend in real terms, bearing in mind that they must be consistent, one with the other, and must allow for both rising costs and improved productivity. This is where debate was most useful, and many views were expressed before trends for these basic component parts were agreed. Alternative views were later tested to find out how much they influenced results.

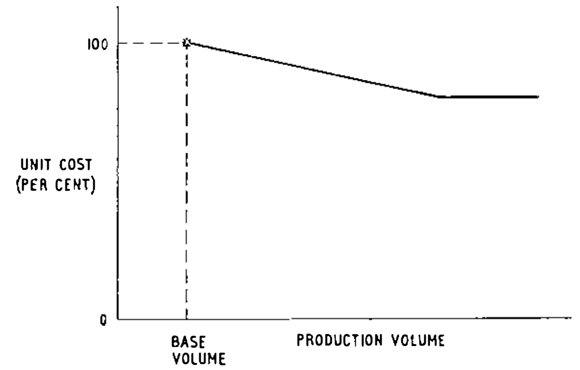

FIG. 3—Volume variation of a modern switching system with rising production levels

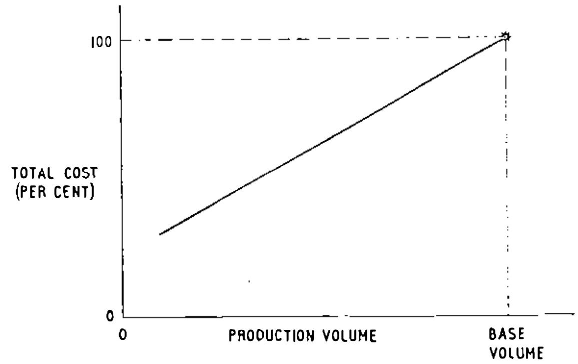

FIG. 4—Volume variation of Strowger equipment with falling production levels

In parallel with the main debate, the cost of each switching system was analysed to see what proportion of the total fell to each component. Finally, it was a simple matter to determine the trend for each component separately, using the agreed trends, and then add together the component parts for each year. In this way, cost trend factors, for each year of a 30-year period, were produced for each switching system. It can readily be seen that this process achieves the equality of treatment between switching systems that was required.

Influence of Production Volume

Changing production volumes are expected to affect the price of equipment. This is known as the *volume variation*. Changes in volume arise from the administration's purchasing program, and this, in turn, reflects the strategy adopted. The strategy, therefore, affects the volume variation; this contrasts with cost trends which are quite independent of the strategy.

To assess the effect of production volume on price, each of the component parts of the price was separately assessed for each modern system by commercial contract advisers to determine the variation to be expected as volume varied. Simple arithmetic brings the component parts together for each volume estimated. The final step was, for each system, to fit a straight-line progression from the base volume up to the maximum volume expected to result in cost savings. Typically, a maximum saving of a few per cent was predicted at a volume several times the base level, as illustrated in Fig. 3.

In the case of Strowger equipment, production volume is expected to fall as the change to modern systems gets under way. The advisers, therefore, estimated the effect on cost of falling volumes. In this case, the unit-cost/production-volume relationship proved to be non-linear, but taking the total cost of the overall volume instead of the unit price, a good linear relationship was established. This is illustrated in Fig. 4, which shows that the line, if extended, would not pass through the origin. There is, therefore, an implied cost at zero production level, indicating a unit price that is rising more steeply as the volume becomes smaller.

The foregoing refers to the volume variation of each switching system in isolation. However, some of industry's overheads are independent of system; for example, the cost of running a manufacturer's head office has to be recovered from selling prices, regardless of the system being sold. To cover this situation, a further sophistication was introduced in the form of an independent constant which operates on the total value of all systems. Thus, a small proportion of total expenditure is viewed as a constant, whilst the bulk of expenditure varies with volume in the normal way.

Maintenance Costs

Maintenance costs are calculated in bulk by using linear formulae, which are applied to the total quantity of equipment in service. A special investigation was undertaken to establish and validate formulae for each category of switching plant. This work, which will be described in a later article in this series, was based on two complementary methods.

A very large number of Strowger exchanges are in service, and it was possible to select a statistically-acceptable sample for regression analysis. It was, therefore, possible to derive and to validate formulae against actual achievement in the field.

The regression analysis method could not be used for modern systems because insufficient field experience of crossbar exchanges had been accumulated at the time of the investigation, and there was no experience at all of normal working TXE4 exchanges. This problem was important because maintenance savings with modern systems is one of the main arguments in favour of replacing Strowger equipment. However, experience with many hundreds of TXE2 small electronic exchanges enabled an alternative method to be adopted. This was to make a theoretical assessment of the maintenance requirements for crossbar, TXE2 and TXE4 exchanges, using uniform methods and data. The result so obtained for TXE2 exchanges was compared with the conclusions obtained by regression analysis of actual exchange requirements, and with the total man-hours actually expended. The achievement of good alignment was taken as confirmation that the theoretical approach was well founded. The theoretical conclusions for TXE4 exchanges are, therefore, also regarded as being well founded.

The assessments showed that, after an initial settling-down period, crossbar exchanges are likely to require about half the maintenance attention of Strowger exchanges, and that, in turn, the requirements of TXE4 exchanges should approach half those of crossbar exchanges. The reduction of the maintenance requirements that can be achieved is limited because some work, for example, power plant maintenance, is virtually independent of the type of switching system.

Miscellaneous Operating Costs

The second subdivision of operating costs is an aggregation of miscellaneous items, the principal one being the cost of power consumed. These costs are brought to account as an overhead on maintenance cost. The use of formulae for each item would, of course, provide greater precision. However, the analysis work needed to achieve this precision was not justified because early sensitivity tests showed that these items had little influence on comparative results.

Operating Cost Trends

The main operating cost is maintenance, in which there are two significant factors, the cost of labour, and the efficiency with which labour is used; that is, productivity. The trend in maintenance labour cost is linked directly to the trend used for manufacturing labour, mutual consistency being a prime objective. Productivity improvement has been estimated against the background of a decade of experience in its measurement in the field. A significant factor is that modern systems will have an excess need in their early years, when teething troubles may arise and experience is being built up. A substantial allowance is made for this on a sliding scale. It applies during the first years at each new exchange, when the system has low penetration.

ADDITIONAL CONSIDERATIONS

The foregoing describes the main cost factors involved in economic studies. However, a great deal of additional information is required before calculations can begin. The more important items of information include production constraints, growth forecasts, rate of wearing out of Strowger equipment, and non-recurring items of expenditure. Data for each of these items has to be provided for each year of the 30-year study period, for each of the network groupings adopted. Another requirement is information to define the extent to which recovered Strowger equipment may be re-used, and the costs involved in doing this.

The residual value of equipment at the end of the costing period has to be established, so that an appropriate credit may be brought to account. These residual values are determined from the proportion of unexpired natural life of each year's purchases at the end of the 30-year period, and the basic value of the system at that time. The basic value for modern systems is assumed to be the price of the cheapest modern system available at that time.

The methodology which has been described may be used to calculate the present value of a strategy. Definition of a strategy requires the unambiguous specification of all requirements. This includes definition of the role to be played by each switching system, production constraints applicable to each switching system and the rate at which Strowger plant should be replaced.

COMPUTER MODELLING

An enormous number of individual calculations are involved in producing the present value of a strategy. For this reason, early manual calculations were quickly abandoned in favour of calculations by computer. However, use of computers has enabled much more to be achieved than speed and accuracy. Progressive development over several years has produced a sophisticated computer model[3] which contains considerable embellishment of the basic methodology, and can calculate a series of present values in a few minutes. This model produces a wide range of analytical detail and supplementary data as a by-product of the main process.

This computer model has been used to compare the present value of pairs of alternative strategies and so produce the n.p.v. Normally, one strategy is selected as the base for comparative studies. The most convenient base is a strategy of pursuing the course that would be followed if no policy change were taken; that is, *carry on as before*. This is then compared with a postulated strategy such as *progressively replace Strowger exchanges with new crossbar exchanges, and do this at such a pace that all Strowger exchanges are replaced by the year 2000.* Of course, much more detail is required to define a strategy fully, but this brief statement is sufficient to indicate an example. The model will determine the n.p.v. of this comparison and, hence, whether the strategy being considered is more economic, or less economic, than the base strategy. However, the model goes further than this and will provide a series of comparisons in one continuous run, covering a range of target completion dates for accelerated replacement strategies which are otherwise identical.

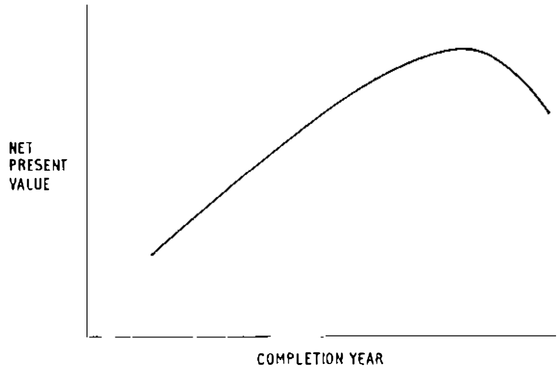

Fig. 5—Characteristic curve for n.p.v. of an accelerated replacement strategy plotted against target completion date

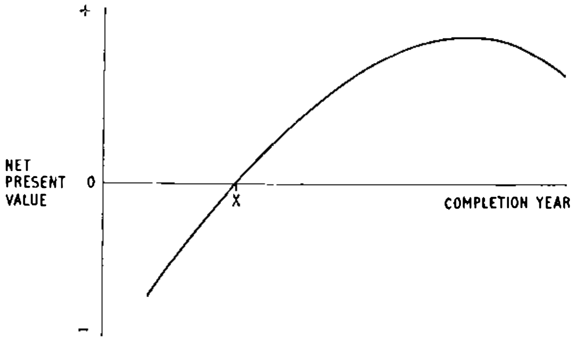

Fig. 6—Curve of accelerated replacement strategy having n.p.v. which is economic for target completion dates later than year *x*

INTERPRETING ECONOMIC RESULTS

If the present value of a strategy to accelerate the replacement of Strowger plant is less than the present value of the base strategy, then the acceleration strategy is more economic because, when the total outgoings are discounted, they are lower. The convention has been adopted that the difference, the n.p.v., should be described as being positive in this situation. The convention is, therefore, that the n.p.v. is the present value of the base strategy minus the present value of the acceleration strategy.

If the n.p.v. for a particular accelerated replacement strategy is plotted against a range of target completion dates, a typical result might be as shown in Fig. 5. The following observations may be made.

(*a*) As the graph rises, the strategy being considered becomes more economic.

(*b*) As the line moves to the right, the later is the completion date.

(*c*) The maximum value for n.p.v. indicates an optimum completion date from the economic point of view.

(*d*) The scale for completion dates varies very much according to the strategy being considered. With some strategies, the scale in Fig. 5 would range from 1980 to just beyond the year 2000. With other strategies, the optimum will fall well into the next century beyond the normal range of the model. In this case, the model will, therefore, provide points on the left-hand rising part of a curve like Fig. 5.

(*e*) The vertical scale may lie wholly within a range of negative values, indicating that the strategy is always less economic than the base strategy. Alternatively, zero n.p.v. may intersect the graph as shown in Fig. 6. This would indicate that completion before the date of intersection, *x*, is less economic than the base strategy, but that later completion is more economic.

The characteristic curve of Figs. 5 and 6 arises from the influence of three underlying factors. These are that

(*a*) as the completion date is postponed, so capital expenditure on replacement exchanges is postponed and, by being discounted more heavily, this improves the n.p.v.,

(*b*) as the completion date is advanced, the less becomes the quantity of new Strowger plant that will have to be purchased for growth at exchanges awaiting replacement, plant which will be scrapped after a short life, and

(*c*) as the completion date is advanced, so the onset of maintenance savings is advanced.

The first trend acts in opposition to the other two. In general, the first trend predominates for early completion dates and produces the rising curve on the left-hand side of Fig. 5. The other two trends tend to become predominant for later completion dates and, together, produce the falling curve on the right-hand side of Fig. 5. Between these two lies the optimum.

Various strategies can be placed in their order of merit, or ranking order, by means of their n.p.v. Early results and experience enabled the wide range of potential strategies to be reduced to about six key ones. These included the base strategy. These key strategies were then subjected to detailed examination and exhaustive tests, including sensitivity testing. If, in the course of these tests, ranking orders remain unchanged despite major changes in the assumptions, then it is concluded that the ranking orders are firm. On the other hand, if ranking orders constantly change throughout sensitivity testing, then it is concluded that there is little to choose between them on purely economic grounds, and a choice may be based on other considerations.

The establishment of ranking orders, and the degree to which these cannot be upset, form the essential conclusions of economic studies. The studies do not aim to forecast with great precision the out-turn of costs over the whole of the 30-year period examined. Although cash flows are accurate at the beginning of the study period, they become more conjectural the further ahead they are predicted. However, since results relate to the differences between strategies, and identical predictions apply to the strategies being compared, ranking orders reveal how strategies will compare over a wide range of future possibilities.

Reference has been made to sensitivity testing. In essence, this means establishing the sensitivity of the n.p.v. to changes in the values of individual input parameters. A typical conclusion might be that, if a particular parameter is increased by 10 per cent, the n.p.v. falls by £5M. Sensitivities will vary from one comparative study to another. Sensitivity tests were carried out at an early stage in the studies to identify the more important parameters. These parameters were then investigated as thoroughly as possible, and much of this work has been described earlier under basic costs. The relationships established by sensitivity testing enable a numerate view to be taken of potential risks. As such, they are an important contribution to the process of formulating a practical and realistic strategy.

SUPPLEMENTARY INFORMATION

A number of by-products are obtained from the work of economic studies which are of considerable value in the process of selecting the best strategy to pursue. An example of this is the effect a postulated strategy will have on manpower requirements. Obviously, a sudden increase, or a sudden decrease, in manpower presents severe administrative and social problems. The computer model estimates manpower requirements, year by year, from the data it has calculated, and prints-out the answers.

EFFECT ON PROFIT

The economic studies show by the n.p.v. whether, or not, an alternative strategy is profitable over the whole of the 30-year costing period embraced by the study. A policy of accelerated replacement will usually mean higher capital expenditure in the early years with reduced operating costs in the later years. The profitability of the business, as shown in the annual accounts, will raise important issues as a consequence. A second computer model was developed to expose these issues. This model is supplied with capital expenditure and operating costs for each year from the main model. It is also supplied with data to permit annual depreciation payments to be calculated; that is, past equipment purchases, past depreciation payments and average lives of the plant that will be achieved. Finally, the model is supplied with a forecast of inflation rates and corresponding interest rates. From these data, the model calculates and prints-out items such as year-by-year forecasts of interest payment, depreciation and overall effect on annual profit.

CONCLUSIONS

The studies which have been undertaken have

(*a*) exposed the n.p.v. results for various strategies and, hence, ranking orders,

(*b*) given an understanding of cause-and-effect relationships, including sensitivity analysis, and

(*c*) provided a range of supplementary information.

Information of this sort enables an administration to make soundly-based policy decisions, weighing economic advantages, or disadvantages, against many other factors which have to be given due weight.

The studies, which have been described, began in 1969 when the earliest manual calculations suggested that the accelerated replacement of Strowger plant might be an economic proposition. Development of the computer model was put in hand at once, and the first output was obtained early in 1970. Since that time, an accelerated replacement strategy based on the use of the TXE4 system at large local exchanges has consistently ranked better than any strategy based on the use of crossbar equipment to replace Strowger plant over a comparable time scale. Although crossbar equipment can be more economic than Strowger for new exchanges which need to be provided, the margin is insufficient to justify its extensive use on economic grounds as the basis of an accelerated replacement strategy.

ACKNOWLEDGEMENTS

Many people were involved in the economic studies which have been described. The author wishes to acknowledge their contribution to the success of this major undertaking.

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Local-Exchange Renewal Strategy: A Model for Decision

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U.D.C. 621.395.34: 658.15: 332.67: 681.3.001.57

The British Post Office (B.P.O.) Board decision to improve the quality of telephone service by renewing the large local-exchange network followed one of the largest and most comprehensive economic studies ever undertaken by the B.P.O. At the heart of this exercise was a sophisticated econometric computer model of the large local-exchange complex. This article describes the principles and facilities of the model that assisted in determining the exchange-equipment strategy of the future.

INTRODUCTION

The British Post Office (B.P.O.) Board has authorized a program of accelerated renewal of large local telephone exchanges with a modern switching system. This followed a very comprehensive analysis of the capital investment and operational costs involved. It was necessary to bring to account very many factors, such as those relating to growth of connexions, traffic, capital and maintenance costs of various switching systems, future trends in equipment and labour costs and the possible utilization of recovered Strowger equipment. Various rates of replacement of Strowger plant and the use of modern switching systems meant that different renewal strategies could be formed. These were then costed, using normal investment-appraisal techniques, to ascertain the relative profitability of one strategy to another. Clearly, the time involved in processing the multitude of calculations for the variety of studies necessary was beyond reasonable manual capability, and a computer was, therefore, employed.

The study required the development of a model to simulate the evolving telephone-exchange population and cost the processes involved in procuring equipment for its developing needs. The objective of the model, however, was not to produce a single optimum strategy, but to provide the decision-takers with information on the likely consequences of different courses of action open to them.

The general methodology for formulating a strategy for local-exchange renewal is described elsewhere,[1] and this article describes the principles and facilities of the econometric computer model that was at the heart of the exercise.

DEFINITION OF A MODEL

In the context of this work, a *model* refers to the representation of a system, network, or other quantifiable situation, in mathematical terms, such that algorithms or equations can be composed to described that situation. The problem involves, firstly, the logical understanding of the circumstances surrounding the situation, and then, the expression of those circumstances in terms that reflect the situation as accurately as is reasonably possible. In a simple form, a quarterly electricity bill may be based on a price p pence/unit of electricity consumed u, plus a standing charge of s pence. A mode of the total bill t would, therefore, be

$$t = pu + s \text{ pence.}$$

The following example from the simulation studies shows how a practical circumstance in the maintenance of a telephone network may be represented in algorithmic form. Assume that the amount of maintenance effort required for a modern-system exchange has been determined under the conditions of a centralized-maintenance procedure; that is, where a number of exchanges are grouped together to achieve greater efficiency of the maintenance effort available. However, until a sufficient number of exchanges are in service in one maintenance area, it is assumed that the effort required for maintenance will, for a time, be increased by a certain factor. Fig. 1 shows the situation in a form that can be represented by a simple linear equation. When fewer than y exchanges are in service, the normal maintenance effort would be uplifted by a factor x (typically 1·5). When z or more exchanges are in service, no uplift is applied, and the multiplying factor of 1 is used. However, while exchange penetration is increasing from y to z exchanges, an uplift factor representing the appropriate point on the slope must be applied. The straight-line slope from y to z exchanges assumes a linear transition during this period. In equation form, the situation is represented by

$$f = x, \text{ when } n \leqslant y,$$

$$f = x - \frac{(x-1)(n-y)}{(z-y)}, \text{ when } z > n > y, \text{ and}$$

$$f = 1 \cdot 0, \text{ when } n \geqslant z,$$

where f is the uplift factor, and n is the number of exchanges in service. Numerical values can be assigned to x, y and z for each system considered, and the resulting values of f, for given values of n, can be used as uplift factors for the maintenance-effort calculations. Other variations to the maintenance requirements may also be made to allow for the settling-in of exchange components and the need to gain maintenance experience of a new system.

In more complex situations, some equations or models may give better predictions of the solution than others, and when the model is tested against live data, its accuracy can be established. Frequently, the variability of a function can be

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contained in a very few independent variables, as will be described later. The model to be described uses over 150 equations of varying degrees of complexity. Many of them are used more than once in any one study, and successive equations normally rely on the successful computation of earlier equations. Therefore, the term *model* embraces a range of situations, from a single simple equation to a complex set of interrelated equations.

THE LOCAL-EXCHANGE MODEL

General

A local-exchange model, known as ALEM, has been developed as an econometric computer model for local-exchange studies. Its objective is to cost the economic factors involved in one strategy, known as the base or existing strategy, and compare these costs with an alternative strategy, normally employing accelerated replacement of Strowger plant. It then presents the result as a measure of the profitability of the renewal strategy over the base strategy in present-value (p.v.) terms. To achieve this objective, the model is required to

(*a*) identify the year-by-year demand for equipment of different systems under a variety of possible futures,

(*b*) determine the capital and annual costs of these equipment demands, allowing for different and changing cost factors,

(*c*) discount the yearly expenditure on each strategy to obtain their respective p.v.s, and contrast them to produce a net present value (n.p.v.) for the renewal strategy being explored, and

(*d*) repeat the above processes for each year in which it is required to complete the replacement of Strowger plant in the network.

Additionally, the model provides year-by-year profiles of equipment expenditure and supplementary data for the study of the depreciation, borrowing and interest implications of the strategy.

The technique adopted in the model is to consider exchanges in groups. Firstly, the large-exchange population is divided into director and non-director groups. Additional groupings are also possible; for example, London director and provincial director. Within these groups, exchanges are divided into a single group for each switching system. By grouping exchanges in this manner, it is possible to reduce the data to manageable proportions, whilst still reasonably representing the population to be studied. The model has the capability of considering six systems in each of the director and non-director groups, of which three are at present utilized; namely, Strowger, crossbar and TXE4 equipment.

The model considers not only the provision of equipment for growth and the normal replacement of worn-out Strowger apparatus, but also the equipment requirements for accelerating, at different rates, the replacement of Strowger exchanges with modern switching systems. The calculation of equipment provision is conducted primarily in terms of connexions, with the traffic-carrying component being a function of connexions.

The main parameter of the model which controls the quantity of each type of equipment is the limit on expenditure imposed for a given system. The type of exchange environment, in which a particular system may best be suited, plays no part in this process, for the actual geographic location of individual exchanges within the groupings, referred to above, is the responsibility of local operational planners. In fact, the technologies of, or facilities offered by, the different switching systems are not examined, for the cost data used assumes that the same basic set of facilities is provided by all systems.

The equations constituting the logic of the local-exchange model are written into an ALGOL program, and occupy over

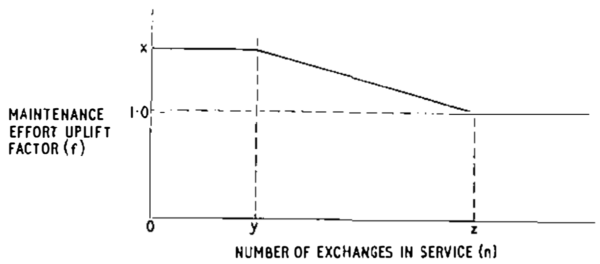


FIG. 1—Variation of maintenance effort with exchange penetration

14,000 words of core storage. It is run on a Burroughs B5500 computer. However, it is being converted to PL1 language, and will be run on the new B.P.O. computer (IBM 370/168) at Harmondsworth.

The general structure of the local-exchange model is shown in Fig. 2, the first section of which relates to the input data. This defines the exchange population and its growth characteristics, the nature of the strategies to be studied, capital and operating cost information, and many other model variables and control factors. The second and main section calculates the quantities of various types of equipment required, year by year, according to the availability and replacement strategy dictated to it. It conducts the costing and other financial calculations to produce the n.p.v. of the particular renewal strategy being investigated. Section three of the model gives the print-out of the many stages through which the model has progressed. Of great importance are such

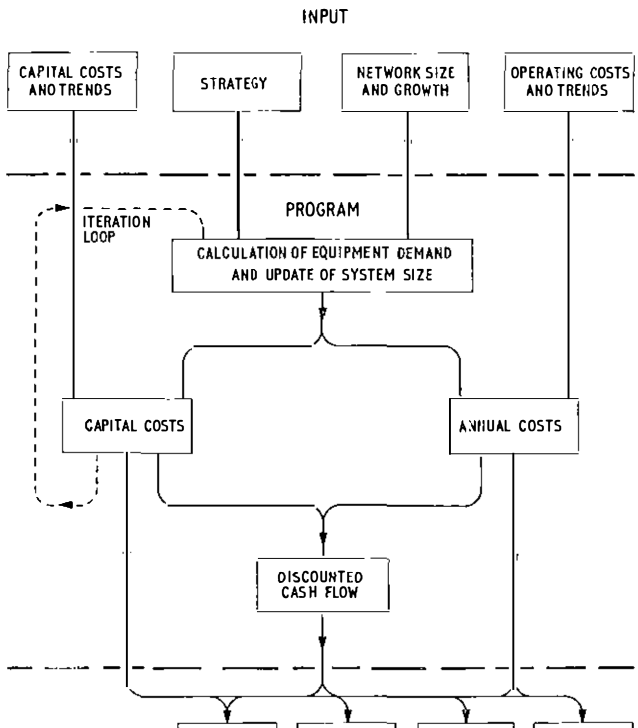


FIG. 2—General structure of the local-exchange model

outputs as the year-by-year profiles of equipment needs, exchange/system penetration, capital requirements and labour needs.

The local-exchange model, therefore, progressively records the changing mix of switching equipment installed according to the strategy being explored. It then creates a model of the developing situation relating to exchange systems, with attendant cost and profitability outcomes.

Input Data

The model requires approximately 2,000 elements of input data for each of the director and non-director studies, and includes forecast values for each year of the 30-year study period. Much of the data has been the subject of deeper study; in particular, the derivation of linear formulae to define capital costs and maintenance man-hour requirements.

The inputs to the model are

(*a*) an input-parameter file of nearly 400 elements which defines the network size and the capital and maintenance cost information at the start of the study, supplies control information for the print-out, and provides a whole range of variables that permit sensitivity testing and basic data variations to be assessed,

(*b*) year-by-year details regarding the order of choice of the type of equipment to be used, together with any capital or manufacturing constraints and a statement as to whether accelerated replacement of Strowger equipment is required in that year; these factors constitute a statement of strategy,

(*c*) the yearly adjustment factor to be applied to the basic capital costs of each system, the maintenance effort and labour costs, etc. for updating the costs to the current year,

(*d*) the net growth of working connexions per annum,

(*e*) the growth in originating calling rate per annum, and

(*f*) the number of Strowger connexions each year needing replacement because they are worn out. This is derived from historical information relating to all past purchases of Strowger plant.

The capital and annual maintenance costs, referred to in (*a*), have a significant role in the model. However, the model assumes that these costs are proportional to two independent variables; namely, exchange lines, or connexions, and originating traffic, such that

$$\text{capital cost of an exchange} = aL + bE + c,$$

where L is the number of lines provided and E is the originating traffic in erlangs. The coefficients a and b and the constant c are input for each switching system via the parameter file, and relate to exchange costs at one point in time; namely, the start year of the study. As subsequent years are being studied, a cost trend or adjustment factor brings the base-date coefficients up to the current-year values.

For a given type of exchange, if L and E are known, then its capital cost can be calculated. If a group of n exchanges of one type are to be costed, then because the equation is linear, the total capital cost would be given by

$$\text{total capital cost} = (aL_1 + bE_1 + c) + (aL_2 + bE_2 + c) + \ldots (aL_n + bE_n + c),$$

$$= a\sum_1^n L + b\sum_1^n E + nc.$$

In general form, total capital cost $= aL_T + bE_T + nc$,

where L_T and E_T represent the summation of the added equipment required by the group of exchanges without their individual components necessarily being known.

The capital-cost equation represents the cost of a new exchange, but when an exchange undergoes an extension, the same principle may be applied. In this case, the cost of the extension equipment would represent the increase in lines and originating traffic provided for the extension. If p and q relate to the size of the exchange before and after the extension respectively, then,

$$\text{capital cost before extension} = aL_p + bE_p + c, \text{ and}$$
$$\text{capital cost after extension} = aL_q + bE_q + c.$$
$$\text{Thus, capital cost of extension} = a(L_q - L_p) + b(E_q - E_p).$$

It is emphasized that the cost relates to plant added to existing exchanges.

Maintenance man-hour coefficients are stored in the input file and called upon when maintenance effort is being calculated. The equations are of the form man-hours/annum $= aL + bE + c$ where L is the number of lines, and E is the originating traffic.

The equations could be processed in a similar manner to the capital-cost equations. However, to take account of such factors as the settling-in of an exchange and centralized maintenance (see Fig. 1), this equation was modified into a more complex statement.

Many other subsidiary items of cost data are included in the parameter file, each making an identifiable contribution to the overall economics. These are brought to account as a percentage overhead on the capital value of plant installed. Among the most significant of these are

(*a*) the variation in capital cost with change in volume of production,

(*b*) capital costs of power plant, accommodation and B.P.O. clerk-of-works' time,

(*c*) annual cost of power plant and accommodation,

(*d*) training costs,

(*e*) re-use and scrap values of Strowger equipment, and

(*f*) cost of spare parts and documentation.

As much of the numerical data as possible has been consigned to the input-parameter file, rather than the program, in order to give the model its considerable flexibility. The ability to accept data variations so readily is one of the most important facilities offered by the model.

The Internal Processes of the Model

The principles adopted within the model are shown in Fig. 3. The model commences by reading from the input data the information relating to the size of the network at the start of the study. The following stages of calculation are then pursued, with the results stored for ultimate print-out if required.

(*a*) The model proceeds to set itself to study the base strategy for the first year, and reads further input data to determine the nature of the strategy to be explored; that is, the order in which switching systems should be studied to meet requirements, and the overriding constraint on expenditure, if any, in that system.

(*b*) It then performs a series of calculations to determine the equipment requirements, firstly to meet the growth of the network, secondly to replace worn out Strowger equipment, and thirdly, but not required by the base strategy, to replace Strowger equipment still serviceable; that is, accelerated replacement.

In practice, each individual exchange is subject to periodic extension to cater for growth, as shown in Fig. 4. The model, however, represents several hundred exchanges, and due to the various sizes and locations of the exchanges in the population, extensions can be taken to occur in a random manner such that the overall effect on the population may be assumed to be a smooth and continuous process.

(*c*) The first-priority system may be, say, crossbar equipment with an expenditure limit of £x-million. It is then necessary to convert that expenditure limit to an equivalent number of crossbar connexions. This conversion takes place

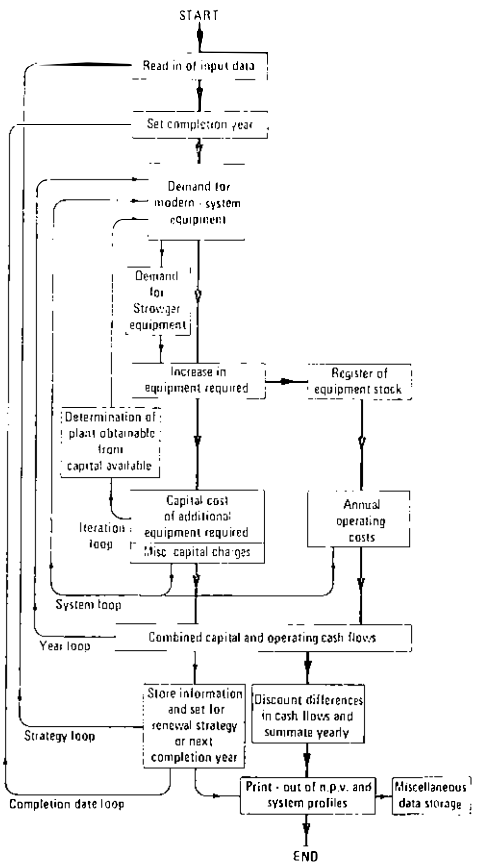


FIG. 3—Internal processes of the local-exchange model

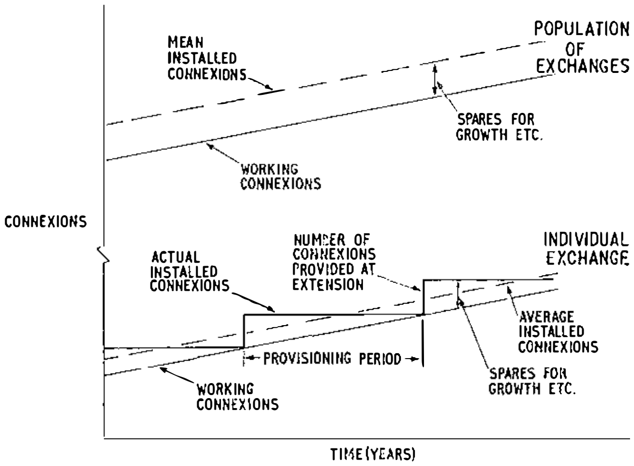


FIG. 4—Representation of connexions growth in the model

by a process of iteration, using the *iteration loop*, because of the indirect relationship between cost and connexions. An estimate of connexions is made, costed approximately with the appropriate capital-cost equation, and the result compared with the expenditure limit. If the estimate is too high or too low, it is decremented or incremented, as appropriate, each time with a repeat costing. When the costing comes very close to the expenditure limit, the associated estimate of connexions is stored as the maximum obtainable in that year.

(*d*) The number of connexions obtainable in (*c*) is then compared with the number required from (*b*). If it is more than enough, then only the number required are costed. Alternatively, if it is not enough, then all those obtainable are used and costed.

(*e*) Having determined the number of connexions provided in the crossbar system, an estimate can be made of the number of exchanges they represent. Likewise, from the input profile of average calling-rate forecasts, the total traffic can be computed. This data, relating to numbers of connexions, exchanges and traffic, is then stored as a statement of the increasing penetration of the new system. At the same time, recovered Strowger exchanges are subtracted from the present quantity of Strowger exchange equipment, to show the measure of decline of that system.

(*f*) The total connexions, traffic and number of exchanges are now known for the crossbar system, and can be applied to the capital-cost equation to obtain a final calculation of the capital cost. At this stage, the capital cost at constant money values is calculated relating to prices at the start of the study. However, it is recognized that, even at constant money values, prices will change with time, due to such factors as productivity and real labour-rate rises. Hence, by applying the price-trend adjustment, the capital cost at current-year prices is determined.

(*g*) Exchange equipment is the most dominant item of all capital-cost factors, and other capital costs are brought to account as a percentage overhead on the basic capital cost. These subsidiary capital costs relate to such items as power-plant provision, accommodation requirements and the labour cost of B.P.O. clerk-of-works' staff. A trend adjustment is also applied as in (*f*) to obtain current-year subsidiary capital costs.

(*h*) Having determined the crossbar equipment to be provided in the year, it is necessary to update the stock register of working and installed equipment as calculated in (*e*), for it is this cumulative total that will be subject to operating charges. Operating charges for maintenance are obtained by applying the coefficients of the maintenance man-hours equation to the total quantity of equipment in service. From a total man-hours value, a cost value can be obtained by using the maintenance man-hour labour rate and factors for settling-in of a new system and centralized maintenance. Other annual charges for the training requirements of maintenance staff, power consumption and accommodation are brought to account in relation to the demand that the equipment makes on these resources. Current-year costs are obtained in a similar manner to capital costs, by the application of annual charges and maintenance productivity trends.

(*i*) The derivation of operating and capital costs for the first-choice system concludes the main calculations for that system. The model is next required to progress to the second-choice system, and it then repeats the above stages, by means of the *system loop*, from (*b*) onwards. As each switching system is studied, more and more of the total equipment requirement in (*b*) is met. Up to a maximum of six systems can be studied in any one run of the model. In practice, only one or two modern systems will be involved. The final system loop is always Strowger, for this equipment must be used to meet the growth and replacement requirements of exchanges not yet converted to a modern system.

(*j*) If a need for additional Strowger equipment is identified, further decisions must be made regarding re-use of Strowger plant. The model assumes that recovered Strowger equipment will contain a proportion of plant that may be refurbished and re-used. Hence, the quantity of new Strowger plant purchased from the manufacturer must be abated by the re-used component. The proportion of manufactured and re-used Strowger plant must then be determined, and refurbishing charges added to the re-used component.

(*k*) Having determined the capital cost of equipment brought into service in any one year, it is necessary to recognize that payments for an exchange would be made over a period of years. The next stage is, therefore, to spread the capital cost payments over the appropriate number of years, so that the outfall of payments approaches the practical expenditure situation.

(*l*) The capital expenditure, operating costs and Strowger equipment scrap values are then combined to give a total strategy cash flow for the year.

(*m*) When all systems have been considered in the first year and the resulting calculations stored, the model then commences to study the second and subsequent years, by means of the *year loop*, each time repeating the processes (*a*) to (*l*) above. Thirty such years were studied in this exercise.

(*n*) The base-strategy study is now completed and the profiles of data for all 30 years are stored to await print-out according to the options indicated in the input-parameter file. The model is then set to study the alternative strategy for accelerated renewal, using the *strategy loop*.

(*o*) The accelerated-renewal strategy follows largely the same process as above, except that accelerated replacement of Strowger equipment is involved. This means that a target date for completing the total replacement of Strowger equipment is required, and the model can study up to ten such completion dates in each run. When this sort of strategy is adopted, an additional component of equipment demand is considered, because, as well as growth and the replacement of worn-out Strowger plant, serviceable Strowger equipment is deliberately recovered. An assessment of these quantities must, therefore, be included. The total quantity of Strowger plant that must be replaced is determined by calculating the number of years n between the current year and the completion year read from the input-parameter file, and then replacing, in the year, $1/n$ times the total Strowger connexions currently in the network. In the renewal-strategy mode, stages (*a*) to (*m*) above are then repeated.

(*p*) If more than one completion date is to be studied in a given renewal strategy, then, for each date, processes (*a*) to (*o*) are repeated using the *completion-date loop*.

(*q*) After the final system loop of each year loop of the renewal strategy, stage (*l*) will have been reached, and the total strategy expenditure as a cash flow is calculated. For each year, the excess cash flow of the base strategy over the renewal strategy is computed. It is then discounted from that year to the start-of-study year by applying the discounting factor required by the discounted-cash-flow (d.c.f.) analysis. The model derives the appropriate discounting factors from its computation of the test discount rate, quoted as a variable in the input data.

(*r*) The model summates, year by year, the d.c.f. amounts to determine the n.p.v. of the renewal strategy being studied, in relation to the base strategy.

(*s*) For modern systems, a residual equipment value is calculated, based on the unexpired life of the plant at the end of the study period.

(*t*) Finally, the n.p.v. derived from the summated d.c.f. (*r*) + (*s*) is printed-out, together with an analysis of its main components. Also, in accordance with the control parameters, information stored earlier in the model is printed-out, or transferred to other files. These are profiles of equipment, labour and capital needs, penetration of the systems and other details for each of the 30 years studied. However, of the possible ten completion years studied, the full data for only one of them is printed-out, but a table of n.p.v.s for all selected completion years may be given.

Print-out

Each full run of the model and its associated print-out, conducted in the batch-processing mode, takes approximately 4 min of central-processing-unit (c.p.u.) time. This relatively short time avoids the risk of computer breakdown, which is a real hazard to models requiring several hours uninterrupted c.p.u. time. The print-out from the local-exchange model, which is 25 m long, comprises

(*a*) the input data,

(*b*) the base-strategy profiles of demand, cost, updated stock, labour requirements, maintenance costs, expenditure profiles, cash flows, etc.,

(*c*) precisely the same profiles as in (*b*), but for the renewal strategy, and

(*d*) the resulting n.p.v. and an analysis of its main components.

Normally, only certain profiles are printed-out, effecting a considerable reduction in the c.p.u. time and length of print-out. In fact, when the effect of one, or maybe two, variables alone is being studied, the run is possible *on-line*, with the results being printed to a teletype terminal. Under these circumstances, a c.p.u. time as low as 40 s is normal. For this sort of timescale, therefore, exploration of renewal strategies and detailed changes in data can be readily undertaken.

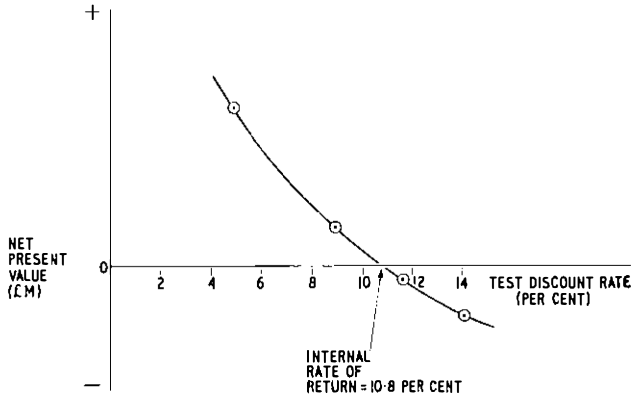


FIG. 5—Determination of internal rate of return.

SENSITIVITY TESTS

A strategy may be sensitive to certain factors more than others, and the process of sensitivity testing adds to the information available to assist in decision taking. Sensitivity tests demonstrate the effect of changing a particular component of the input data. The input data is in a form which can be readily varied and so a wide variety of conditions can be investigated. It is possible to study various changes to the strategy, or connexions-growth forecasts etc., and this permits the model to follow variations ranging from slight to radical changes in direction. Individual items such as *crossbar capital cost*, or *labour rate*, can be altered, whilst keeping all other factors constant. A computer run then reveals the effect attributable to that one input variation. Each factor in the model may be varied, in turn, with the remaining factors being unchanged, and an assessment made of the cases producing a significant change in the n.p.v. The objective is to determine the change in the n.p.v. for a given percentage change in an input component, be it capital cost or network growth etc.

Four main aspects were found to be sensitive areas in the study. These were

(*a*) connexions-growth forecast,

(*b*) capital cost,

(*c*) maintenance cost, and

(*d*) capital-cost trends.

Consequently, variation in these areas was scrutinized closely, and a greater proportion of effort was directed to their study.

N.P.V. AND INTERNAL RATE OF RETURN

The n.p.v. and the internal rate of return (i.r.r.) of a study are readily obtained using the model. The i.r.r. is that test discount rate which would enable the investment to break-even over the costing period; that is, zero n.p.v. It is a useful measure of the return offered for additional capital outlay when assessing the risk involved.

The i.r.r. can be determined by running the local-exchange model with different test discount rates, until a zero n.p.v. is achieved. In practice, this may be done by interpolation between points close to zero, as shown in Fig. 5. Alternatively, a subsidiary package program is available that calculates the i.r.r. from the n.p.v. results of a few runs of different test discount rates.

MODEL VALIDATION AND DEVELOPMENT

The progressive development of the model focused attention on the need for it to earn its credibility by validation of its output data. The many logical steps taken within the model were processed in simple stages and the results printed-out at each stage. Errors could then be readily identified and the calculations checked. The full print-out of variables has been an essential aid in checking and fault finding, as well as for use in consultation with experts in the costing, planning, purchasing and financial fields, aimed at assessing the reasonableness of the results.

A useful aspect in the model's design was the incorporation of *switch functions*, whereby certain aspects of the logic could be included, or excluded, on an optional basis. By setting a certain input parameter to *unity*, the optional element of the logic or facility would be included, and by setting it to *zero*, it would be excluded.

From an early stage in the model's development, it was producing answers to some preliminary questions. This steered the evolution of the model towards its objective soon after the initial runs. There will be continuing evaluation of strategies and in more detail, with both the data and model being amended, where necessary, to accommodate the availability of revised information. As the authorized renewal strategy progresses, the model will offer the facility of checking that the practical outfall is either on course, or is deviating by the amount revealed in the print-out.

CONCLUSIONS

The decision to pursue a planned strategy of accelerated replacement of Strowger equipment did not rely solely on the local-exchange model. It involved consideration of all aspects of the business, and of the industrial consequences. Many expert commercial and technical judgements were entertained and debated. However, the financial consequences of each strategy considered were exposed by the local-exchange model, and its ability to explore many alternatives rendered it a powerful tool at the heart of the exercise, thereby assisting in determining the exchange-equipment strategy of the future.

ACKNOWLEDGEMENT

The author would like to acknowledge the work of the many colleagues in various departments of Telecommunications Headquarters, who readily assisted in the conduct of this far-reaching exercise.

References

1 BENSON, D. L. Local-Exchange Renewal Strategy: Formulating a Strategy. (In this issue, p. 130.)

Book Review

"S.O.S.—The Story of Radio Communication." G. E. C. Wedlake. David and Charles Ltd. 240 pp. 37 ill. £4·25.

As a largely non-technical account of the development of radio communication, from the first tentative experiments in the latter years of the nineteenth century to the appearance of communication satellites, this work is perhaps rather lighter fare than that to which the attention of readers of this *Journal* is customarily directed.

Nevertheless, the book could possibly serve as an introduction to the subject for the younger generation, who might, understandably, be under the impression that the achievement of broadcasting technique was the principal aim of the early pioneers, and that colour television was the apotheosis of their efforts. Since, however, this particular aspect has already been thoroughly covered by Asa Briggs *et al.*, the author usefully devotes the larger part of his account to the twenty or so years preceding the birth of broadcasting. This less-familiar period was mainly dominated by the activities of Marconi and his enthusiastic associates, who were concerned primarily with developing wireless telegraphy, as they termed it, both as a much-needed means of reliable long-distance communication for marine and commercial purposes, and, latterly, to meet the needs of the armed services in two world wars. The author regards the sinking of the *Titanic* in 1912 as an event of some significance in this context, because of the way in which it tragically emphasized, for the sceptics, the importance of what was being done to improve the safety of life at sea.

It is a pity, however, that in an introductory work of this kind, the author should make a number of categorical assertions of questionable historical accuracy; this is especially noticeable in the early pages. Similarly, dates, usually given with some precision, nevertheless sometimes differ from those generally accepted; indeed on occasions, events described in the text are given different dates in the chronology at the end of the book.

The so-called "technically-minded" are catered for by a somewhat fragmentary appendix, which mainly features circuit diagrams of early apparatus, an essential component of which, we are assured, was a pair of brass balls. Unfortunately, a misplaced capacitor in some of the diagrams, would prevent these items from functioning in the accustomed manner. The reiteration of the epithet "first", as applied to events, becomes rather tedious after a time.

Finally, some place-names, particularly in the maps which accompany the text, have suffered from careless proof-reading, other evidence of which is also apparent. A number of interesting and rarely-published plates are included.

D. A. J.

The CANTAT 2 Cable System: Evolution and Design

A. P. DAVIES, and A. W. H. VINCENT, C.ENG., M.I.E.E.†

U.D.C. 621.315.28:621.395.457:621.395.64

This article, which is the first of a series in this issue of the Journal describing CANTAT 2, traces its evolution from earlier submerged repeater systems. The planned design in terms of level and noise performance is then discussed, followed by an outline of the measured results on the laid system. The article concludes with an indication of the immense task involved in manufacturing the equipment for a system of this size.

INTRODUCTION

The last submarine cable between the U.K. and Canada was CANTAT 1, laid in 1961.[1] This provided 80 × 3 kHz circuits, and was the precursor of the design of the system laid in the Pacific Ocean in 1964–67, for the latter part of which, design evolution had increased the circuit capacity to 120 × 4 kHz circuits, or 160 × 3 kHz circuits. This was then a deep-water version of the cable systems laid in the North Sea in 1963–64.[2]

Since then, evolution of the long-life transistor by the British Post Office (B.P.O.) Research Department[3] has permitted two significant increases in circuit capacity on submarine cables—the 8-supergroup, 5 MHz system and the 23-supergroup 14 MHz system (1,840 × 3 kHz circuits). During 1966–70, 5 MHz systems were laid extensively between the U.K. and Europe, both in shallow- and deep-water versions, and the design is still current for lower-growth routes.

The need for a cable having a capacity greater than 1,000 circuits was foreseen in 1967, following successful feasibility studies by the B.P.O. Research Department into amplifiers having upper frequencies above 10 MHz using the type-10A transistor.[4] At about this time, problems due to *noise overload instability* were found on repeaters using a common amplifier for both high- and low-band paths.[5] Separate amplifiers were, therefore, adopted for the two transmission bands and it was then found that the type-10 A transistor could be used to an upper frequency of 14 MHz.

Many shallow-water 14 MHz cable systems, designed and made by Standard Telephones and Cables Ltd.,[6] have since been laid to Europe. Deep-water versions have also been sold commercially since about 1969, but CANTAT 2 is the first adaptation of the 14 MHz system for transoceanic deep-water use to be owned, in part, by the B.P.O.

When a 3,000 nautical mile, 14 MHz cable system to Canada was first mooted in 1970, the basic repeater design was examined in detail by the contractor to determine its suitability for the project. In particular, an examination was made of the effect on noise performance of the variations in cable loss, due to sea-bottom temperature changes on the two continental shelves. For depths in excess of 1 nautical mile, the sea-bottom temperature is predictable and unvarying. Hence, cable systems laid almost entirely in deep water require less margin against repeater output-level variation than does CANTAT 2, in which almost half the system noise allowance is used by the two long shallow-water sections.

† Network Planning Department, Telecommunications Headquarters.

SYSTEM NOISE PLANNING

The mean channel noise for the system and the noise in the worst channel should not exceed 1 pWp/km and 2 pWp/km, respectively. The target of 1 pWp/km is equivalent to a noise level of −52·8 dBm0p/channel* to be met with the planned mean loading of −12 dBm0/channel on 1,840 channels. These requirements must be achieved after allowing for variations of the cable attentuation due to temperature changes and additional repair cable over the life of the system. These effects vary the repeater operating levels and, hence, modify the accumulation of thermal and intermodulation noise contributions from individual repeaters. An allowance must also be made for level misalignments due to unavoidable inaccuracies in the system equalization. After allowing for these level variations, the repeater operating at the highest transmission level must have sufficient overload margin to cope with these misalignment and changes due to ageing.

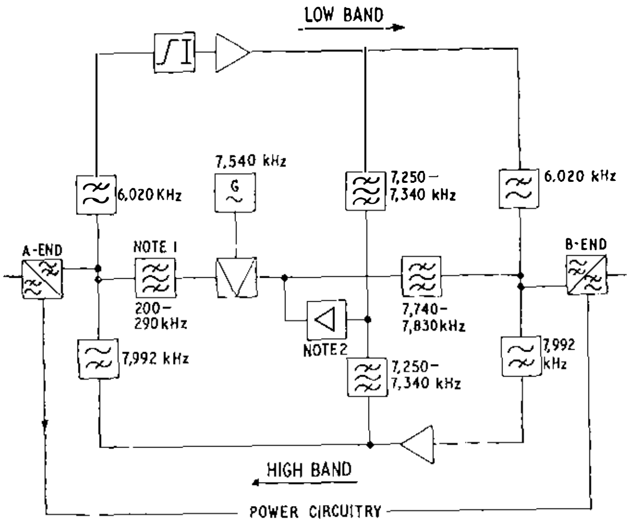
Level Variations and Equalization Misalignment

The main abyssal span of CANTAT 2 is planned on the basis of maintaining the optimum operating levels, within the limitations imposed by equalization errors. These errors are minimized by submersible equalizers, placed in every fifteenth repeater section, and adjusted during the laying operation. This virtually invariant span comprises about 80 per cent of the total repeater sections.

Seasonal temperature variations are confined to the shallow-water sections over the continental shelves. Prime consideration must be given to noise in the highest-frequency channel (13·7 MHz), since this is subject to the greatest seasonal loss variations, the estimated total being ±8·2 dB for 370 nautical miles and ±4·9 dB for 200 nautical miles for the U.K. and Canadian ends, respectively.

The allowance for additional repair-cable loss was 6·6 dB at 13·7 MHz, equivalent to 1 nautical mile of the 1·47 in cable used over the continental shelves, where most cable ruptures occur due to fouling by trawling gear, etc. Deep-water cable is rarely disturbed and repair would entail the addition of at least one repeater section plus repeater, thus allowing level misalignments to be avoided. The worst case for repair addition was assumed—all repairs accumulating evenly at one end.

* dBm0p—Psophometrically-weighted level measured at a point of zero relative level.



Note 1: Crystal filter which identifies the repeater
Note 2: Noise amplifier

FIG. 1—Block diagram of repeater

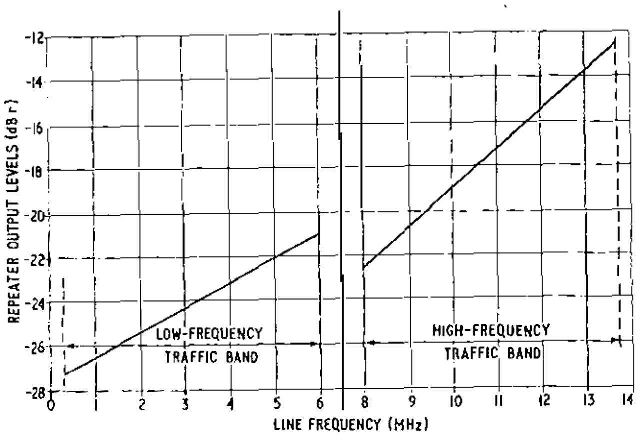


FIG. 2—Optimum repeater output-level/frequency characteristics

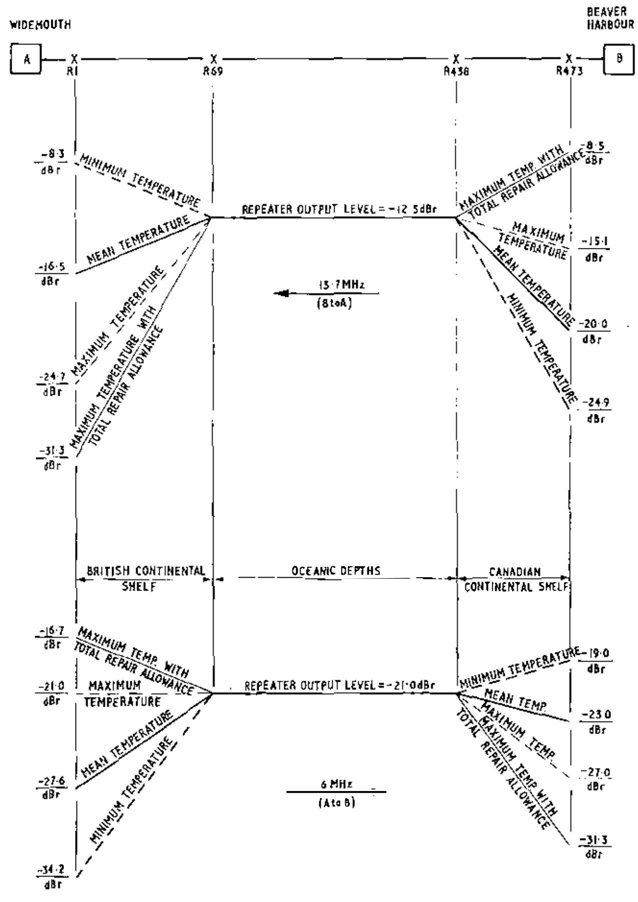


FIG. 3—System level plan

System Overload Levels

A block diagram of the repeater is shown in Fig. 1, and for the pre-emphasis applied to the high-frequency (h.f.) amplifier,[6] the computed mean output level for the optimum output-level/frequency characteristic (Fig. 2) is $-16\cdot6$ dBr. The total load in the h.f. direction is $(-12 + 10\log_{10} 1{,}840) = +20\cdot6$ dBm0. With 1,840 channels, the multiplex signal may be assumed to behave as white noise (peaking factor of 13 dB), giving a total high-band peak power of $(20\cdot6 + 13) = +33\cdot6$ dBm0. The peak power at the amplifier output is, therefore, $(33\cdot6 - 16\cdot6) = +17\cdot0$ dBm.

Since the amplifier overload is +28 dBm (sine-wave, peak), the overload margin is 11 dB with the optimum levels of Fig. 1. Level errors due to misalignment and ageing may be up to ±3 dB and ±4 dB respectively, giving a net overload margin of 4 dB with respect to a system with all repeaters at the nominal optimum levels.

The System Level Plan

The system levels were planned not to exceed 4 dB above nominal under all operating conditions, and the final plan (Fig. 3) requires level gradients over the two continental-shelf sections at mean annual temperature, in order to conform to the +4 dB limit.

Grading system operating levels to accommodate variations of loss is established practice, previously achieved by slight variations in the cable-section length. However, with two-way transmission, correct adjustment of the h.f. direction is wrong for the low-frequency (l.f.) path. Although the noise and overload margins in the low band are usually ample, they would, nevertheless, be reduced.

In CANTAT 2, independent final adjustment of repeater gain can be made for each direction, immediately before the capsule is sealed into the sea housing. For the continental-shelf sections, the gains were, therefore, adjusted to produce the required level offsets in each band, all cable sections being cut to maintain the average loss at nominal value throughout the system. The average offsets are quite small and well within the adjustment range and statistical spread of gain of individual repeaters. Use of repeaters adjusted for nominal gain in an offset section would, therefore, cause only slight upset to the level plan and, usually, a spare repeater could be selected to match the required gain.

The Canada–U.K. direction was chosen for the high-band path (Fig. 3) because the worst condition is then deferred until the full repair-cable allowance is inserted at the U.K. end. Also, with the other direction, the smallest tolerance would occur with no repair-cable addition at minimum annual temperature, and the repair-cable addition would, therefore, be limited by overload if it were all at the U.K. end. This applies in reverse to the low band, but this is less important, as explained above.

For navigational reasons, the system should be layed from east to west, away from the A terminal, each submersible

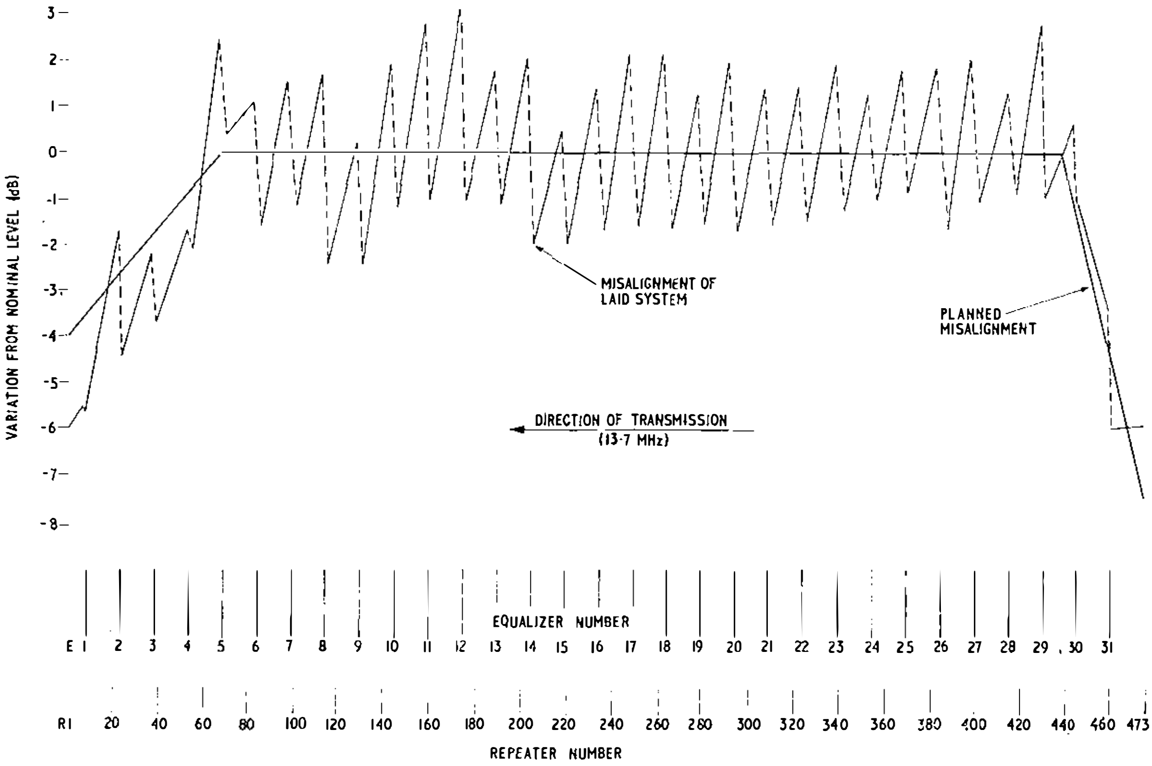


FIG. 4—Level misalignment of laid system at 13·7 MHz

equalizer being adjusted to anticipate the high-band correction of the next block of 15 repeater sections to be laid. There was, therefore, a risk of a high-band level error being built into the equalizer. With careful block measurement before starting the lay, the risk was considered small.

Estimation of System Noise Performance

The estimation of the noise performance of a repeater loaded with multiplex traffic is detailed elsewhere.[7,8,9,10] From this parameter, the overall system noise performance can be estimated as follows.

Firstly, the overall noise performance should be estimated for an ideal system of N repeater sections, with each repeater operating at the optimum transmission levels, and then the modifications owing to expected variations of line levels can be estimated.

Thermal Noise

The estimate of total thermal noise in the ideal-level system from the noise of a single repeater is simply $10 \log_{10}N$ dB, for the addition of N equal power contributions of random noise from N repeaters.

Second-Order Intermodulation Noise

Second-order ($A \pm B$) intermodulation products tend to cancel in repeater pairs because of the phase reversal inherent in the three-stage amplifiers. However, the phase/frequency distortion between successive repeaters, due mainly to the sharp cut-off characteristics of the directional filters, prevents complete cancellation, and a random power addition factor $10 \log_{10}N$ dB is reasonably accurate. Second-order intermodulation is predominant in the low band (312–6,012 kHz), but as the high band (8,000–13,700 kHz) is less than one octave, no $A \pm B$ products fall in band and only third- and higher-order products are present.

Third-Order Intermodulation Noise

In a multiplex band having a large number (1,840) of channels, the predominant form of third-order intermodulation product is $A + B - C$,[8,9,10] as more products fall into any one channel than from other forms. Also, products from successive repeaters tend to add on an in-phase, or voltage-addition, basis. In the low-band, and the low- and middle-frequency regions of the high-band, the phase/frequency distortion reduces the voltage-addition law for $A + B - C$ products to approximate power addition ($10 \log_{10}N$ dB). However, at the h.f. end of the high band, the phase/frequency curve approaches linearity and there is a tendency towards voltage addition ($20 \log_{10}N$ dB), particularly for single products from interfering channels A, B and C grouped closely around the affected channel. The total distortion in one channel is the sum of thousands of products from interfering channels distributed throughout the band, many of which are subject to considerable phase distortion. However, the h.f. end of the high band is transmitted at relatively high levels (see Fig. 2). Thus, the majority of the total $A + B - C$ power into an h.f. channel is derived from other high-level channels at that end of the high-band spectrum. Consequently, the total $A + B - C$ interference into h.f. channels tends more towards voltage addition than into channels at lower frequencies in the band. For planning purposes, an addition factor of $15 \log_{10}N$ dB was considered safe, from previous experience. These considerations demonstrate the importance of giving prime consideration to the noise into the highest-frequency channel.

Higher-Order Intermodulation Products

Fourth and higher orders of intermodulation noise do not need to be considered, although they may need to be assessed for future systems of higher bandwidth.

The Effect of Repeater Gain

The gain of repeaters used successfully on shorter routes is

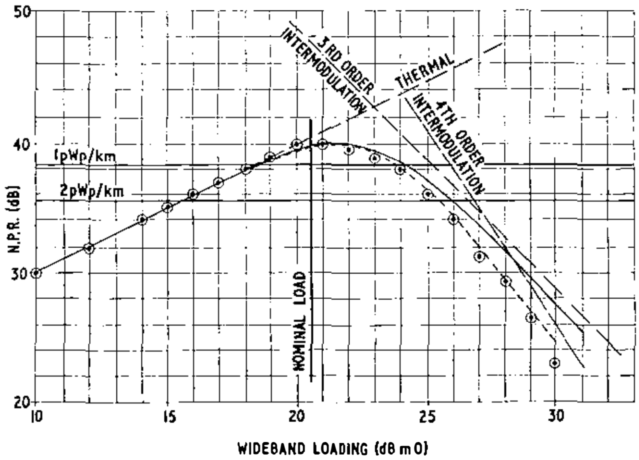


FIG. 5—N.P.R. at 13·478 MHz

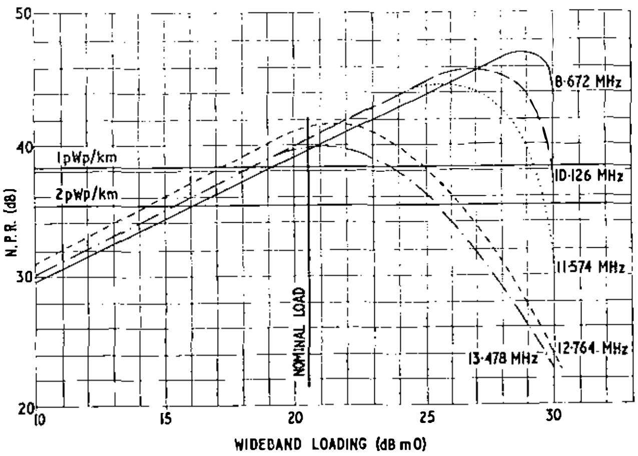


FIG. 6—N.P.R. measurements in the h.f. band

43 dB at 13·7 MHz and follows the cable loss at other frequencies. For CANTAT 2, the estimated total system noise derived from the single-repeater performance indicated that the noise requirements might not be met under all prescribed level variations. Two solutions were possible.

The more elegant and economical solution was to make the repeater gain temperature-dependent by means of thermistors in the line-amplifier feedback networks, thereby reducing the system level changes with temperature to less than one third the uncompensated changes. Unfortunately, an evaluation program to prove the thermistor reliability to the exacting standards of submerged-system operation could not be completed in time for CANTAT 2, although the method will be used on later systems.

The second solution—reducing the repeater gain to 40 dB at 13·7 MHz and *pro rata* at other frequencies—was applied, but at increased cost due to the extra repeaters required. This reduces the total system noise as follows.

Considering the 13·7 MHz channel with the repeater output levels unchanged, the thermal noise is 3 dB less from each repeater due to the higher signal levels at the repeater input. However, the thermal noise is increased by $10 \log_{10} (43/40) \simeq 0 \cdot 3$ dB because more repeaters are contributing. The net improvement in thermal noise is, thus, 2·7 dB. The intermodulation noise from each repeater is unchanged because the output levels remain the same, except for some improvement due to changes in the line-amplifier feedback characteristics to reduce the external gain. This improvement is offset by the third-order summation factor, $15 \log_{10}(43/40) = 0 \cdot 5$ dB. The high-band amplifier design was modified accordingly, and an improvement of about 4 dB in third-order intermodulation was obtained, giving a net improvement of 3·5 dB in third-order noise. It was unnecessary to modify the low-band amplifier because its performance was more than adequate, the gain being reduced by increasing the loss in the amplifier input circuit. These measures were considered to be sufficient to meet the requirements of CANTAT 2.

MEASURED RESULTS ON THE LAID SYSTEM

To analyse the noise performance of the line transmission equipment, the misalignment of the laid system must be considered and the measurement method must be related to the system noise requirement.

Level Misalignment of the Line Equipment

The level misalignment at 13·7 MHz on commissioning is plotted in Fig. 4, together with the levels planned for the mean-temperature condition. The block equalization was closely controlled and level errors were confined to about ±2 dB, resulting in a worsening of about 0·2 dB for thermal, and 0·4 dB for third-order, noise performance.

Noise Measurement

The noise performance of CANTAT 2 was measured by means of the *noise power ratio* (n.p.r.), called *signal–noise density ratio* in the C.C.I.T.T.† and C.C.I.R.‡ transmission recommendations,[11, 12] wherein traffic is simulated by a white-noise signal of appropriate bandwidth and a power density equivalent to the power level/channel of traffic. Narrow-band stop filters suppress the noise power in selected test-frequency slots, and at the receiving end, the level is measured through a highly-selective band-pass filter at the test-frequency. The ratio, in decibels, between the received level with and without the slot suppressed in the transmitted noise band is a direct measure of the ratio between the channel traffic power and the noise generated in that channel by the simulated loading in the rest of the spectrum.

N.P.R. Requirements for the System

The channel noise target of 1 pWp/km amounts to −52·8 dBm0p/channel for CANTAT 2, equivalent to an unweighted noise power of −50·3 dBm0/channel with a mean channel traffic loading of −12 dBm0 and an n.p.r. of −12 −(−50·3) = 38·3 dB. For the maximum channel noise of 2 pWp/km, the n.p.r. is 35·3 dB. Fig. 5 shows the estimated system n.p.r., assuming the planned line levels at mean temperature and a third-order intermodulation addition of $15 \log_{10}N$.

The Measured N.P.R.

Figs. 6 and 7 show the measured n.p.r. for five slot frequencies in the high and low bands. These measurements included noise contributions from the wideband translating equipments, but separate tests established that the terminal contributions were negligible. The n.p.r. measured in the 13·478 MHz slot is also shown in Fig. 5 for comparison with the planning estimate. The n.p.r. values shown for the thermal, third- and fourth-order noise add to produce the smooth curve drawn through the measured points, the fourth-order

† C.C.I.T.T.—International Telegraph and Telephone Consultative Committee.
‡ C.C.I.R.—International Radio Consultative Committee.

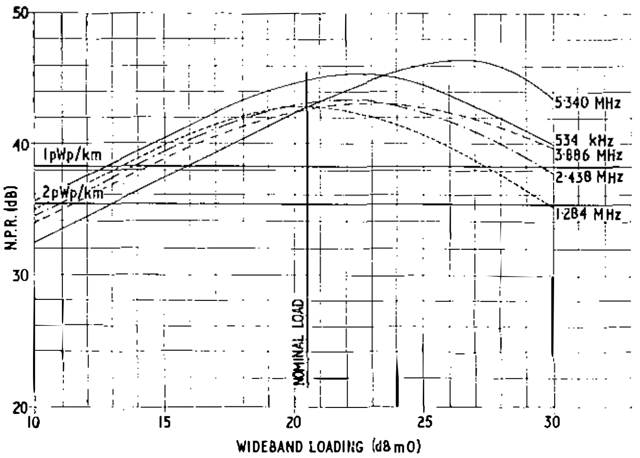


FIG. 7—N.P.R. measurements in the l.f. band

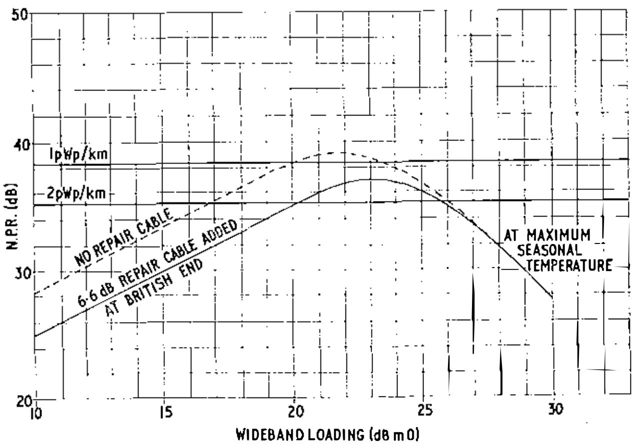


FIG. 8—N.P.R. at 13·478 MHz adjusted for worst conditions of temperature and repair-cable addition

element being added to approximate the effect of higher-order intermodulation at high loading levels. The estimated third-order element represents an addition factor of about $16\log_{10}N$ dB, compared to the planning estimate of $15\log_{10}N$ dB.

Fig. 6 shows that the 13·478 MHz slot has the worst n.p.r. in the high band. At 12·764 MHz, the margins are improved and the addition factor is about $14{\cdot}2\log_{10}N$ dB, but the shape is similar to that at 13·478 MHz. The n.p.r. curves at 11·574 MHz, 10·126 MHz and 8·672 MHz all have positive n.p.r./loading gradients of 1 dB/dB, representing purely thermal noise up to very high loading levels. This indicates a third-order addition factor of about $10\log_{10}N$ dB, as for random addition, and the margins are ample.

Fig. 7 shows that the low-band noise margins are ample, with a range of loading levels of at least 11 dB for which the n.p.r. is better than the 38·3 dB target. At the nominal loading level, margins of at least 4 dB are maintained with respect to the noise target. At high loading levels, the n.p.r./loading characteristic falls off at about 1 dB/dB, indicating mainly second-order intermodulation as expected. Higher-order intermodulation is not evident until the loading level approaches +30 dBm0.

The Effect of Seasonal Temperature Variations

The lowest n.p.r. measured (13·478 MHz), adjusted for the worst conditions of maximum temperature and repair-cable addition at the U.K. end, meets the maximum channel noise requirement over a loading level range of at least 5 dB (Fig. 8). This range will cover the maximum expected ageing variations.

Conclusions on Noise Performance

Measurements indicate that the system has sufficient margins to meet the channel noise requirements with the worst combination of temperature, repair-cable addition and ageing effects envisaged. The form of addition of the third-order intermodulation contributions from each repeater is the most difficult aspect to predict. If the law of addition for N repeaters is $K_3\log_{10}N$ dB, then from the measured n.p.r. results on CANTAT 2, $K_3 \simeq 16$ in the 13·478 MHz slot. Measurements of the $2A-B$ intermodulation products, by the application of two discrete frequencies adjusted so that $2A-B = 13{\cdot}478$ MHz, confirmed the system planning assumption of $K_3 = 15$. However, other equally-valid theoretical approaches to K_3 computation gave values of 15·2 and 16·7. Whichever evaluation is the most valid is of particular interest for future system design, but is academic for CANTAT 2 now it is completed.

FACETS OF MANUFACTURE

The problems of producing a complete system as big as CANTAT 2 to a tight schedule are manifold, and this article does not attempt to cover such a wide subject. However, a *résumé* of some of the facets of manufacture relating to the external plant is given below.

Cable

Any cable factory is designed for large-volume production, as submarine cable cannot be made to a consistent performance any other way. However, for CANTAT 2, 3,000 nautical miles of cable had to be manufactured and stored in large circular pans so that it was available for loading on to a cable ship in the correct sequence, each 6 nautical mile length being made for a unique, designated geographical position. This is organizationally desirable and electrically necessary, because each length must provide its planned loss of 40 dB at 13·7 MHz at the temperature and pressure at its location.

To cut cable to an equivalent "sea-bed" length, the attenuation coefficients for temperature and pressure must be known accurately. At present, however, only the temperature coefficient can be determined by simulation under controlled conditions in the factory, the depth coefficient being deduced from results of deep-water laying trials. Fortunately, the laying effects of 1·47 in lightweight cable had been experienced previously at the frequencies to be used. The coefficients can be calculated from the theoretical variation of the cable constituents with temperature and pressure, but, to date, these computed changes have not matched the results obtained to the degree necessary.

For earlier lower-frequency systems on smaller cables, a temperature coefficient of 0·16 per cent/°C was assumed for all frequencies. However, for CANTAT 2, the temperature coefficient of polyethylene is significant for frequencies above about 4 MHz and temperature correction cannot be applied as a simple percentage of loss. This aggravates the ship-board design of the submerged equalizer networks and complicates the terminal-station, variable temperature equalizer design. The CANTAT 2 cable was made using a pressure coefficient of $0{\cdot}11 + 0{\cdot}52d$ per cent, where d is the depth in nautical miles, and a temperature coefficient of 0·135 per cent/°C at 13·7 MHz, rising to 0·17 per cent/°C at 0·3 MHz.

Repeaters

The most difficult item to manufacture is the repeater, each one having about 330 components and many closely-toleranced mechanical parts. These must be available in time and must be sufficiently reliable to ensure not more than one repeater failure in 25 years' service. Hence, each part must be adequately specified and meticulously inspected to ensure that it meets its specification. For CANTAT 2, which required almost 500 repeaters, the problems of securing the component supplies were immense.

Failure of any one of at least 50 per cent of the components would cause system failure, but the high-voltage capacitors in the power-separating filter and the semiconductor devices in the main transmission paths were the most probable cause of repeater failure and were, therefore, given special attention. Although not a vital component, the supervisory-circuit oscillator crystal was a further cause for concern, as it identified the discrete position of the repeater in the route. Inevitably, some crystals would fail to meet their stringent specification and re-manufacture implied such lengthy delays that it was decided to modify the submerged repeater monitoring equipment to permit it to be programmed to any sequence of supervisory frequency order.[13] Hence, any repeater could be used in any location, and no ship loads were delayed due to non-availability of specific repeater allocations.

About 2,000 high-voltage, oil-filled, paper-foil capacitors were required for CANTAT 2 at a manufacturing rate of 50 per week. Each had to burnt-in for 1,000 h at 12 kV before being tested, so a failure meant at least two months' delay. In the event, supply just met demand.

Manufacture of the main transmission path transistors was thought most likely to cause delay and these were, therefore, 50 per cent over-ordered. The system design for CANTAT 2 was conceived to have a potential maximum length of 4,000 nautical miles. This requires about 670 repeaters using about 4,000 transmission path transistors, failure of any one of which would result in total system failure. The maximum failure rate specified for the types-4A and -10A transistors, used in the low- and high-band amplifiers respectively, was, therefore, set at 1 in 4,000 in 25 years. For CANTAT 2, about 1,500 of each type were required, and it was decided to make three batches of 800 of each type to provide the extra 50 per cent and to avoid total loss from one failure during validation testing. However, to achieve a 1-in-4,000 failure rate, 4,000 devices must be made in each batch, 1,000 of which were placed on operational test for 3,000 h for potential use in the system, the remaining 3,000 being tested to destruction to prove the validity of the batch.[3] More than 30,000 transistors were produced and some batches failed to meet the standard for CANTAT 2, but the supply of proven devices just kept pace with repeater production.

Submerged Equalizers

The submerged equalizers consist of a fixed equalizer, which corrects to within reasonable limits the misalignments arising from manufacture, and an adjustable equalizer, which is made on the ship to correct for laying effects and other unpredictable misalignments. However, the adjustable equalizer also has to correct for the extent to which the fixed equalizer fails to correct for predictable misalignment, for, despite making extensive simulated tests on the first ten repeaters and cable sections, the fixed-equalizer networks did not ideally match the true misalignment. This highlights the problem of trying to simulate the exact conditions of a laid cable.

The submerged equalizer is entirely passive and introduces an overall loss which is made good, in submerged repeater systems, by cutting short any cable section including an equalizer by an amount equivalent to the planned maximum equalizer loss. For CANTAT 2, this was 13·3 dB, equivalent to one-third of a cable section, or 2 nautical miles. Hence, the short cable sections each side of the equalizer are cut to a defined length, unlike repeater sections, which are cut to a defined loss. By cutting to a loss value, the small random variations in cable tolerances produce a random spread of section lengths. This assists in minimizing the build-up of troublesome in-phase echo paths, and production was planned to achieve a degree of length variation. For the equalizer sections, however, the problem of in-phase echopaths at the lower frequencies is significantly greater due to the repetitive nature of the section length, the relatively low loss of the short cable section, and the poor return loss of that section of the equalizer made on-board ship (for speed and simplicity many 2-terminal sections are employed). Because of the large number of equalizers (30), the equalizer cable sections were cut to cause a sequential phase difference of about 60° in the loop delay time at 300 kHz at successive equalizers so that the phase pattern only repeated at every sixth repeater. This was reasonably successful, the magnitude of the 25 kHz ripple, due to the 40 μs equalizer-section echo-time, being 0·15 dB.

CONCLUSION

The technical problems associated with the design of a submarine cable have been outlined in sufficient detail to identify the specialized problems met on a project of this magnitude, together with some idea of the production problems involved. The noise performance attained conforms to modern international practice, and was met at a higher channel loading than that previously applied to a transatlantic route. The cable, therefore, not only provides a channel capacity greater than that previously available from all existing cables, but the individual channels are of a higher noise standard than has been attained hitherto, and this standard of performance should be met for the 25-year specified system life.

ACKNOWLEDGEMENT

CANTAT 2 uses a proprietary system developed, manufactured and installed by Standard Telephones and Cables Ltd., and the authors acknowledge the very close co-operation given by the contractor to them and their colleagues, thereby materially assisting in the success of the project.

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The CANTAT 2 Cable System: Planning and Laying the Cable

Capt. O. R. BATES†

U.D.C. 621.315.285:527.6:551.462

This article summarizes the navigational techniques available for cable-laying purposes, and continues with a description of the survey of the route of the CANTAT 2 cable. The planning and execution of the laying operation is then described, and the article concludes with a summary of the transmission problems involved in laying the cable.

INTRODUCTION

Planning a 3,000 nautical mile submarine cable route has always been a problem. However, an error of 1 per cent, or 30 nautical miles, only represented an uncertainty of ± 1 repeater for CANTAT 1; whereas for CANTAT 2, it produces an uncertainty of ± 5 repeaters. This is unacceptable, both economically and from the following important marine considerations, which impose tight constraints on positional accuracy.

(*a*) The sea bed of the Atlantic Ocean is not a flat plateau. (Fig. 1). The underwater mountainous region, known as the Mid-Atlantic Ridge, is not homogenous, but consists of broken formations of peaks and gullies having impressive gradients and a height above the mean sea-bed level of more than 1 nautical mile in places. Sometimes, as in the Azores Islands, the peaks exceed 2 nautical miles in height.

(*b*) To enable the laid cable to be repaired expeditiously, it is vital that the exact path of the cable be accurately known. Previously, an error of a few miles could occur, using earlier available navigational systems when over 1,000 nautical miles from land.

NAVIGATIONAL TECHNIQUES

Before electronic aids became available, mariners employed the centuries-old methods of astral navigation and dead reckoning. The former requires sufficient visibility to measure the angular altitude of stars above the horizon and an accurate knowledge of time. The accuracy can be about 1 nautical mile, but it is highly operator and weather dependent; an ill-defined horizon and a rolling ship do not permit high accuracy. Dead reckoning over extended passages is highly inaccurate, depending on assessments of speed, duration and distance run from the last "known" position, and the effects of tidal currents and drift due to wind. Its principal use is to assess the probable position following the last obtainable starfixes. These methods are accurate enough for passage-making between two ports, but not for good cable work, and have, for many years, been supplemented by electronic aids. However, these have the following limitations.

(*a*) *Radio direction-finding* has relatively low accuracy and is limited by the extent of radio coverage. Except when close inshore, its potential accuracy is little better than ± 5 nautical miles.

(*b*) *Radar* is limited to line-of-sight distance, about 24 nautical miles. The accuracy is good at short distances, but decreases with increasing distance.

(*c*) *Decca* can provide very accurate "fixes" within about 200–250 nautical miles of the *master* transmitter. However, this requires a master and a web of three or more *slave* transmitters about 100 miles from the master and preferably each other, all transmitting the same instantaneous signal with the slaves being phase-locked to the master. Hence, many in-shore areas of the world are not covered. The ship's receiver automatically compares the phase difference between the received master signal and at least two of the received slave signals in order to obtain one or more intersects, which are plotted on special charts to obtain the position. This method is used extensively for cable work in European waters where excellent coverage is normally available. The potential accuracy is remarkable, being of the order of about ± 5 m in areas of good coverage.

(*d*) *Long Range Aid to Navigation* (*LORAN*) is similar to the Decca system, but works at lower frequencies with wider separation between the master and slave stations (about 2 MHz and 400 miles respectively). The receiver compares the time difference between ground-wave pulses transmitted in time-locked synchronism from the master and at least two slave transmitters, and the position is determined by plotting on special charts. The more recent equipment, LORAN C, working at a lower frequency than LORAN A (100 kHz) and with a more sophisticated detection circuit, is capable of high potential accuracy (20–500 m according to local conditions) and range. However, the LORAN receiver must be calibrated against a known position and if, for any reason, this lock is lost during passage or laying operations, an error can easily result which is not readily detected; recalibration against a known position is then necessary.

(*e*) *Omega* uses eight transmitting stations to provide a world-wide very-low-frequency (10 kHz) hyperbolic navigational lattice. Each line of position is determined from the phase difference of the signals received from any pair of transmitting stations. The accuracy is approximately ± 1 and ± 2 nautical miles for day and night respectively. Because of its worldwide coverage, this is a possible second-string navigational aid during cable laying, but it was off the air for most of the lay of CANTAT 2 and its potential as an integral part of the Hydroplot system[1] could not be assessed. When it was

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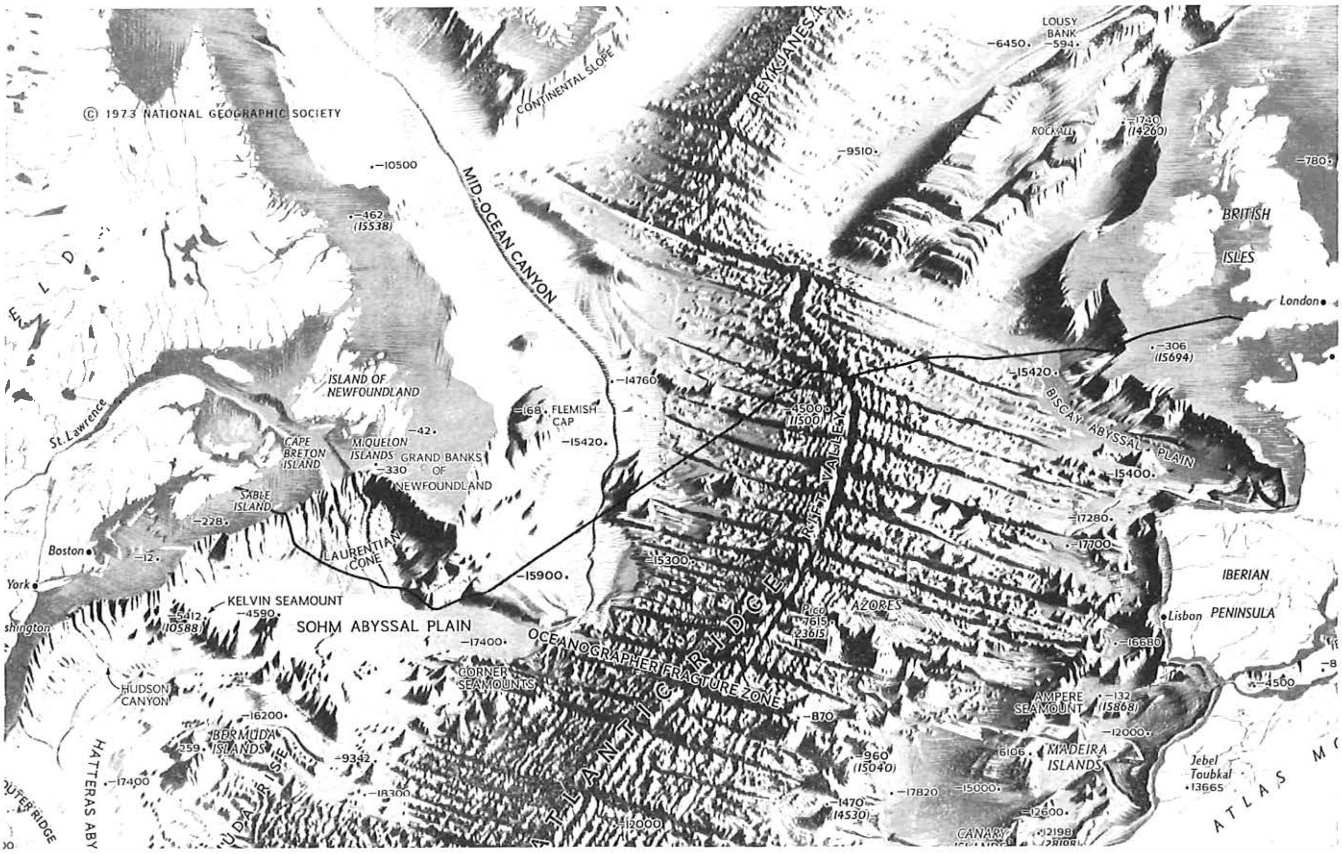

FIG. 1—Map of Atlantic Ocean floor showing route of CANTAT 2 cable

available, it seemed to be useful under transoceanic laying conditions.

Fortunately, the very accurate satellite navigator became available commercially, and a set was purchased for surveying a route and, subsequently, laying the CANTAT 2 cable. This decision has been fully justified by the excellent results consistently obtained during all the deep-sea laying operations during 1973. The basic operating concept is outlined elsewhere.[1] An accurate assessment of position (within about 10 m under good conditions) is only obtained during that part of the orbit when the satellite can be "seen" by the ship's aerial and, to be reliable, this orbit should be at least 15° above the horizon. This only occurs every hour or more, but it provides an excellent update to the LORAN C continuous read-out facility. Its availability was, therefore, essential to any meaningful sea-bed survey.

THE ROUTE SURVEY

The planned route and depth of the cable was such that the near-shore areas might be subject to fishing hazards, particularly over the Canadian continental shelf, which is one of the world's finest fishing areas. The U.K. continental shelf off Cornwall was likely to be much less subject to fishing interference, but, even so, it was decided to examine the prevailing sea-bed conditions. The survey was, therefore, separated into three parts as described below. However, prior to the shelf surveys, C.S. *Ariel* cut and cleared eight old abandoned cables from the planned path of CANTAT 2 on the U.K. shelf, and C.S. *Alert* recovered or diverted nine cables on the Canadian seabed, the work being completed in early spring 1971.

The Deep-Water Survey

The French cable ship *Marcel Bayard* was chartered for this extensive operation and, with the help of marine scientists from Bath University, the Eastern Abyssal Plain was surveyed during June 1971, and the Ridge and Western Abyssal Plain during August/September 1971. The path of a preferred route, avoiding as far as possible existing cables, was examined in detail using a precision sonar depth recorder. The sea-bed temperature and soil samples were also taken at intervals. Particular attention was given to the North Atlantic Ridge region, and this showed that the planned route must be altered by some 10 nautical miles. The CANTAT 2 cable had to cross the U.S.A.–France TAT 2 cable in this region and so the new route was planned to cross TAT 2 approximately at right angles and well away from repeater positions.

The Canadian Shelf Survey

The purpose of this survey was to establish the suitability of the sea-bed sub-soil for cable burial using the variant of the cable *mole-plough*, developed by the American Telephone and Telegraph Company (A.T. & T.) for underwater use. Virtually the only way to establish route and sub-soil suitability is to make a dummy run of the route and use the cameras mounted on the plough to observe for surface obstructions to be avoided, such as large boulders.

The cable plough used (see Fig. 2) can bury a cable at least 20–24 in below the sea-bed, and is a highly-sophisticated machine, having such features as

(*a*) three remotely-controlled television cameras and the necessary underwater lighting,

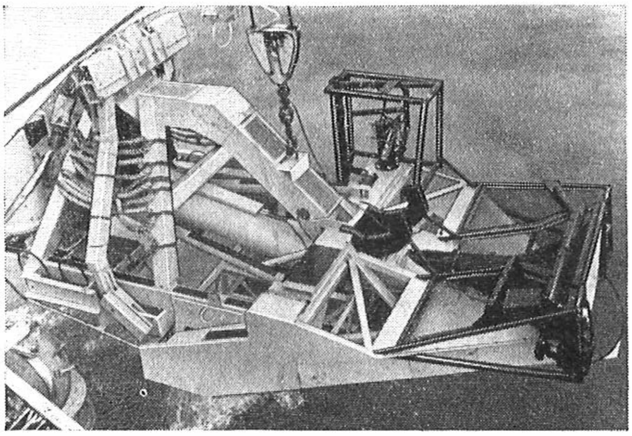

FIG. 2—Cable plough

(*b*) detectors to record the roll and pitch of the plough for telemetering to the surface, and

(*c*) hydraulic motors for lowering and retracting the plough share and tailgate.

The plough is, therefore, large and heavy, being some 24 ft long, 9 ft wide and weighing about 17 tons. A force of 15–30 tons, depending upon the type of sea-bed, must be exerted to tow the plough with the ploughshare at 24 in depth, and the Canadian Coastguard Ship *John Cabot* is still the only suitable ship to undertake this work.

The survey was made during the summer of 1971 and confirmed the feasibility of cable burial from about 12 nautical miles from the Canadian landing point to the 300-fathoms contour, about 160 nautical miles out from the coast. However, the sea-bed was much firmer over the last 50 nautical miles, with a sub-strata of rock 15–18 in below the surface, which would inhibit burial to the preferred depth of 24 in. The suitability for burial was also tested of lightweight cable having either the extra protection of a light-wire armouring, or an added oversheath extrusion of high-density polythene. Both proved equally suitable, so the latter type was chosen for its relative cheapness.

The U.K. Shelf Survey

This survey, made by *John Cabot* during the spring of 1971, confirmed the expected areas of rock outcrop between the North Cornwall landing at Bude and the relatively shallow water off Southern Ireland. About 160 of the 260 nautical miles of sea-bed to the 300-fathom contour could be ploughed, but this was not continuous. It was, therefore, decided to lay a conventional heavily-armoured cable. Subsequently, vulnerable areas might be buried by a submersible craft then being developed, which could excavate a trench under a laid cable using high-pressure water jets. In doing this in Autumn 1973, the submersible *Pisces III* was involved in the accident during her routine recovery which prompted the much-reported international rescue operation. This rescue resulted in the adoption of new safety standards for such manned vehicles. Paradoxically, this directed interest towards alternative burial methods, and trials are taking place both of unmanned vehicles and of ship-mounted excavating machines using techniques similar to those used for oil-drilling.

PLANNING THE LAYING OPERATION

The overall route chosen was approximately 2,715 nautical miles long, comprising about 170 and 270 nautical miles from the Canadian and U.K. landing points to the 300-fathom points, respectively, and a deep-water section of about 2,275 nautical miles. For transmission and economic reasons, it was decided to use 1·47 in coaxial cable, giving a repeater spacing of 6 nautical miles. With this spacing, one or more repeaters would be raised or disturbed if the deep-water cable were raised for repair, and so, for CANTAT 2, it was decided that the cable would be cut on the sea-bed surface and both ends raised separately, if a repair were required. New grapnels are being developed for this purpose. Therefore, the extra 6 per cent slack allowed previously in deep water was no longer necessary, and an average of 3 per cent slack was allowed to provide a good sea-bottom "fill" in the deep-water section. This is an average figure to be apportioned during the lay, more being allowed over the Mid-Atlantic Ridge and less over the abyssal plains. The system length ordered was, therefore, just over 2,800 nautical miles—a saving of some 12 repeater sections (more than £0.5M) over that required for a 6 per cent allowance.

The total weight of the cable and the 473 repeaters needed is about 15,000 tons, implying a ship with a large stowage capacity and able to lift the largest possible weight. The cable ships, therefore, virtually chose themselves; *John Cabot* to lay and bury the cable on the Canadian shelf, and the C.S. *Mercury*, flagship of the Cable and Wireless fleet, to lay the U.K. shelf cable and the entire deep-water cable. A ship's maximum weight of stowed load cannot be defined simply, as it varies with fuel and water carried which depends on the time the ship is at sea, but *Mercury* is weight-limited to about 4,500 tons of cable and repeaters, and stowage-space-limited to about 92,000 ft^3 of cable. Therefore, the CANTAT 2 shipping program for *Mercury* was one weight-restricted load of armoured U.K. shelf cable and four space-limited loads of lightweight deep-water cable. The Canadian shelf cable could just be carried in two loads by *John Cabot*, but this necessitated four Atlantic crossings, as the cable was made at Southampton.

A laying program was planned to commence in mid-May 1973 and end with the final splice by *Mercury* on December 13, 1973, and this was adhered to very closely, the final splice being made five days earlier than planned.

THE LAYING OPERATION

Cable Ploughing

The cable ploughing operation was carried out by *John Cabot* during June and July 1973. British Post Office (B.P.O.) and A.T. & T. staff shared the responsibility for plough control and B.P.O. staff joined the Standard Telephones and Cables Ltd. (S.T.C.) transmission team to provide technical approval of the work. The two operations were entirely successful; the first 100 nautical miles of cable was buried to the maximum depth of 24 in at speeds approaching 1·5 knots and a mean towing tension of about 30,000 lbf: the last 70 nautical miles to the deep-water transition was laid much more slowly, reducing to below 0·5 knots at times, and frequently the burial depth had to be reduced to about 15 in due to bedrock, the towing tension exceeding 70,000 lbf at times. The plough is towed from the stern of the ship while the cable is paid out over the bowsheaves, at a controlled hold-back tension, such that the cable does not touch the sea-bed, but enters the plough bellmouth at a defined angle observed by one of the television cameras. The cable hold-back tension needed was about 5 tons.

The repeaters were painted white instead of the traditional black, and only with the few lengths of tarred armoured cable used was there any difficulty in remote observation. Indeed, the only potentially serious difficulty occurred after ploughing had been completed. A link of medium-armoured 1 in coaxial cable was included between the 1·47 in buried cable and the few lengths of 1·47 in lightweight cable to be

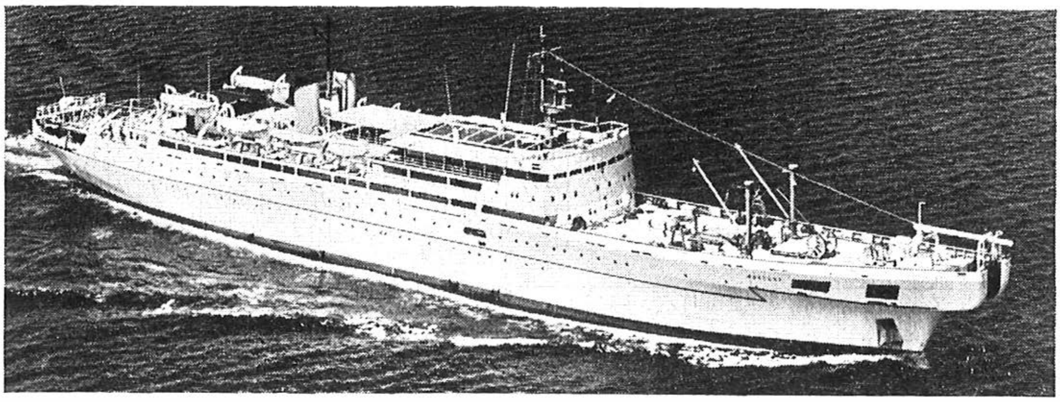

FIG. 3—C.S. *Mercury*

laid to the final splice position. However, the water used to flood the *John Cabot* cable tanks to stabilize the cable temperature for transmission measurements was contaminated with a petrol derivative. This remained after the water was pumped out and softened the impregnation over the armour wire so that the linear cable engine was unable to apply any hold-back tension, the runaway being controlled by throwing sand into the engine wheels.

Repeaters cannot be passed through the share of the plough, which is only about 4 in wide. When a repeater enters the plough, the share tail-gate, which normally guides the cable down the share, is raised hydraulically. The repeater and adjacent lengths of cable, therefore, merely sit on the sea-bed, sinking somewhat into the sea-bottom, which has been disturbed by the ploughshare. When the repeater has passed through the plough, the tailgate is again lowered into the share to resume normal burial. Thus, every 6 nautical miles, a partially-exposed repeater and about 100 ft of cable are vulnerable to fishing damage. To reduce this risk, it was decided to bury these sections using high-pressure water jets from a manned submersible vehicle—*Pisces*. This has been safely accomplished.

The burial operation imposes a very high strain on the Bridge-Officer controlling the ship, and the fact that the operation went smoothly reflects the skill and application of the ship and the plough teams.

The U.K. Shelf and Deep-Water Operations

Mercury has a displacement of 11,499 tons, a length of 473 ft, a beam of 58·67 ft, and is a twin-screw, diesel-engine ship commissioned in 1962 (see Fig. 3). Three cable tanks are fitted and up to 168 repeaters can be stowed. The normal complement is 135 officers and crew, but for the CANTAT 2 operations, from June 1973 to the end of the year, this was augmented by 12 S.T.C. engineers, two B.P.O. engineers and two B.P.O. officers. A B.P.O. designed linear cable engine had been fitted prior to the operation and modified by Cable and Wireless to operate in the constant-speed payout mode (B.P.O. ships prefer constant-tension operation). This engine was further developed between the lays to operate virtually automatically, with the driver providing oversight only.

For the first operation, to lay most of the U.K. shelf cable, *Mercury* was loaded to the limit of her draft, fuel oil and fresh water being reduced to the minimum. The load consisted almost entirely of 1·47 in coaxial cable, single-armoured with the largest gauge steel wires used for cable protection (0·3 in). This cable weighs 19·7 tons/mile, the total load being about 4,500 tons, including 35 repeaters, each weighing 0·6 ton. After measuring the route sea-bed temperatures for transmission-loss correction, *Mercury* recovered the end of the U.K. shore-end cable, laid by *Ariel* during April, and spliced the ship's load to it on 27 June 1973, completing the 175 nautical mile operation three days later. The weather was fine and the lay uneventful.

The second operation comprised the residue of about 60 nautical miles of armoured cable and 492 nautical miles of deep-water unarmoured lightweight cable. The weather was good and the operation, between 23–30 July, uneventful. Parachutes were not used on any of the deep-water repeaters, joint B.P.O./A.T. & T. trials having shown that they do not contribute significantly to the sinking rate of repeaters held in suspension by the cable.

Mercury's remaining three operations, between early September and early December, were all deep-water lays about 640 nautical miles long. Each contained seven ocean blocks, 90 nautical miles long, this being the distance between the submerged equalizers. It was planned to lay an equalizer every 24 h, implying a payout speed of 3¾ knots, but the increasingly severe weather conditions forced an increase of speed to combat the high winds. During *Mercury's* last operation, wind speeds up to force 11 necessitated a speed increase to over 5 knots. This imposed a considerable strain on the S.T.C. engineers, who had to design and make equalizers at reduced time intervals. Even at these speeds, the cable was frequently laying at an angle approaching 90° to the ship. However, the planned course was held remarkably well and the exact course and repeater positions were plotted to very close limits with the satellite navigator.

During this last operation, two interesting incidents occurred. Shortly after commencement of payout, *Mercury* passed over a surface-laid tuna fishing line suspended between two small buoys hardly visible in the winter Atlantic night. Some 9 nautical miles later, the weight of the cable and suspended repeater caused the line to cut through the cable to the centre core, resulting in an earth fault. The consequential recovery and repair of this fault caused a delay of about 60 h. The second incident happened a few days later during a severe storm when a large wave struck the ship on the starboard beam, distorting one of the main shearstrakes (ribs), bending the plating and breaking a number of armour-plate glass portholes over 20 ft above the waterline. This caused considerable flooding and the operations control room was out of action for 48 h but, fortunately, the cable power-feeding equipment was relatively unaffected and it was possible to continue paying out cable.

Despite these periods of very severe storms, the weather always abated when reasonable calm was essential—for making the initial and final splices, etc.—and the completion date was at no time delayed by the adverse weather.

To speed up completion, the Danish C.S. *Northern* was

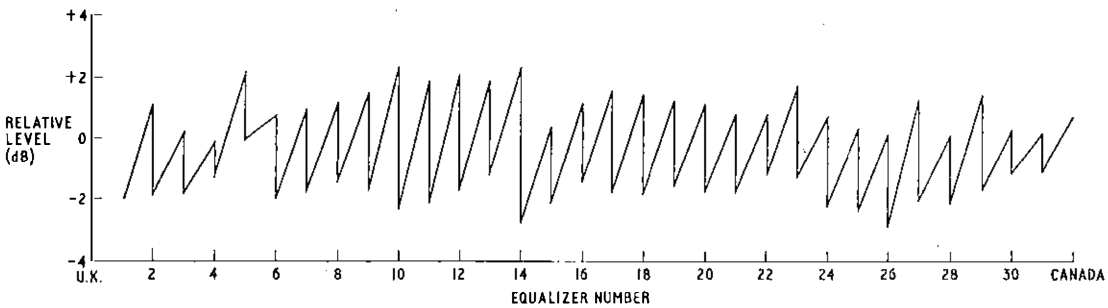

FIG. 4—Route level diagram

chartered to grapple, lift and buoy-off the end of the Canadian shelf cable, and remeasure the sea-bed temperatures. *Mercury* recovered the Canadian buoyed-end on 7 December 1973 and, following successful transmission tests to the Canadian terminal station, the final splice was slipped to the sea-bed on 8 December 1973.

SOME TRANSMISSION OBSERVATIONS ON THE LAID CABLE

CANTAT 2 is the world's largest-capacity transoceanic system and, although not the longest, employs far more repeaters and equalizers than any other system. The sequential equalization of the accumulated minor misalignments of nearly 500 repeaters was a formidable task, bearing in mind the limited correction network designs available to the S.T.C. test team and the short time available to assess, make and install the attenuation-distortion correction required at each equalizer. The results obtained were consistently excellent and the overall system level was contained within the design tolerance limits. A diagram of the levels attained along the route at 13 MHz is shown in Fig. 4, and is typical of the results achieved.

A small computer was used on board the ship to obtain the end-of-block level predictions used to determine the equalizer requirements about 10 h before it was passed overboard. It was only where sudden depth changes occurred, over the edge of the continental shelf and the Mid-Atlantic Ridge, that the predictions were not entirely consistent between successive hourly measurements. This was expected from previous experience, and is due to

(*a*) the uncertainty over the exact sea temperature at the varying bottom strata, and

(*b*) the changing length of the suspended cable catenary between the ship and the point at which the cable reaches the sea-bed.

The catenary length is a function of the weight of the cable in water, the ship's speed and the depth. In 2 nautical miles of water, the touch down point is some 10 nautical miles behind the ship, but this distance shortens significantly where the depth reduces quickly and vice versa. It is very difficult to predict the exact effect this will have on transmission performance while paying-out cable, and some engineering judgement of the computer results based on experience is desirable. The problem was largely avoided, however, by arranging the ship loads to permit the decision on equalizer requirements to be left until the situation was stable.

Another problem was the progressive increase in time taken for the system performance to stabilize after power was applied. As it is desirable to reconcile the results obtained with prediction before paying-out cable, the stabilization time can be a potential embarrassment if the weather outlook is unsettled. Towards the end of the operations, complete stabilization time exceeded 12 h, but, fortunately, the weather never prejudiced the operation at this critical time.

The performance of the Canadian shelf cable during its burial operation was surprising. Firstly, the measured sea-bed temperatures were higher than expected in June and July, and varied considerably over short distances, due to the interplay of the cold Labrador Current and the warm Gulf Stream. Secondly, the laid cable had a larger loss than expected and this had to be equalized out. This may be due to the temperature at the burial depth being different from that at the sea-bed. The cyclic pattern of temperature change on the Canadian shelf is not in phase with that on the U.K. shelf, but calculations have shown this will not degrade the system performance.

One of the problems of the transmission engineer is an accurate knowledge of the cable temperature; in particular, the cable stowed on the ship, which can be subject to considerable temperature gradient and variation. *Mercury's* cable-tank temperature is stabilized by spraying the cable with water, using circumferentially-mounted jets fed from a re-circulatory system having a substantial reservoir capacity. This proved very effective, the cables rapidly assuming the same temperature as that of the water.

ACKNOWLEDGEMENTS

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Reference

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The CANTAT 2 Cable System: Terminal Equipment

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U.D.C. 621.315.28:621.395.463:621.395·64

The terminal equipment, used in the CANTAT 2 cable system, is described in this article in general terms. Those aspects of the equipment, which are particular to this system and differ from terminal equipments used in the inland network, are described in more detail in three main sections; namely, terminal transmission equipment, power-feeding equipment and submerged-repeater monitoring equipment.

INTRODUCTION

CANTAT 2 terminal equipment, installed at Widemouth Repeater Station, Bude, and at Beaver Harbour, Nova Scotia, differs from the normal inland cable system terminal equipment and this article highlights the following special features of the CANTAT 2 terminals.

Firstly, one cable carries both directions of transmission, necessitating frequency division of the two directions separated by a filtration gap. The traffic bands are 312–6,012 kHz, Widemouth to Beaver Harbour, and 8,000–13,700 kHz in the reverse direction. The low-frequency (l.f.) direction is designated A–B, making Widemouth the A terminal and Beaver Harbour the B terminal. To utilize the available bandwidth fully, the system baseband differs from the standard national hypergroup assemblies. Therefore, the terminal equipment must include extra equipment normally associated with repeater-station plant, such as supergroup translation equipment (s.t.e.) and any special carrier frequencies, in order to present the circuit assemblies at standard frequencies and levels. For CANTAT 2 an assembly of 23 standard supergroups was used.

Secondly, although many conventional cable terminals power feed dependent repeaters, none does so on the power, security and stability scale of the submarine-cable power-feeding equipment. The total power consumed by the repeaters on CANTAT 2 is about 7 kW, fed in approximately equal parts from each terminal.

Lastly, although the overall system performance is extensively monitored by transmitted pilots, the performance of each individual repeater can only be determined by special monitoring facilities built into each repeater.

TERMINAL TRANSMISSION EQUIPMENT

The terminal transmission equipment (t.t.e.) comprises all the equipment between the supergroup distribution frame and the 2-wire point leading to the sea cable head, including the derivation of special carrier frequencies, the generation of the many pilot frequencies used to monitor and control the system performance, and the provision of four audio-frequency speaker channels. At the U.K. terminal, all trans-atlantic circuits are extended to the inland network at supergroup frequency, but, at the Canadian terminal, some supergroups are broken down to audio by means of 3 kHz channel equipments.

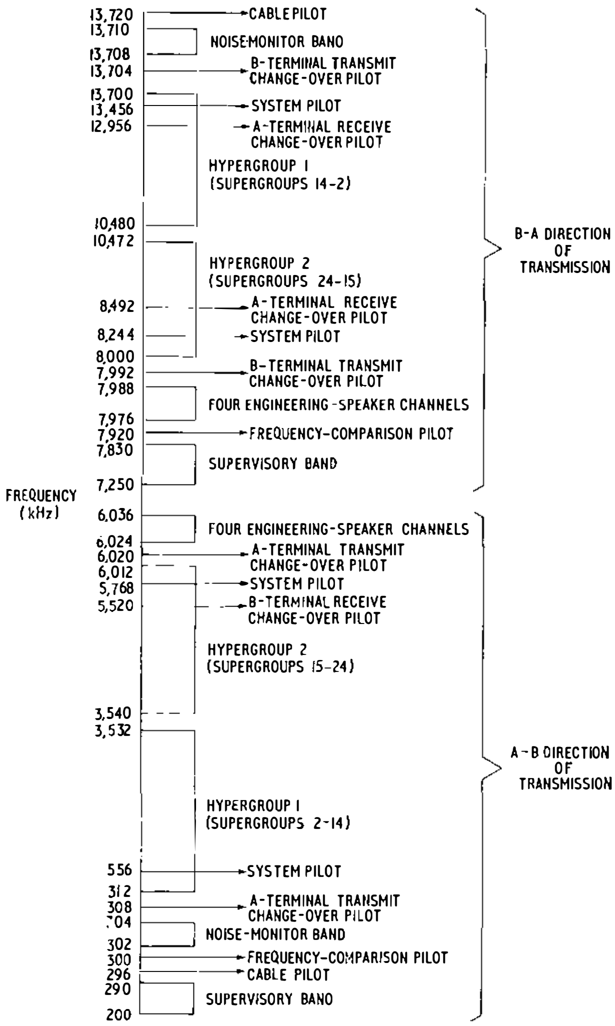
The maximum security of service is provided against both equipment failure and incorrect operation of maintenance routines by such means as

(*a*) duplication of all main transmission paths carrying more than one supergroup, with automatic change-over to the reserve circuit (except for the system directional filters), and

(*b*) protection of test points to limit the change in traffic level to 0·25 dB when the test outlet is either open or short circuited, most of these test points being at a level equal to that of the signal path.

The t.t.e. occupies nine 9 ft, 62-type racks and, apart from the reversal of the frequency bands, the Canadian and U.K. equipments are virtually identical. Thus, only specific points of difference are identified, and the general description applies to either.

Figs. 1 and 2 show the system frequency spectrum and block diagram of the A-terminal of the t.t.e., respectively. The



Note: Frequency axis not to scale

FIG. 1—CANTAT 2 frequency spectrum

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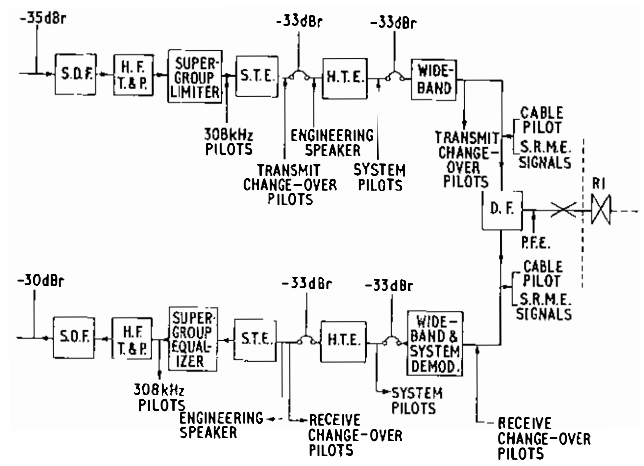


S.D.F.—supergroup distribution frame
H.F.T.&P.—high-frequency test and patch
S.T.E.—supergroup translating equipment
H.T.E.—hypergroup translating equipment
S.R.M.E.—submerged repeater monitoring equipment
P.F.E.—power-feeding equipment

FIG. 2—Simplified block diagram of A-terminal transmission equipment

equipments are powered from 20-volt regulated power units fed from the station 24-volt battery. Standby power units automatically supply the load in the event of failure.

The t.t.e. is designed such that the terminal amplifiers normally operate with at least 3 dB more overload margin than the submerged repeaters, even with 1 mile of repair cable added. Furthermore, the total noise contribution of the combined transmit and receive paths does not exceed 100 pW0p.

The t.t.e. can be divided into the s.t.e. and hypergroup translating equipment (h.t.e.), the wideband equipment and the ancillary facilities such as the pilot and engineering-speaker arrangements.

Supergroup and Hypergroup Translating Equipment

Transmit Direction

The connexion with the inland system is made at basic supergroup frequencies (312–552 kHz). Each input, at a level of −35 dBr, is fed into a supergroup limiter, provided to prevent high-level signals from causing interference on the submarine system (see Fig. 3(*a*)). The limiter is followed by equipment to inject a 308 kHz supergroup section pilot on each supergroup.

Standard international supergroup equipment cards are used for translation, but they are engineered to produce 13-supergroup (2–14) and 10-supergroup (3–12) blocks, forming hypergroups 1 and 2, respectively. Passive combining networks are used to form working and standby paths for each hypergroup, giving four hypergroups at the output of the s.t.e. Hypergroup 2 is modulated with a carrier of 6,576 kHz for translation into a supergroup 24–15 assembly, thereby providing a combined hypergroup output of supergroups 2–24 in the frequency range 312–6,012 kHz. Both hypergroups are factory equalized from hypergroup input to wideband input, and 556 kHz and 5,768 kHz system pilots are injected into both working and standby combining networks. The four 3 kHz engineering service channels are injected into hypergroup 2 immediately prior to the 6,576 kHz modulator; these are above the traffic band in the A–B direction, and below it in the B–A direction.

Receive Direction

The received broadband signal is divided into the two hypergroups at the wideband equipment output for both working and standby equipment, hypergroup 2 then being translated back to the supergroup 3–12 formation (see Fig. 3(*b*)). A residual equalizer in each hypergroup path enables the overall performance to be achieved at all equipment interface points. The four hypergroup outputs are monitored, and the working path is selected immediately prior to the receive s.t.e. by change-over switches controlled by the working and standby 1,056 kHz pilots on each hypergroup. To simplify filter design in the s.t.e., adjacent supergroups are fed from different distribution units, and each selected hypergroup output is distributed into the odd and even supergroups. Eight receive change-over pilots are, therefore, derived and no preference is given to either set, automatic change-over normally occurring when the pilot on any one or more of the working paths deviates by 2·5 dB, and the pilot on any of the standby paths does not. Each supergroup is routed via 308 kHz pilot-extraction equipment and individual supergroup residual equalizers. Each output is duplicated using a hybrid network to allow in-service patching if required. The engineering service channels are extracted at the even supergroup distribution point of hypergroup 2.

Wideband Equipment

A simplified block diagram of the wideband equipment is shown in Fig. 4.

Transmit

The h.t.e. output is fed through a band-stop filter, which permits the noise produced between the wideband points of the system to be monitored in a 2 kHz band below the main traffic band in the l.f. direction, and above it in the reverse direction. The main traffic path comprises several amplifiers and the following networks.

(*a*) A system transmit equalizer is provided for possible use during system commissioning to shape the transmitted signals for optimum performance.

(*b*) A terminal equipment equalizer is provided to mop-up minor manufacturing discrepancies of certain networks, producing output characteristics on both transmit paths, within specified limits.

(*c*) Variable temperature equalizers are provided to compensate for changes in cable attenuation due to sea temperature changes, and are switched to maintain the system pilots within ±0·5 dB of nominal.

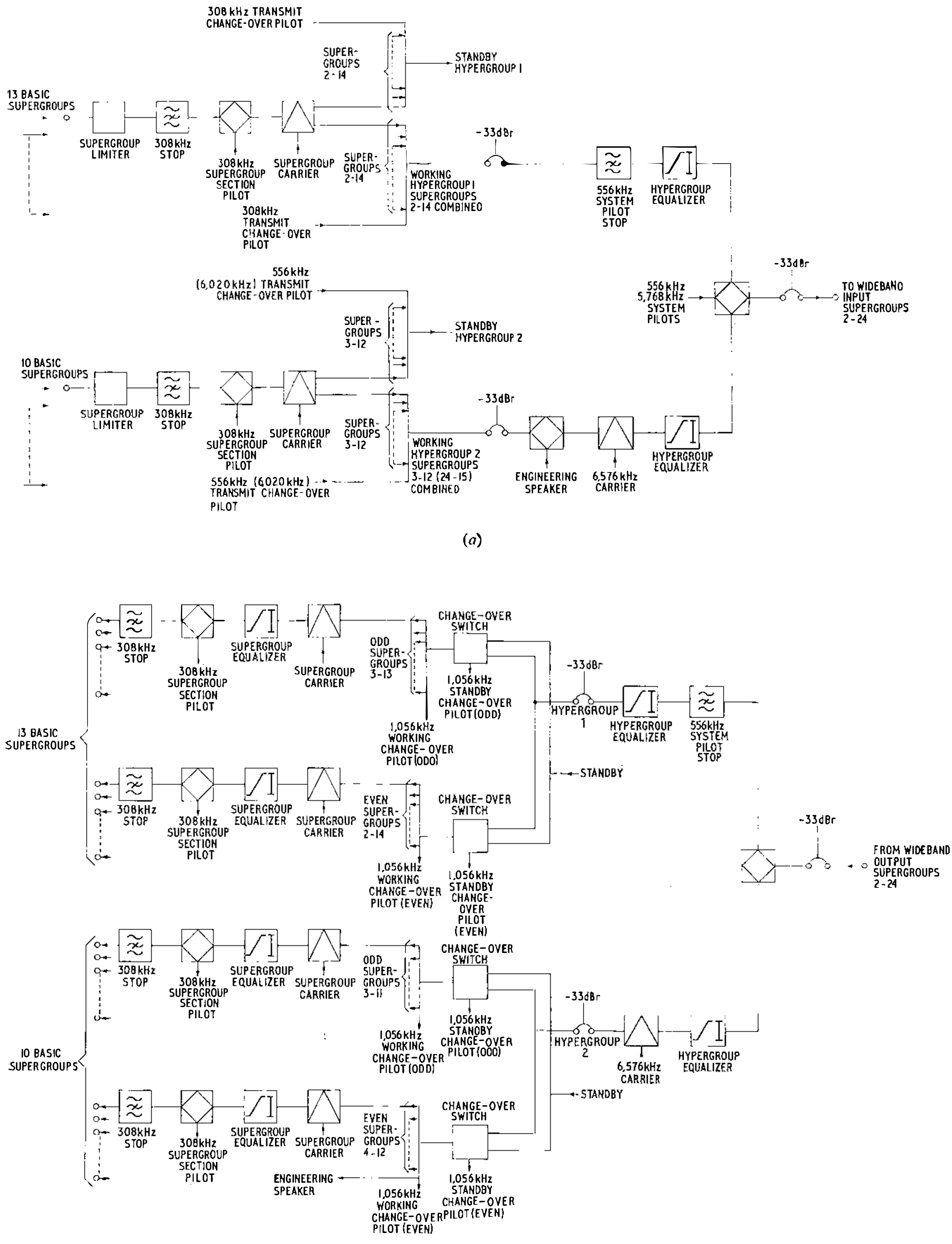
(*d*) Cable simulation networks and equalizers are provided to achieve the correct input levels at the first submerged repeater and, also, the required system pre-emphasis.

(*e*) Repair-cable simulation networks are provided to compensate for attenuation changes due to cable repairs.

Prior to the directional filters, mercury-wetted reed relays select the working terminal equipment under the control of the change-over pilots. On change-over, an interruption of up to 10 ms may occur, due mainly to the recognition time of a pilot failure. The cable pilots and submerged-repeater-monitoring-equipment (s.r.m.e.) transmit signals are injected immediately before the directional filters, which provide the four-to-two-wire conversions. They are duplicated, but the change-over is manual and performed with U-links. The B-terminal transmit path contains a system modulator with a 14,012 kHz carrier supply for translation into the high-frequency (h.f.) band.

Receive

The receive wideband equipment is duplicated from the receive hybrid, which is preceded by extraction networks for receive cable pilot and s.r.m.e. signals. At the receive hybrid, the receive path change-over pilots are injected into both working and standby paths. This eliminates reliance on the system pilots from the remote terminal, as has hitherto been the practice; thus, less interruptions occur, as change-over of a transmit path will not cause the remote terminal to change-over. The networks on the receive path are similar to those



(*a*) Transmit
(*b*) Receive
Note 1: Supergroup 2 not translated
Note 2: Amplifiers not shown

FIG. 3—Simplified block diagram of supergroup and hypergroup translating equipment

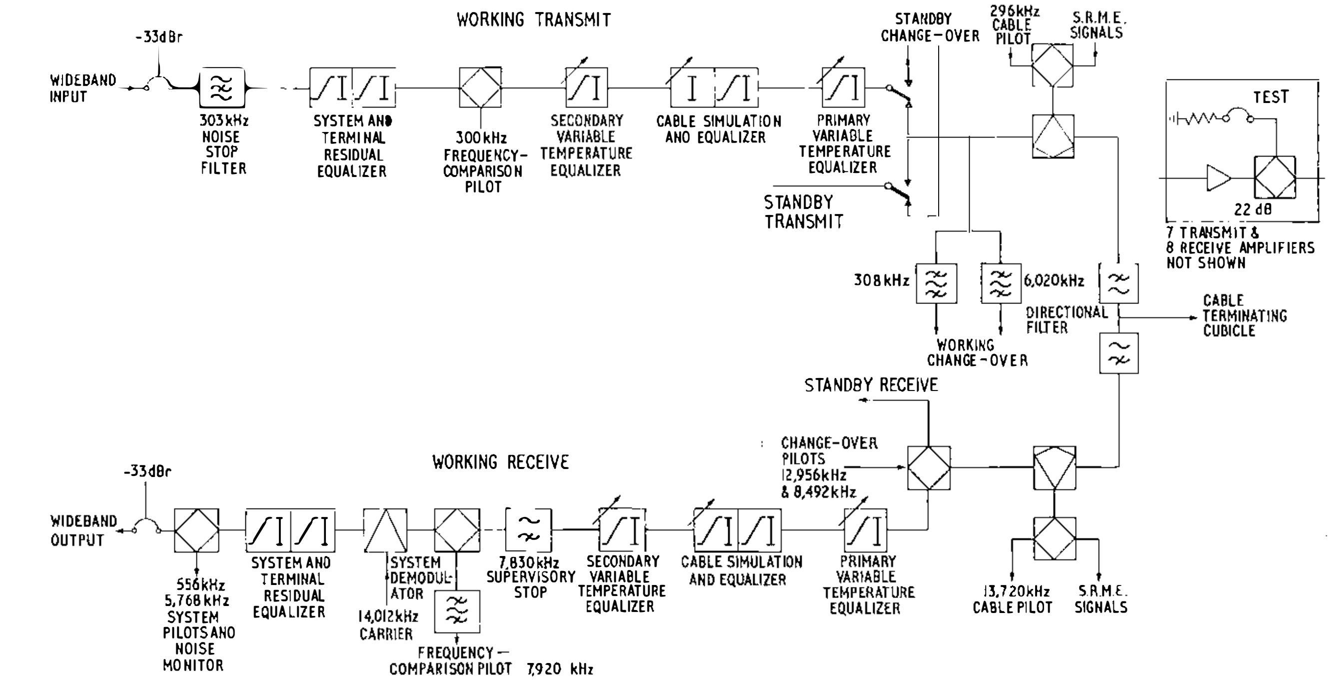


FIG. 4—Simplified block diagram of A-terminal wideband equipment

on the transmit path. A system demodulator is required at the A terminal to translate the received high band into the normal baseband spectrum.

Metal covers prevent accidental removal of all U-links capable of interrupting traffic; the U-links provide an interface test point for commissioning and special-test purposes. A series of engraved coloured lamps are provided at key points in the main transmission path for easy recognition of the traffic-carrying path and observation of the standby-path status.

Pilot Equipment

The pilot equipment may be sub-divided into the following groups.

(*a*) *Terminal Pilots*—These control the change-over switches which select the working transmit and receive terminal equipment. On the transmit path, 308 kHz and 556 kHz pilots are injected at the s.t.e. combining network and monitored at the transmit change-over point. The pilots are monitored at 308 kHz and 6,020 kHz at both A and B terminals, but in the latter, they are extracted at 13,704 kHz and 7,992 kHz and then translated before being monitored.

The receive control pilots, injected at the wideband receive path input, are 8,492 kHz/12,956 kHz and 1,056 kHz/ 5,520 kHz at the A and B terminals respectively, but are all monitored at 1,056 kHz at the receive path selection point at the h.t.e. output. Four 1,056 kHz pilot monitors may be connected to either the working or standby paths by U-links.

(*b*) *System and Cable Pilots*—The system pilots are injected and extracted at the transmit input and receive output wideband paths, respectively, the frequencies being 556 kHz and 5,768 kHz (A–B) and 13,456 kHz and 8,244 kHz (B–A). These pilots monitor the overall system performance (working and standby) between wideband points, and form the basis for variable temperature equalizer switching to maintain wideband points within 0·5 dB of nominal. The cable pilots, having frequencies of 296 kHz (A–B) and 13,720 kHz (B–A), permanently monitor the submerged plant alone; they are, therefore, injected and extracted at the directional filters.

(*c*) *Supergroup Section Pilots*—These 308 kHz pilots can be injected on all but five supergroups, in which the translated frequency involved is used for other pilot functions; injection on these five supergroups is barred mechanically on the U-link panel through which all 308 kHz pilots pass. The panel permits connexion of section pilots when required, or as a permanent feature. Extracted 308 kHz pilotsarealsofedviaa U-linkpanel, enabling permanent monitoring of selected supergroups by one of three 308 kHz monitors and recorders. These pilots permit the frequency-response to be measured at all amplifier test points throughout both terminals. Measurements at the last transmit and the first receive amplifier at the remote terminal indicate system attenuation changes without injecting potentially-hazardous external signals.

(*d*) *Frequency-Comparison Pilots*—These are derived from national standards, or station master oscillators; they are independent of modulation stages and are exchanged between terminals. The 60 kHz signal is multiplied up to 300 kHz (A–B), or 7,920 kHz (B–A), transmitted to the remote terminal, and then divided back down to 60 kHz. The line frequencies used avoid the use of the system modulator and demodulator.

All the pilots are injected at a level of —20 dBm0. All pilot generators, except for the cable pilot, are duplicated with automatic and manual change-over facilities, and the working output of each generator is monitored. The working and standby receive system pilots and transmit change-over pilots are permanently monitored. Over the specified temperature and voltage range, the generators and the monitors have a level stability of better than 0·1 dB/week, and the oscillators a frequency stability better than 5 Hz/week.

Speaker Equipment

Standard 3 kHz equipment provides the four service channels. One is a dedicated cable-system speaker with signalling and speaking facilities available on the terminal equipment, the remainder being available for the metropolitan centre speaker communications. The four audio channels are translated into the bands 6,024–6,036 kHz (A–B) and 7,976–7,988 kHz (B–A) for transmission over the line. The whole of the speaker equipment is duplicated and designated *Regular* and *Alternate*, change-over being manual by U-links. The equipment is independent of the main transmission path change-over as it is connected to both paths.

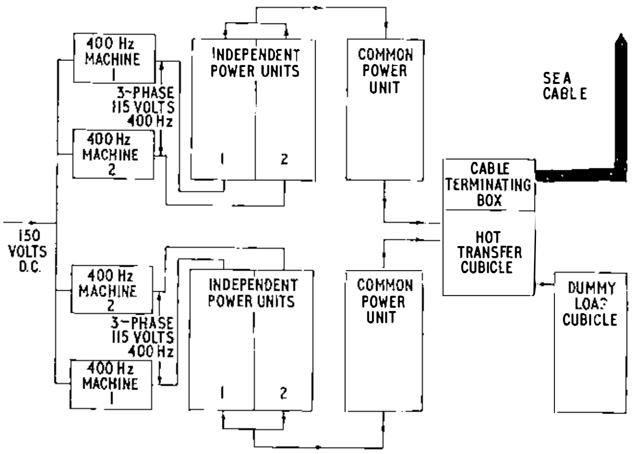


FIG. 5—Block diagram of power-feeding equipment

POWER-FEEDING EQUIPMENT

The submerged repeaters are energized by a direct current of 490 mA, fed into the centre conductor of the cable with an earth (sea) return path. At 490 mA, a nominal 20 volts is dropped per repeater and about 6 volts per cable section. Hence, for the 473 repeater sections of CANTAT 2, the total terminal voltage is 12·3 kV; say 14 kV to allow for the probable large earth potential variations. Direct current is extracted by relatively simple inductor-capacitor filters in each repeater. To keep the voltage applied to these capacitors to a minimum, power is fed from both terminals working in series-aiding, one feeding positive voltage and the other negative. Security of service has been provided by fairly extensive duplication of the facilities at each terminal and duplicate 150-volt, 1,000 ampere-hour batteries supply rotary inverters which generate power at 400 Hz for transformation to high-voltage in the power units.

Layout Arrangement

A block diagram of the equipment is shown in Fig. 5.

Each complete power-feeding equipment (p.f.e.) comprises eight free-standing cubicles with rear-door access. Staff are protected from all components and wiring at high voltages by mechanical interlocks, controlled by key-locked isolating switches. These also ensure that all switching operations are made in the correct and pre-determined sequence. The functions of the various equipments are summarized below.

400 Hz Motor Alternators—These machines operate from a 150-volt d.c. input and generate a 115-volt, 3-phase, 400 Hz output. They consist of a d.c. compound-wound motor, flexibly coupled to a 3-phase brushless-type alternator, the stator assembly of which carries the alternator a.c. windings. Mounted on a common shaft are the rotating field assembly, the exciter armature and rotating rectifiers. Motor alternators were used as there was insufficient time to develop suitable high-power static inverters.

Independent Power Unit (*i.p.u.*)—The i.p.u. contains the transformer and rectifiers for converting the 3-phase, 115-volt a.c. input to the requisite high direct output voltage, and also regulates the output current. Two i.p.u.s are connected in parallel in a current-sharing condition, and if one fails, the other takes up the full load and continues to feed the system. Each i.p.u. can be switched to a regulated short-circuit position for testing purposes.

Common Power Unit (*c.p.u.*)—The c.p.u. contains the current and voltage monitoring circuits for the i.p.u. output, the output smoothing networks and the shut-down initiating circuits necessary for repeater protection.

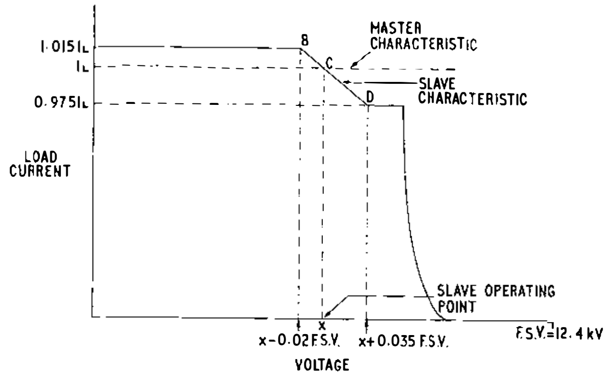


FIG. 6—Master/slave characteristic

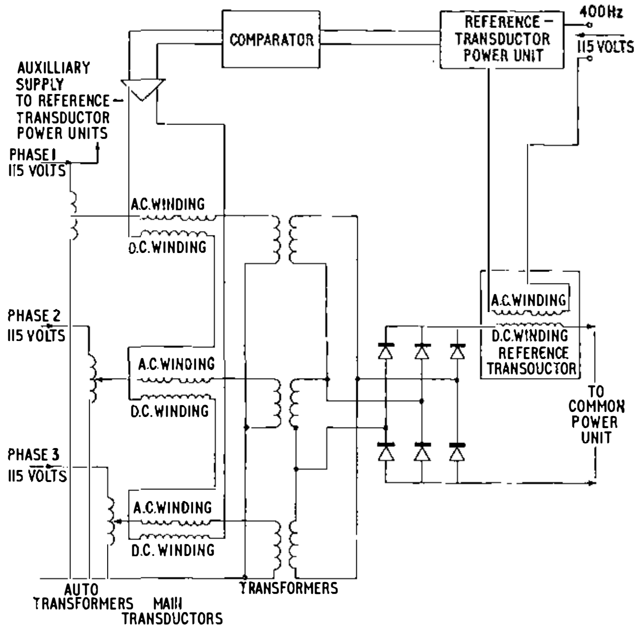


FIG. 7—Circuit elements of i.p.u. for line-current regulation

Hot Transfer Cubicle (*h.t.c.*)—The h.t.c. contains a make-before-break switch which allows the suite on-line to be changed-over, without interrupting the line current. The standby suite is routed to the dummy load. The h.t.c. also contains the cable terminating box.

Cable Terminating Box (*c.t.b.*)—The c.t.b. contains the impedance-matching transformer for connecting the 54-ohm sea cable to the 75-ohm transmission circuits, and the filter circuits which separate the traffic signals from the power-feeding current.

Dummy Load Cubicle—The dummy load consists of eight variable rheostats. These are used to adjust the standby voltage to that of the suite on-line prior to changing over, and to provide a range of test conditions for checking the satisfactory operation of the suite not on-line.

Master/Slave Operation

Energizing the system in series aiding, with both terminals regulated to the same value of current, is difficult. Therefore, the power control circuit is designed such that one end—the *master*—operates with a constant-current characteristic, and the other end—the *slave*—operates at a predetermined output voltage. The slave operates about point *C* on the *BCD* portion of the master/slave characteristic (Fig. 6). The slave characteristic is obtained by deriving a reference potential, proportional to the i.p.u. output voltage, from the primary voltages of the input transformers. This reference potential is applied to the comparator circuits. The comparator in the master terminal is controlled by the line current only and is a true constant-current source.

Regulation of Line Current

The i.p.u. derives a constant d.c. output from the 115-volt, 400 Hz, 3-phase source, and each i.p.u. can produce the required full output. Transductors provide the required regulation and consist of an a.c. and a d.c. winding, such that the reactance of the a.c. winding is varied by the current in the d.c. winding.

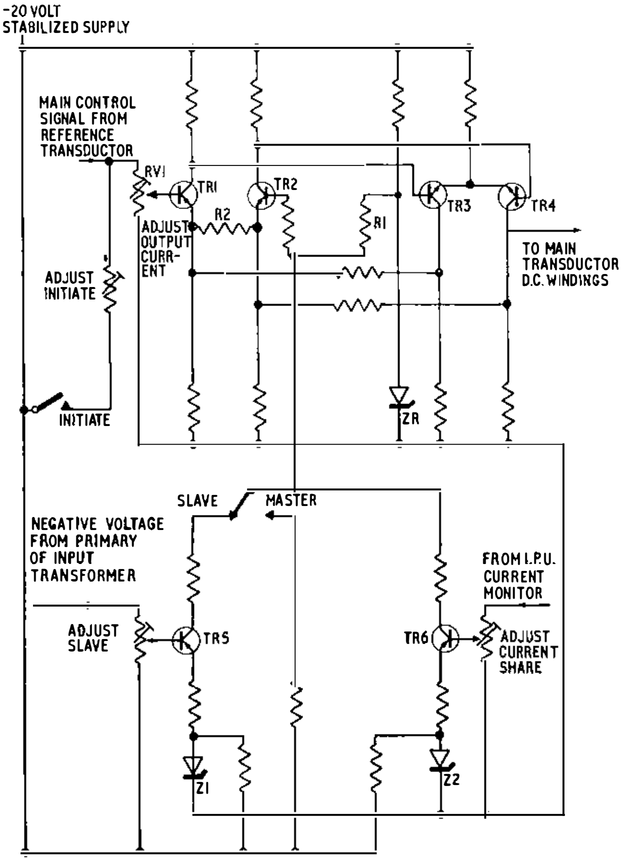


FIG. 8—Simplified control circuit

Each of the 115-volt input phases is connected to an auto-transformer (Fig. 7). The tapping selected determines the limiting voltage of the equipment. This must be set such that, with an open circuit on the cable, the maximum voltage that can be fed to line does not exceed the maximum voltage that can be applied to the repeaters. The limiting voltage must also allow for a 2 kV increase due to magnetic storms. The phases are connected via the a.c. windings of the main transductors to the transformers and rectifiers, and the d.c. output is connected through the d.c. winding of the reference transductor. Output changes from the i.p.u. alter the reference transductor a.c. winding reactance to the 400 Hz square wave connected across it, and vary the signal applied to a comparator circuit in the control unit, shown simplified in Fig. 8.

Transistors, TR1 and TR2 form the comparator circuit driving a long-tailed pair: transistors TR3 and TR4. The main control voltage from the reference transductor, applied to the base of transistor TR1, is compared with the reference voltage on the base of transistor TR2, this being altered for current-sharing and slave operation by feeding a current through resistor R1 via transistors TR5 and TR6. With nominal line current, the comparator is balanced, transistors TR1 and TR2 base potentials being equal. Hence, transistors TR3 and TR4 conduct equally, and the output to the main transductor d.c. windings remains unchanged. If the line current increases, the base of transistor TR1 is driven more negative and conducts more. The current through transistor TR2, therefore, reduces due to the emitter-coupling resistor R2. Transistors TR3 and TR4 thus conduct more and less, respectively, and the output drive from transistor TR4 collector to the main transductor d.c. windings is reduced. This increases the reactance of the main transductor a.c. winding and, hence, the output line current is reduced to nominal. The potentiometer RV1 permits the nominal line current to be adjusted. The system level stability against line-current variation was specified to be not greater than $\pm 0 \cdot 5$ dB for line current changes of $\pm 0 \cdot 2$ per cent. This was not quite achieved, as the overall system changed $0 \cdot 6$ dB for a $0 \cdot 2$ per cent current change made during the commissioning tests. This is likely to be of small consequence as the p.f.e. current stability is consistently better than $0 \cdot 1$ per cent, due partly to both terminal stations being temperature-controlled to within 1°C.

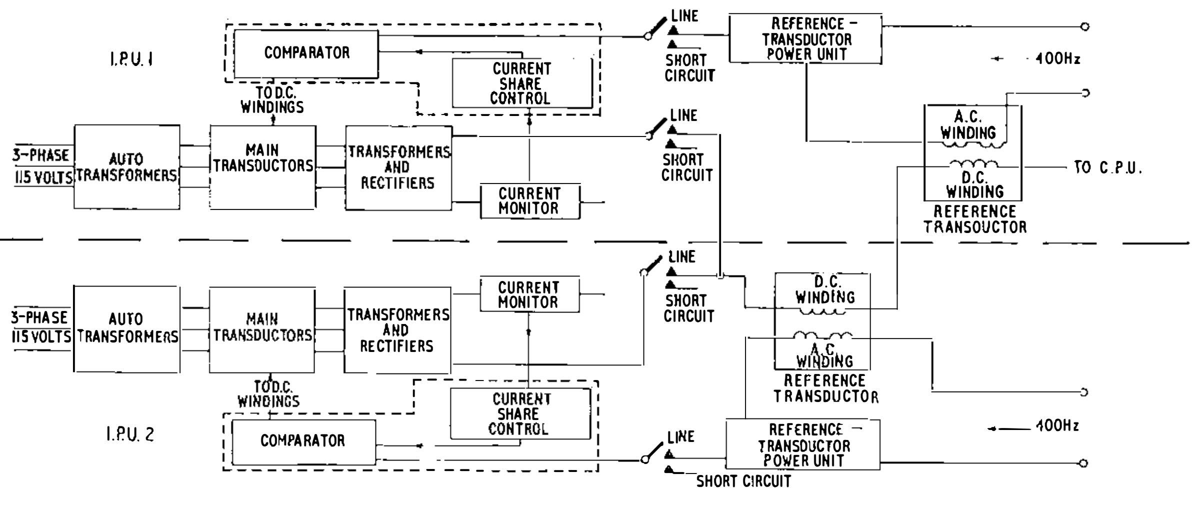


FIG. 9—Block diagram of i.p.u. illustrating current sharing

Current Sharing

Under current-sharing conditions, the system is fed from two i.p.u.s in parallel, while the two i.p.u. reference transductors are connected in series. The control loops, therefore, operate to the line current value whilst the current-sharing circuits operate according to the i.p.u. output current values.

Assume only i.p.u.1 is feeding the system with the nominal regulated line current I_L (Fig. 9). When i.p.u.2 is switched to line, the output from its current monitor and current-share controls alter the reference potential in its comparator circuit to balance at a c.p.u. current of $1{\cdot}025\ I_L$. The i.p.u.2 reference transductor is only sensing the i.p.u.1 output current and initiates an increased i.p.u.2 output current. The i.p.u.1 reference transductor senses this line current increase and, since it is set to balance at I_L, initiates a reduction in i.p.u.1 output current. The i.p.u.2 output current continues to increase and that of i.p.u.1 to decrease, the c.p.u. line current remaining constant, until they reach the value at which their comparator reference voltages are the same. These references are set such that each unit operates between 45–55 per cent of the nominal system line current.

Initiate/Receive

The equipment is switched-on to power the system using one terminal to trigger the switch-on circuits of the other. The master terminal is designated the *initiate* and the slave terminal the *receive*. At the master terminal, one i.p.u. of the suite connected to the system is switched to the INITIATE condition, biasing the comparator reference potential to give an output line current of 80 mA. The i.p.u. is then turned ON, and energizes the system with 80 mA.

At the slave terminal, one i.p.u. is switched to the RECEIVE condition, the supply to operate its input contactor being interrupted. When the i.p.u. is switched to line and turned ON, it only receives 80 mA from the distant terminal. The received 80 mA is applied to a time-delay circuit to prevent inadvertent switch-on due to earth currents, or induced currents. Having received 80 mA for 2 min, the i.p.u. turns ON and starts energizing the system. It feeds the cable with increasing current until the output voltage reaches its limiting value. At the initiate terminal, when the line current has increased to 140 mA, the comparator-circuit bias is switched out and the i.p.u. is triggered fully ON. The line current at both terminals rises to the working value of 490 mA, the voltages at the master rising and the slave falling until it reaches the preset slave working point. When both ends have stabilized, the second i.p.u.s are turned ON, the system then being fed with two i.p.u.s in current sharing, at each terminal.

SUBMERGED-REPEATER MONITORING EQUIPMENT

The s.r.m.e., used on CANTAT 2, is the logical development from the equipment used on proprietary 14 MHz short systems. The important new feature is the programmable unit, enabling the repeaters to be scanned automatically, in any order, regardless of their geographical location and crystal-filter frequency. The narrow frequency spacing between the crystal filter of the individual repeaters (150 Hz) and the total uncertainty (±250 Hz) of the repeater local oscillators, coupled with the large number of repeaters makes this imperative. The s.r.m.e.

(*a*) periodically monitors the performance of all (or part) of the submerged plant (repeaters and cable), and

(*b*) locates faults (provided the system can be powered).

For ergonomic reasons, the s.r.m.e. is designed as a separate self-contained console, using 62-type practice, instead of the standard rack installation previously used.

TABLE 1
Supervisory Frequencies used on CANTAT 2

Frequency (kHz)	Function
9,550 9,460	*B*-frequencies for measurement of (2*A*–*B*) intermodulation from B terminal
9,300 9,210	Second and third harmonic return frequencies—translated from 200–290 kHz at B terminal
8,400	*A*-frequency for measurement of (2*A* – *B*) intermodulation from B terminal
7,830 7,740	Loop-gain frequencies (A receive or B send)
7,540	Crystal-oscillator frequency in each repeater
7,340 7,250	Noise pick-off filter in each repeater. Also picks off second and third harmonics produced by l.f. amplifier and (2*A*–*B*) intermodulation product produced by h.f. amplifier
3,670 3,625	Fundamental frequencies for measurement of second harmonics from A terminal
2,447 2,417	Fundamental frequencies for measurement of third harmonics from A terminal
290 200	Loop-gain frequencies (A send or B receive). The repeater identifying crystal-filter frequencies are in this band

Facilities

The s.r.m.e. can measure

(*a*) loop gain (A- and B-terminal measurements),

(*b*) second- and third-harmonic performance of the repeater low-band amplifiers (A-terminal measurement),

(*c*) intermodulation (2*A*–*B*) performance of the repeater high-band amplifiers (B-terminal measurements), and

(*d*) repeater noise (B-terminal measurements).

Tests (*a*) and (*d*) are performed at varying intervals with the system carrying traffic, and tests (*b*) and (*c*) when the system is out of service; e.g., after a cable fault, as the frequencies used (Table 1) are all in the traffic band and the test levels may degrade the system performance even with the appropriate supergroups removed. The s.r.m.e. has three operational modes—*manual*, *semi-automatic* and *automatic* and all measurements may be made in any mode.

Repeater Oscillator

The uncertainty, or drift, of the repeater 7,540 kHz crystal oscillator influenced some aspects of the equipment design; mainly, intermediate-frequency (i.f.) filter bandwidth and scanning techniques. The sole identifying characteristic of any repeater is its narrow-band crystal filter (3 dB bandwidth 25–40 Hz). In the A-terminal harmonic and B-terminal loop-gain and intermodulation measurements, a test tone from the terminal may excite a return response from the two repeaters having crystal-filter frequencies adjacent to the required repeater, if their local-oscillator frequencies have changed sufficiently. For example, the effect on B-terminal loop-gain measurements of the worst case of drift is shown in Table 2.

TABLE 2
Effect of Oscillator Drift on B-Terminal Loop-Gain Measurements

Repeater Number	Crystal-Filter Frequency (Hz)	Repeater Local Oscillator		B-Terminal Transmit Frequency (Hz)
		Drift (Hz)	Frequency (Hz)	
R_{n-1}	$fx - 150$	+150	$fc + 150$	$fc + fx$
R_n	fx	0	fc	$fc + fx$
R_{n+1}	$fx + 150$	−150	$fc - 150$	$fc + fx$

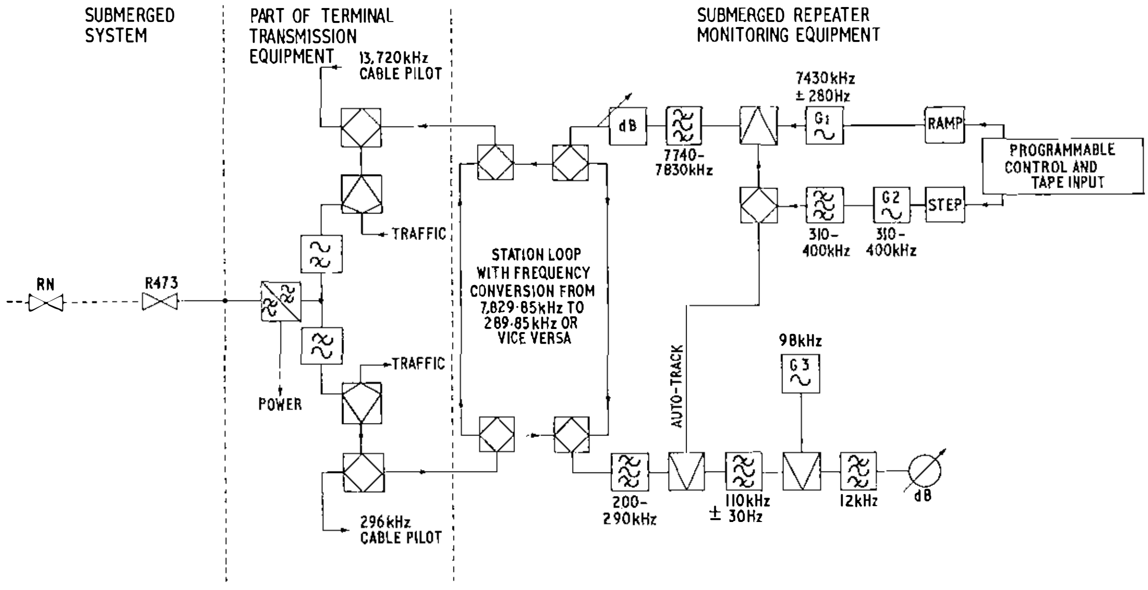


FIG. 10—Simplified block diagram for measurement of loop gain from the B terminal

This shows that the single transmit tone excites three repeaters. A narrow-band (60 Hz) receive i.f. filter and correct auto-tracking were, therefore, provided to give the necessary discrimination of returned signals.

Tests in which the test signal is first selected by the repeater filter before being modulated are unaffected by oscillator-frequency drift. Loop-gain measurements from the A terminal are unaffected, provided the 110 kHz i.f. filter is made 500 Hz wide to cater for the worst case. Noise measurements from the B terminal are also unaffected because, within the confines of the repeater 90 kHz noise pick-off filters, the modulation process is self-adjusting due to the non-selectivity of noise production; the receiver sees the narrow (20 Hz) noise band, issuing from the identifying crystal filter, directly.

Scanning

Because of manufacturing tolerances of the repeater crystal filter, its ripple (up to 4 dB) and a small, but significant temperature coefficient, it must be scanned during measurements to get reproducible results. If a single nominal frequency is transmitted, a 3–4 Hz shift in the filter characteristic, or test tone, can cause 2 dB change in the return signal. The peak response is, therefore, measured each time, it being assumed to be invariant.

To cater for repeater local-oscillator variations of ±250 Hz, a total scan of ±280 Hz is applied from the appropriate oscillator (G1 of Fig. 10). However, only about 5–10 per cent of the scan is effectively used in exploring the filter. Therefore, the 560 Hz range is split into 24 slots, each of 100 Hz and overlapping adjacent slots by 80 Hz. The difference from nominal of each repeater local oscillator is measured manually on commissioning the system, and each repeater is allocated one of the 24 slots to centralize the local oscillator in the appropriate slot. Thus, to measure the B-terminal loop gain of a repeater with a local-oscillator error of +100 Hz and a 250 kHz identifying filter (Fig. 10), synthesizer G2 is set to 360 kHz (250 kHz + i.f.) and modulated with the sweep oscillator G1 offset by +100 Hz, giving a centre frequency of 7,430·1 kHz. The transmit frequency then sweeps over 7,790·05–7,790·15 kHz and the crystal filter is swept over 249·95–250·05 kHz after modulation by the repeater local oscillator. The swept return signal is modulated, in the receiver, by the 360 kHz auto-track signal to give a swept i.f. response centred on the 110 kHz i.f. filter, this being slightly wider than the widest repeater filter. The final result is displayed on a decibelmeter and recorder. Three scanning speeds are provided, in the ratio 1 : 2 : 4, interrogation of every repeater in the system taking about 4 h at the slowest speed.

Program Control

Rohde and Schwartz programming equipment is used when making measurements in the semi-automatic and automatic modes. A punched control tape, containing the synthesizer frequencies corresponding to the nominal identifying-filter frequencies and the repeater local-oscillator offsets in an eight-hole code, is scanned by the tape reader. This information is fed to the program control unit, where it is converted into binary-coded-decimal code for the synthesizer and 1-out-of-10 code for the relay unit which selects the appropriate offset slot for the sweep oscillator. Three stores, with addresses N, K and E, are used in the program control unit, and the complete information on the tape for one repeater is, typically, of the form $N917K335E020: where $ is a command signal denoting new instructions; N917K335 denotes the correct repeater (9·17335 MHz −8·9 MHz = 273·35 kHz—identifying filter frequency of repeater No. 11); and E020 denotes the slot for offsets between −60 Hz and −40 Hz. If the next repeater interrogated has an identifying-filter frequency of 273·2 kHz and an offset in the same range, the programming information becomes $K320, the contents of stores N and E remaining unchanged.

A single tape controls all s.r.m.e. test functions from one terminal for testing any required number of repeaters. In the semi-automatic mode, the tape only controls the selection of the repeaters via the synthesizer, scanning being done manually on the sweep oscillator, which also tunes the receiver via the auto-track path.

System Application

The normal routine measurements on the CANTAT 2 system using the s.r.m.e. are the loop gains at both terminals and noise at the B terminal. At the A terminal, there are three tapes available controlling

(*a*) monthly loop-gain tests of all the repeaters,

(*b*) weekly tests of the repeaters west of each submerged equalizer, plus a few selected ones, and

(c) daily tests of the first and last repeater in the system, and the two repeaters at the edges of the continental shelves.

Tests (a) and (b) check general system behaviour together with the various pilots. Test (c) checks the parts of the system subjected to temperature variations. To eliminate errors at the terminal due to setting-up and calibration, and return-level differences due to deliberate transmit-level changes, test results are generally evaluated in loop-gain differences rather than absolute values.

The temperature-affected parts of the system, repeaters R1 and R70 on the U.K. shelf and R436 and R473 on the Canadian shelf are tested. It is justifiably assumed that the high- and low-band gains of R1 and R473 do not vary, nor do the conversion losses of (R1 and R70) and (R473 and R436). The results of test (c) then reflect the variations, due to temperature, of the partial system losses between the B end of R1 and the A end of R70, and similarly, the A end of R473 and the B end of R436 at the s.r.m.e. frequencies. There is a direct correlation between the changes of these loop-gain results and the required settings of the variable temperature equalizers at the two terminals.

The other main application of the s.r.m.e. is for fault location. Location of a total cable break is simply a repeater count from the terminal closest to the break, single-end power feeding only being possible up to about half system length. Under other fault conditions, with the system normally powered, the location is determined from loop-gain tests in conjunction with the receive-pilot readings. A loop-gain measurement from the A terminal to repeater R_n indicates that the fault may be in one of the following, the corresponding behaviour of the receive pilots being as shown, assuming a flat increase in loss:

(a) the l.f. amplifier of R_{n-1}, giving a drop in pilot levels at the B terminal,

(b) the h.f. amplifier of R_n, giving a drop in pilot levels at the A terminal,

(c) the supervisory circuit of R_n, giving no change in pilot levels at either terminal, or

(d) the cable section between these repeaters, giving a drop in pilot levels at both terminals.

A similar evaluation of the loop-gain measurements from the B terminal would also be made.

CONCLUSIONS

Extensive effort was necessary to complete all the tests and equalization needed to satisfy the specified system requirements. An on-site miniature computer was used for equalization calculations, and supergroup response measurements were made using automatic scanning equipment. The attenuation/frequency response limits of ± 1 dB, with no more than $0 \cdot 5$ dB variation over any 48 kHz band under any change-over conditions, were achieved on all supergroups. The overall tests demonstrated that CANTAT 2 met all expectations. They also indicated that the specified system performance should be maintained over the life of the system, with 1 mile of repair cable added, and with the expected range of sea-bed temperatures. Nearly 60 days of intensive work was needed to complete the comprehensive test program, much of it on a 24 h shift basis. This concentrated effort at the end of a long project assisted in making the system available nearly three weeks early.

ACKNOWLEDGMENTS

The successful completion of the commissioning and acceptance of the system, earlier than contractually agreed, was only made possible by dedication and co-operation by staff at all levels in Standard Telephones and Cables Ltd., the Canadian Overseas Telecommunications Corporation and the B.P.O. (Telecommunications Headquarters and the South Western Telecommunications Region.)

Cable Laying by Satellite Navigation

J. RICHARDSON†

U.D.C. 621.315.285: 527.6: 528.28: 629.783

This article first outlines the principle of navigation by satellite. It then describes the integration of satellite navigation and many other navigational techniques into the composite Hydroplot system used for navigation during the route survey and laying operations of the CANTAT 2 submarine cable system.

INTRODUCTION

Several navigational satellites have been placed in polar, or near-polar, orbit round the earth at an altitude of approximately 600 nautical miles. The angular displacement of their orbits at the Equator is nearly 45° (see Fig. 1). These satellites provide contact to any position in the world, on almost an hourly basis, and each satellite takes about 100 min to complete its orbit. Each satellite transmits phase-modulated data on two frequencies, in 2 min messages, consisting of time-synchronization signals, a tone signal on the even 2 min mark, and fixed and variable parameters describing its orbit. Thus, the satellite becomes a self-contained radio beacon, radiating on frequencies of 400 MHz and 150 MHz.

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PRINCIPLE OF OPERATION

The satellite navigational message is controlled by a chain of tracking stations and a computing station. The computing station computes an orbit that best fits the Doppler curves obtained from the tracking stations. Using this computed orbital shape, the computing centre extrapolates the position of the satellite for each 2 min of its orbits for the next 12 h. These data, together with any time corrections etc., are injected into the satellite memory for transmission to earth at the appropriate time. These transmissions are monitored to ensure accuracy of data.

The satellite receiver picks-up the signals from the satellite, measures the Doppler shift, decodes the message and organizes the data for positional fix by a computer. To obtain a fix, it must be possible to measure the position

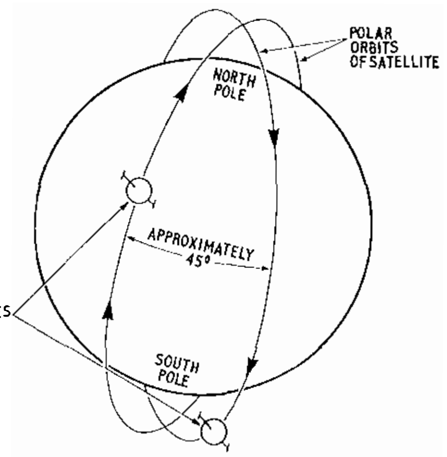

FIG. 1—Polar orbits of navigational satellites

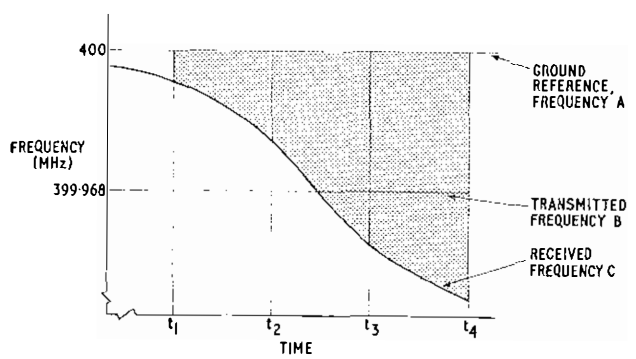

FIG. 2—Geometric representation of integrated Doppler count

relative to that of the known satellite orbit. This is done by measuring the Doppler shift of the received 400 MHz signal using a very accurate frequency standard within the ground receiver, and this measurement is a unique function of the observer's position to that of the satellite.

The ionosphere causes refraction of the 400 MHz signal path producing inaccuracies in the Doppler count, and to correct this error, a second 150 MHz signal is used. Both these frequencies carry the same message, and the refraction difference between them is measured and used to correct the Doppler count.

The best possible estimate of the ship's speed and course during a satellite pass must be available for the computation of the ship's position. The height of the aerial, as a function of the geodetic height, must also be allowed for in the computation. This entails perusal of a geodetic contour map, to which the ship's aerial height above sea level must be added. As the time of the message is all important, accurate time injection for the computation is necessary. Although the frequencies are given as 400 MHz and 150 MHz, they are, in fact, offset by 32 kHz and 12 kHz respectively to give 399·968 MHz and 149·988 MHz.

The Doppler measurement is a measure of the difference in frequency count between the received frequency C and the ground reference frequency A, occurring at each 2 min timing mark. It is the integral of the difference in frequency at the 2 min time interval. This can be interpreted geometrically as being equal to the shaded area of Fig. 2 and expressed mathematically as $\int_{t_1}^{t_4}(C - A)\mathrm{d}t$.

For each wavelength that the satellite moves closer to the observer, one cycle is added to the count. The reverse happens

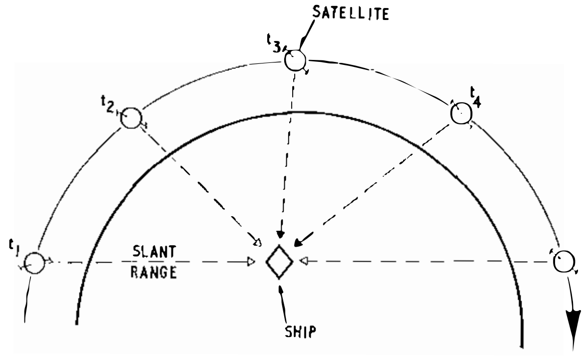

FIG. 3—Variation of slant range with satellite position

once the satellite passes its zenith. The Doppler count is a measure of the range difference to the observer, and at 400 MHz, each count is equal to 0·75 m. Thus, it is a very sensitive measure of the slant range difference at the 2 min points (see Fig. 3).

During a satellite pass, up to eight messages are received, each slightly different from the previous one. At least three messages are required for a fix. Obviously, the more received, the more accurate the position becomes. The number depends primarily on one factor; namely, the time taken for the pass, this being dependent on the elevation of the satellite to the observer at its zenith. It is generally accepted that the elevation should be at least 10° and not more than 75°. This allows enough time for a clear three messages during a lower pass, and avoids exceeding the receiver's ability to interpret the very rapid Doppler changes which occur at the higher-elevation pass.

A simple explanation of the calculation of the ship's position is as follows. The computer knows where the satellite was throughout its pass, and also its velocity and slant range. The navigator determines the ship's position by dead reckoning. The received Doppler curves should then be A, B and C (for three messages), but they are $(A + x)$, $(B + y)$ and $(C + z)$. Therefore, the ship is not exactly where the navigator has said, and the error is corrected by computing a series of successive approximations to give the fix that aligns with the Doppler information to hand. The resultant is output in the form of latitude and longitude, at a precise time.

THE HYDROPLOT SYSTEM

The Hydroplot system, used during the CANTAT 2 cable lay, is developed from the need to use a computer for satellite navigation. It is an integrated navigational system especially designed for cable ships and is unique to the British Post Office (see Fig. 4). As many of the navigational aids as practicable are interfaced to the computer for positional calculation and generation of historic data of the lay. This data is produced in plain language and is time dated. The computer used is a Marconi Elliot 905. This is a digital computer with an 18-bit word length, using integrated-circuit technology, and having a 16 kbit store of 1 μs cycle time.

To appreciate more fully the effect of the advance made in navigational accuracy by the introduction of this integrated system of navigation, the navigator's problem when laying a major submarine cable system, of immense capital cost, must be described. The problem of surveying the CANTAT 2 cable route is described elsewhere.[1] This is basically the need to find a path for the system which is clear of all projections, valleys etc., and to plot that path with a certainty that the

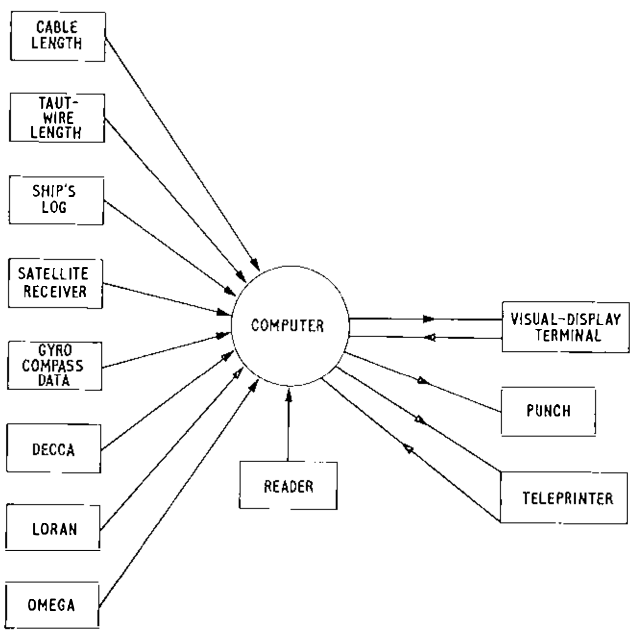

FIG. 4—Block diagram of the Hydroplot system

laying ship will be able to follow the projected route faithfully. This entails days of block surveying of certain areas before the route is agreed and plotted. The laying ship is informed of the conclusions, and of the degree of cable slack over each mile of the route. This is the percentage figure by which the cable length paid out is greater than the distance travelled over the ground. Thus, the navigator must take account of the course the ship is to make and the amount of cable to be paid out over that course, and this means only one thing—very accurate navigation.

The dead-reckoning position, as defined for this purpose, covers all positions obtained from the course steered by the ship and her speed through the water, and from no other factors. Thus, data from the ship's gyro compass and log are interfaced to the computer to give the dead-reckoning position, but this does not take into consideration wind, tide, currents or any combination of the three. With the hydroplot system, the dead-reckoning position can be modified to show the course required and the speed over the land. It then portrays the projected course.

The hyperbolic navigational aids (LORAN, Decca and Omega)[1] are also interfaced to the computer to compute the running position of the ship in terms of latitude and longitude. To give greater flexibility, any two lines of position from any combination of the hyperbolic navigational aids can be used to obtain an output in latitude and longitude. Comparing the best of these with the (modified) dead reckoning shows whether the ship is on the course required, or whether it is offset by wind, tide etc., provided that the two positions originated from the same point. This is assured, at approximately hourly periods, by a positional fix from the satellite receiver. Both the modified dead-reckoning position and the ship's own track positions are then updated and any offset that the ship may have can, therefore, be detected and rectified.

Both the taut-wire and cable-mileage counters are interfaced to the computer to give the distance and speed over the land, as well as the amount of cable paid out and the percentage slack applying at any time. Historic data is fed-out to the teleprinter by command at the mile marks, repeater positions or equalizer positions. Cumulative counts of both repeaters and equalizers are automatically maintained.

The running commentary of operations is displayed on the visual-display terminal. This has a cathode-ray display unit, with integral refresh storage, character generator and data transmission interface, together with a data-entry keyboard. The keyboard permits the operator to compose messages for transmission to the computer, and to check and edit the information by means of the built-in editing facilities. This is the control point once the system program has been read into the computer.

The software for the Hydroplot system is assembled in SIR language, and consists of an 8-hole punched-tape input to the computer via the reader. The paper-tape station consists of a photoelectric device capable of reading 250 characters/s, a paper-tape punch capable of punching 110 characters/s, and a teleprinter. This includes an integral paper-tape punch and paper-tape reader, which operate at 10 characters/s. The teleprinter punch is used only for subsidiary program input tapes; for example, presenting to the computer station co-ordinates for LORAN, etc. The reader is used to read any data that has been output to the system punch.

The maintenance of the system is by test tapes and the exchange of plug-in boards. Daily, weekly and monthly preventative maintenance is carried out on the paper-tape station, this being mechanical rather than electrical.

CONCLUSION

The successful operation of the Hydroplot system depends on the reception of good hyperbolic navigational aids and the assurance of adequate satellite fixes. Accepting these reservations, the navigator is presented with a very accurate navigational device. As a bonus, the computer tends to smooth out the dawn and dusk effects inherent in the hyperbolic systems at long range. Also, because the speed of the ship during a lay rarely exceeds 5 knots, any deviation rectification due to offset will not affect the laid position of the cable as the rectification is made immediately the offset becomes apparent. As this is under constant review, the position of the laid cable tends to be in a straight line between projected alter-course points.

Reference

1 BATES, CAPT. O. R. The CANTAT 2 Cable System: Planning and Laying the Cable. (In this issue, p. 148).

The Optical Fibre as a Transmission Line

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U.D.C. 621.391.63:677.521

The basic properties of the optical-fibre waveguide are described, together with the various limitations to bandwidth and some possible remedies.

INTRODUCTION

The basic principles and some of the technology of optical-fibre waveguides have been described in previous articles in this *Journal*.[1,2] First thoughts on the subject were that, because of the high frequency of light, the potential bandwidth of an optical communications system would be enormous; several orders of magnitude above that of a microwave system, for instance. The assumption made, for such a high bandwidth, was that the system would be very much like a scaled-down version of one at microwave frequencies. There would be a single-frequency source (a laser), a single-mode dielectric waveguide (the fibre), but with a straight detector (a photodiode) rather than a heterodyne detector. In the years that followed, the concept has enlarged rather than changed, so that a number of different types of fibres and sources are now being actively studied. This diversification has been due to the order in which successes have been achieved, to new ideas on how optical communications could be used, and to the recognition of new bandwidth-limiting effects in the fibres themselves.

OPTICAL-FIBRE WAVEGUIDE

The optical fibre is a dielectric waveguide at optical frequencies. Instead of travelling along conducting surfaces, as in the more conventional metal waveguides, the wave is guided by two regions of the dielectric. The inner region, the core, has a higher refractive index than the outer, or cladding, region. There are no conduction currents, only displacement currents and, as a result, some modes have a component of both electric (E) and magnetic (H) fields in the direction of propagation. These modes are designated EH or HE modes, the predominant field being written first.

In a hollow metal waveguide, the wave is contained within the space enclosed by the conducting walls, but there is no such well-defined boundary in the dielectric guide although, in a practical situation, most of the energy is concentrated within the central core. Since it is not confined, but only guided, the wave on a dielectric guide will, in certain conditions, radiate off into space or into the cladding. Without metal boundaries, at which the tangential electric field must be zero, the solution of Maxwell's equations depends on matching the fields at the boundary between the core and the cladding. Instead of the usual solutions via the zeros of the functions, this produces a transcendental equation which is best solved by computer. However, with the core and cladding refractive indices very nearly equal, it is possible to obtain explicit solutions that are accurate enough for practical purposes.[3]

With these differences in mind, the dielectric guide can be treated as any other transmission line. It can be made monomode or multimode, and its fields, propagation constants, group velocities and impedances can all be determined.

FIELD CHARACTERISTICS

A fibre conforms naturally, but not exclusively, to a geometry where a cylindrical core is surrounded by a cylindrical cladding, as illustrated in Fig. 1. The solution to the

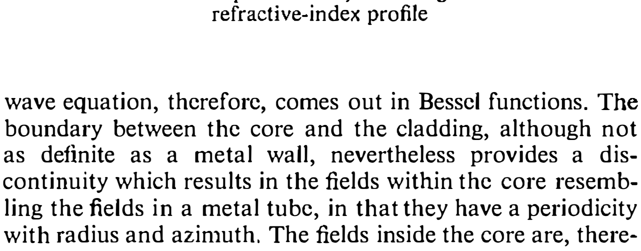

FIG. 1—Monomode optical fibre, showing cross-section and refractive-index profile

wave equation, therefore, comes out in Bessel functions. The boundary between the core and the cladding, although not as definite as a metal wall, nevertheless provides a discontinuity which results in the fields within the core resembling the fields in a metal tube, in that they have a periodicity with radius and azimuth. The fields inside the core are, therefore, described in terms of the Bessel-J functions, which are quasi-periodic. The fields in the cladding, on the outside of the boundary, die away to zero at infinity, and are described by the exponential-like Bessel-K functions. The graph in Fig. 2 shows the field distribution in the core and cladding. The Bessel-J functions correspond to the sine and cosine functions in rectangular-co-ordinate geometry, and the Bessel-K functions correspond to the hyperbolic sine and cosine functions (sinh and cosh respectively). Unless the core region is small compared with the wavelength, the external fields die away rapidly with radius, and there is no need to take the cladding beyond about five times the core radius for a monomode fibre transmission line.

The fundamental mode of the dielectric guide is the HE_{11}. It has components of H and E fields in the direction of

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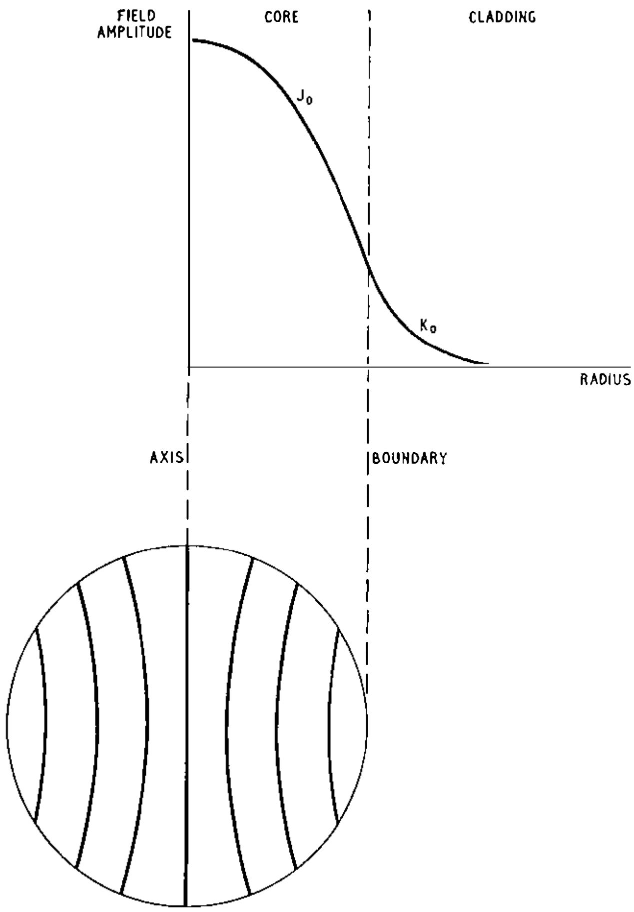
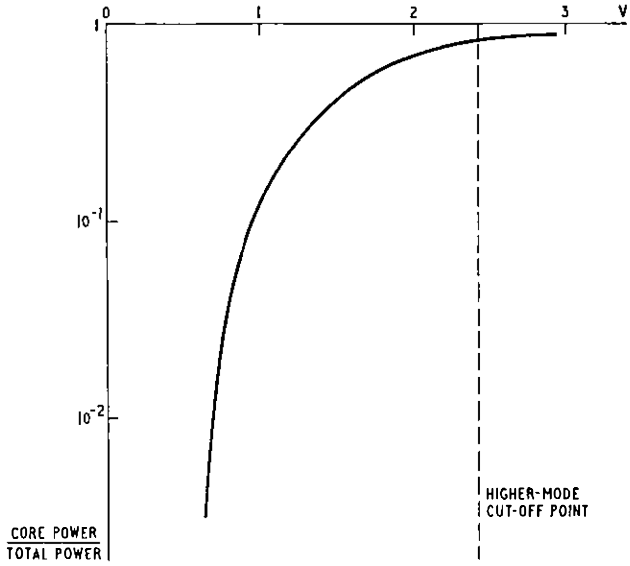
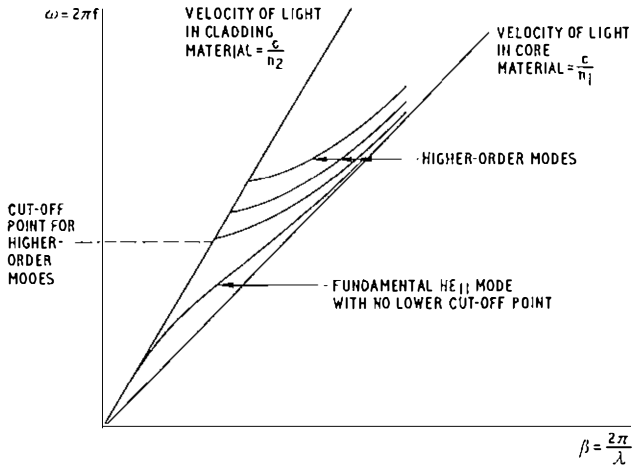


FIG. 2—Field distribution in core and cladding, and E-field pattern of HE_{11} mode in core



Note: $n_1 = 1{\cdot}5$, and $n_2 = 1{\cdot}49$

FIG. 3—Proportion of power in the core of a monomode guide, as a function of the normalized frequency



Note: c is the free-space velocity of light

FIG. 4—Optical-waveguide modes

propagation, and one field variation in both radial and azimuthal directions. The field inside the core, illustrated in Fig. 2, resembles that of the fundamental mode (H_{11}) in a cylindrical metal tube. If the diameter of the metal tube were to be reduced sufficiently, the wave would no longer fit into the tube and would become cut off. However, as the core of a dielectric guide is reduced, the field, not being confined, spreads out into the cladding, until the amount of energy carried by the core becomes so small that guidance is lost.

Normalized Frequency

An important parameter in optical guides is the normalized frequency, V, given by

$$V = \frac{2\pi a}{\lambda_0}(n_1^2 - n_2^2)^{1/2},$$

where a is the radius of the core, λ_0 is the free-space wavelength, and n_1 and n_2 are the refractive indices of the core and cladding respectively. The normalized frequency can be represented as a wave number, $2\pi a/\lambda_0$, multiplied by the numerical aperture of the fibre, $(n_1^2 - n_2^2)^{1/2}$. Fig. 3 shows the proportion of power in the core of a monomode guide, as a function of V.

Higher-order modes have cut-off values determined by $J_l(V) = 0$, where l is related to the mode number, the first being at the first zero of $J_0(V)$, where $V = 2{\cdot}405$, so that a fibre is monomode for $V < 2{\cdot}405$. It is interesting to compare this cut-off condition with that of transverse-magnetic modes in a metal tube, where $J_l(2\pi a/\lambda_0) = 0$.

TRANSMISSION CHARACTERISTICS

The propagation characteristics of fibre guides can best be illustrated on a conventional ω/β diagram, where β is the phase-shift propagation constant, and $\omega = 2\pi f$, where f is the frequency. Fig. 4 shows the modes of an optical waveguide plotted on such a diagram. The velocities of light in the cladding and core materials are shown as two straight lines, with the mode lines for the optical guide lying between them. The difference in velocity between the core and cladding has been very much exaggerated; for a practical fibre with a refractive-index difference of about 1 per cent, the lines would lie much closer together. The group velocity of a wave is given by the gradient, $d\omega/d\beta$, of the mode line. The dispersion, or variation of group velocity with frequency, is dominated in optical fibres by the contribution due to the material itself.

Multiple-Path and Material-Dispersion Effects

The main advantage of the monomode fibre is that it has a single transmission path. Its disadvantage is its small core, being typically 2–3 μm in diameter, which causes difficulties in jointing and coupling. Low-loss monomode fibre was first made by Corning in 1970,[4] using the technique of doping the centre of a silica fibre with titania in order to increase its refractive index. However, at that time, the gallium-arsenide laser, necessary as a source intensive enough to couple into the small core, had not been developed sufficiently to run continuously at room temperature. When a low-loss multimode fibre, in the form of a silica tube with a liquid tetrachlorethylene core,[5] was announced, it could be used with a source which had already been developed sufficiently to run continuously: the light-emitting diode (l.e.d.). The l.e.d. cannot be used with a monomode fibre because of its low intensity, but can launch a reasonable amount of power into the large core of the multimode fibre, illustrated in Fig. 5. This combination, however, is severely restricted in bandwidth because of two effects: the multiple-path effect and the material-dispersion effect. The multiple-path effect is explained in waveguide terms as the result of different modes having different group velocities at any one frequency. For large values of V, that is, a very much over-moded fibre, the number of modes is approximately equal to $V^2/2$.

The spread in group velocity is less than the difference between the cladding and core velocities, by a factor of $1 - (2/V)$. The spread in arrival time, Δt, over a length, L, due to the multiple-path effect, is given by

$$\Delta t = \frac{L}{c}(n_1 - n_2)\left(1 - \frac{2}{V}\right),$$

where c is the velocity of light in free space.

Looked at from the point of view of rays of light reflecting from the boundary, as illustrated in Fig. 5, rays making a steep angle with the axis travel further, and take longer to arrive, than rays with a shallow angle. Using rays, the maximum difference in arrival time is given by

$$\Delta t = \frac{Ln_1}{c}\left(\frac{n_1}{n_2} - 1\right).$$

The discrepancy between the mode and ray approaches is explicable in part by the fact that, with a simple ray theory, no account is taken of cylindrical geometry.[6] The ray theory can be used to give reasonably accurate results when V is large and the refractive-index difference is small.

Graded-Index Fibre

A solution to the problem of the multiple-path effect was found early on in Japan and the U.S.A., with the invention of *Selfoc*[7, 8] and similar graded-index fibres. In such fibres, as illustrated in Fig. 6, the refractive index, n, is made to decrease parabolically with the radial distance, r, from the axis, according to the law:

$$n = n_1\{1 - \Delta(2r/d)^2\},$$

where d is the effective diameter of the core. Light in the outer regions of the core travels faster than light near its centre. There is a continuous self-focusing effect, and the difference in transit time for steep- and shallow-angle rays is much smaller than for the hard-boundary, multimode fibre. The time difference can be reduced still further by a slight departure from the parabolic law.

One type of graded-index fibre[9] is made by diffusing the core–cladding boundary while the fibre is being drawn from a double-crucible arrangement, in which the inner crucible, containing the core glass, has a nozzle placed sufficiently far back inside an outer crucible, holding the cladding glass, for the boundary to diffuse as the glasses flow out of the crucibles. Thallium is used as the diffusing ion.

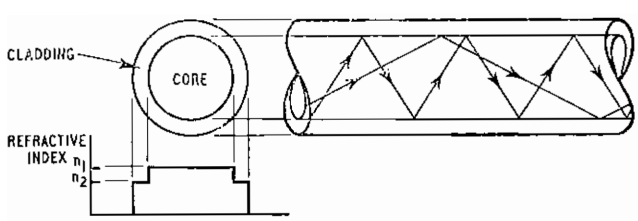


FIG. 5—Multimode fibre, showing cross-section and refractive-index profile

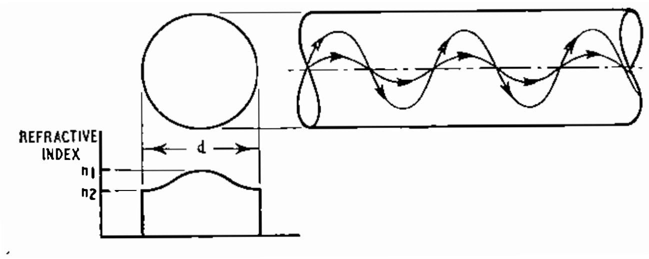


FIG. 6—Graded-index fibre, showing cross-section and refractive-index profile

Graded-index fibre has half the number of modes of a plain multimode fibre and can, therefore, only carry half the power for the same refractive-index difference and core diameter. Apart from this disadvantage, graded-index fibre has the good points of both monomode and multimode guides: virtually a single path, but with a reasonably-sized core.

MODE-MIXING

Another possible solution to the multiple-path effect is to mix the signals between the paths continuously along the fibre, so that all signals have nearly the same total path length and, hence, the same arrival time. One method of achieving mode- or path-mixing is to perturb the diameter of the core in a quasi-periodic manner along the fibre. The periodicity contains a range of pitches, or spatial frequencies, such that the modes are coupled together, but not coupled out into the radiation field in the cladding. In order for modes m and n to couple together, the difference in their propagation constants, $\Delta\beta$, must be equal to the propagation constant of the periodic structure caused by the variations in the diameter of the core. Hence,

$$\Delta\beta = \frac{2\pi}{\lambda_p} = \beta_m - \beta_n,$$

where λ_p is the pitch of the variations in core diameter, and β_m and β_n are the propagation constants for modes m and n.

The propagation constants are bunched closely together amongst the lower-order modes, and are spread out more at the higher orders. Therefore, to mix the modes without radiation, it is necessary to provide a perturbation of the core diameter that contains all the spatial frequencies up to, but not including, the frequency that will couple the highest-order mode out into the cladding.[10] This is easier said than done and, in practice, some loss is inevitable. A possible method of introducing the perturbations is to vibrate the fibre over a range of frequencies whilst it is being drawn.

Bending to a tight radius has to be avoided, for example, when making the fibre up into cable, or laying the cable in ducts; otherwise the penalty of extra loss will be incurred. Fortunately, with the values of refractive-index difference likely to be used for practical fibres, the critical radius is small enough, of the order of a few centimetres, not to be a problem. For monomode fibre, loss due to bending only starts to become serious at a very much smaller bending radius; that is, of about 10 mm. When a monomode fibre is bent, the wave-front on the outside of the bend will apparently have, at some distance from the axis, a velocity greater than that of light in the medium. This is clearly impossible, and the energy carried at distances beyond this critical point radiates off the guiding structure.[11]

Another cause of radiation is the scattering of light out of the fibre, due to various effects. Rayleigh scattering is caused by imperfections which are small compared with the wavelength, such as particles, or regions of different refractive index, in the glass. The loss varies inversely as the fourth power of the wavelength, and is not now a serious problem at optical-communication wavelengths centred around 850 nm.

Non-linear effects, such as stimulated Raman and Brillouin scattering, do not become noticeable until the optical power density is large. In monomode fibre, the critical level is about 1 watt. In multimode fibre, it would be of the order of several kilowatts.

Scattering, and random variations in the fibre, are liable to produce an amount of mode-mixing, no matter how carefully the fibre is drawn, although, with the latest fibres, the effect is not apparent for lengths of under about 1 km. For most telecommunications purposes, lengths over 1 km will be needed between repeater points, and the proportion of the total loss, caused by the mode-mixing process, then becomes important. An analysis has been made in respect of such random mode-mixing,[12, 13] using the assumptions that the modes are coupled only to their nearest neighbours, in terms of their propagation constants, and that the loss due to radiation varies as the square of the ray angle. The results predict that the relative power in the rays stabilizes to a particular angular distribution, no matter how the light is launched into the fibre. The analysis also predicts that, if a very short pulse of light is launched, then, at the far end of the line, it will have spread out to an asymmetric shape, such as is shown in Fig. 7, which is the trace of a pulse from an actual fibre. The pulse-width increases only with the square root of distance when mode-mixing is present, compared with a linear relationship when there is no mode-mixing, but the loss is higher in the first case.

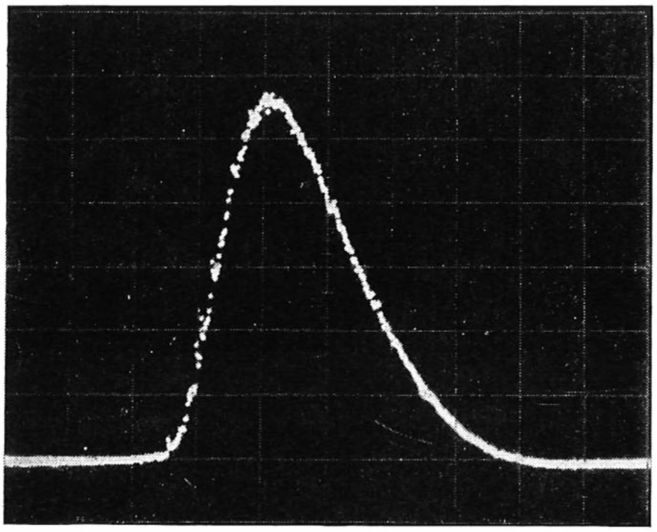


FIG. 7—Asymmetric distortion of short light pulse after transmission through optical fibre

MATERIAL DISPERSION

A second, serious limitation to bandwidth, which occurs when an l.e.d. is used, is that caused by dispersion of the refractive index of the fibre's core and cladding materials.[14] This material-dispersion effect causes additional curvature of the ω/β lines for the guided modes (see Fig. 4). Thereby, the variation of modal group-delay with frequency is changed by a large amount for typical fibre materials. The question arises as to whether mode dispersion and material dispersion might be, to some extent, set off against each other. Unfortunately, in monomode guides, and for most of the operating region in multimode guides, both types of dispersion have the same sign and, hence, reinforce each other. A particular kind of monomode guide has been proposed,[15] in which the mode dispersion is of the opposite sign, but no experimental results have been reported yet. One fortunate fact about material dispersion in fibres is that the material with the lowest dispersion—silica—also has the lowest loss.

Material dispersion on its own will not limit the bandwidth of a fibre. The effect only becomes important when the optical spectral spread of the signal transmitted along the fibre greatly exceeds the modulation bandwidth due to the baseband signal alone. However, a typical multimode, heterojunction, gallium-aluminium-arsenide laser, used as a source, has a spread in wavelength of 2 nm, which corresponds to a frequency spread of 720 GHz—far exceeding any sideband effects for the modulation frequencies that are realizable at present. The l.e.d. has much wider spreads, typically 20–40 nm, and 7–14 THz. The bandwidth of a silica fibre, 1 km long, fed by such an l.e.d., would be 160 MHz, and would decrease as the length increases. Some time ago, when the target for low-loss fibre was 20 dB/km, the loss itself was the main factor restricting the range. Now, however, with an achievable attenuation of 2 dB/km, the bandwidth limit imposed by a source with a wide frequency spread, together with material-dispersion effects over long lengths of line, is serious. The use of a monomode laser, with a spectral spread two orders lower than that of an l.e.d., will greatly ease the problem. Some method of correcting for material dispersion will, undoubtedly, be developed.

COUPLING AND JOINTING

As with other transmission lines, the optical fibre must be connected to its source and detector with the minimum amount of loss. The simplest and, in general, most efficient way to couple to an l.e.d. is to butt the fibre directly against the diode. The radiation from the diode is nearly isotropic, and the coupling efficiency is proportional to the solid angle of rays that can be accepted by the fibre, which is, in turn, equal to the square of the numerical aperture.[16] If the diameter of the source is smaller than that of the fibre core, as with a gallium-arsenide laser, then the butting efficiency can be improved with a lens. Such lenses have been fabricated by a photographic resist method on the end of the fibre itself.

Good joints, with low transmission loss and a low reflexion coefficient, are essential for a practical system. Both the source and the detector will, probably, be manufactured already coupled to fibre tails, which will then be joined to the transmission line at each end. Repairs to a broken fibre cable would be more difficult to deal with. It may be an advantage to arrange the fibres so that they can be easily identified and joined as a group; for example, by fixing them side by side along a flat tape. Several different types of joint have been demonstrated in the laboratory. The best have a loss as low as 0·1 dB. Monomode fibres are the most difficult to join, because of their small cores. Graded-index fibres are marginally more difficult to join than multimode fibres, but their alignment is not so critical as that of monomode fibres.

The main types of joint are described below. They consist of the *fusion junction*,[17, 18] and two types of junction using connectors, called the *sandwich connector*[19] and the *rotating eccentric connector*.[20]

For each of these joints, the ends of the fibres have to be prepared beforehand. One of the best ways to obtain suitable fibre-ends is by the *scratch-and-pull* technique. The fibre is put into a known amount of tension, over a surface of known radius of curvature, and is then scratched with a diamond to produce a break with clean ends.

Fusion Junction

To make a fusion junction, the ends of the fibres are butted together with their cores aligned, and are then fused together, using a hot wire as a heater. This technique is delicate, but good joints can be made in the laboratory between multimode fibres. The advantages of this technique are the absolute permanancy of the joint and its small size.

Sandwich Connector

For the sandwich connector, a groove is made in a plastic or metal plate by pressing into it a fibre of the same diameter as the fibres to be joined. The latter are then butted together in the groove, and a drop of index-matching liquid is added to fill any small gap between the ends. Another plate is placed on top of the fibres, and the assembly is clamped together. This method can give losses of down to 0·3 dB for monomode fibre, and 0·2 dB for multimode fibre, provided that the cores are accurately centred in the fibres.

Rotating Eccentric Connector

For the rotating eccentric connector, the fibres are glued into capillary tubes which are eccentrically mounted in metal bushes, so that, by turning the bushes, the cores can be aligned. The cores do not have to be centred in the fibres, and the joint can be easily taken apart and remade. The disadvantages are that a fairly bulky and costly structure is left attached to the fibre, and that the degree of eccentricity has to be matched to the dimensions of the particular fibres to be joined.

Fibre and Source Combinations

The capabilities of the various combinations of fibre and source are summarized in Table 1.

TABLE 1
Combinations of Fibre and Source

Source	Fibre		
	Multimode	Graded-Index	Monomode
L.E.D.	Range and bandwidth limited by mode and material dispersion	Range and bandwidth limited by material dispersion	Launching efficiency too low to be useful
Laser	Range and bandwidth limited by mode dispersion	Suitable for medium and high bandwidth on long repeater sections	Suitable for high bandwidth on long repeater sections

SUMMARY

The l.e.d., used with the multimode fibre, gives the lowest bandwidth, which can be improved by mode-mixing, but with the penalty of some extra loss. The restriction on bandwidth, due to the multiple-path effect, can be almost entirely removed by using a graded-index fibre, but the upper limit of any system using an l.e.d. is set by the line width of the l.e.d., together with the dispersion of the fibre material. The choice for higher bandwidths is, therefore, the gallium-arsenide laser, together with either graded-index or monomode fibre. The former has the possible advantage of being easier to join, although efficient joints can be made in monomode fibre. The next major step seems to be the development of a reliable monomode gallium-arsenide laser. Then, for high-bandwidth systems, at least, the system will be remarkably similar to the original concept.

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TXK3 Director-Area Local Exchanges using BXB1112 Crossbar Equipment

Part 2—System Features and Maintenance Arrangements

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U.D.C. 621.395.344.6.004.5: 621.395.722

Part 1 of this article described the TXK3 system which has recently been introduced into the British Post Office public telephone network. The use of crossbar switches in the multi-outlet switching-block configurations was discussed, and a typical director-area exchange trunking arrangement was shown. Part 2 describes some of the more important features of the system, outlines the general maintenance policy, and describes various maintenance aids.

TXK3 SYSTEM FEATURES

Some of the more important features of the TXK3 system are discussed below.

Automatic Distribution of Traffic Load

In order to equalize the traffic loading on the selection equipment, cyclic distribution is used. This provides a rotational priority of access from a common circuit to the multiswitches in the selection unit, so that successive calls are routed through the multiswitches, subject to their being available, in priority order.

Priority distribution is used between

(*a*) line-selection-unit (l.s.u.) common relays and l.s.u. primary sections, so that successive originating calls are routed to different primary sections,

(*b*) l.s.u. markers and l.s.u. terminal sections, so that a calling subscriber on any terminal section is first in order of connexion at least once in 10 calls on a 520-line l.s.u.,

(*c*) group-selection-unit (g.s.u.) markers and g.s.u. secondary sections, so that, for two successive calls, different secondary sections are given priority, and

(*d*) register finders and registers, so that successive calls on the register finders seize the registers on a rotational basis.

The following methods are used to distribute traffic over common equipment which, for security reasons, is provided in pairs.

(*a*) Markers and translators are seized alternately.

(*b*) Information-path channels are used on a random-choice basis.

(*c*) Pre-selection couplers are selected at random by originating registers. When a coupler is seized by more than one register, a choice is made between the registers on a fixed-priority basis.

(*d*) Selection couplers are also chosen randomly, but simultaneous seizure by either the originating or incoming registers is dealt with on a rotating-priority basis.

Automatic Repeat-Attempt

Connexions are established in successive steps or phases; that is, the group-selection phase and the line-selection phase. Each step is set up by the corresponding marker, which controls and checks the selection of a path. If a check proves negative, or if the period of a phase exceeds a set time, the register releases the connexion and proceeds to make another attempt automatically. Because of the priority-distribution feature, each attempt normally uses a different path through the switching stages. When a repeat-attempt is unsuccessful, a third attempt can be made to set up the connexion. If the final attempt is unsuccessful, call-failure conditions are signalled to the caller by the return of tone. Both originating and incoming call failures are indicated by the return of equipment-engaged tone for a period of 24–48 s. If this period expires, an originating-subscriber's line is released back as far as the line circuit with no tone applied to it, (the *parked* condition) and an incoming junction is placed into a locked-out condition, again with no tone applied.

Automatic Alternative Routing

The g.s.u. marker can be wired to signal route-busy conditions to the register, via the information path. In these circumstances, the register releases the connexion, re-applies to the translator for alternative-routing information and proceeds to establish the call over another outgoing junction route. The alternative-routing information may contain additional code digits required for tandem working.

Calls to Unobtainable or Engaged Numbers

If a call is destined for an unobtainable number, an appropriate service-category signal is returned from the l.s.u. This signal instructs the controlling register to re-route the call to a special junctor which returns number-unobtainable tone, and which is connected to an outlet of the appropriate g.s.u. In some cases, this instruction may be returned from the translator.

Similarly, when an engaged subscriber is called, the originating register re-routes the call to a special junctor, which returns engaged tone. However, for incoming calls, engaged tone is sent directly from the incoming junctor.

L.S.U. Marker Distribution Frame

For terminating calls, the called number is passed to the l.s.u. marker from the register and is decoded to give the equipment number of the line circuit with which the called number is associated. This is effected by means of a strapping field, the principle of which is illustrated in Fig. 9. The field

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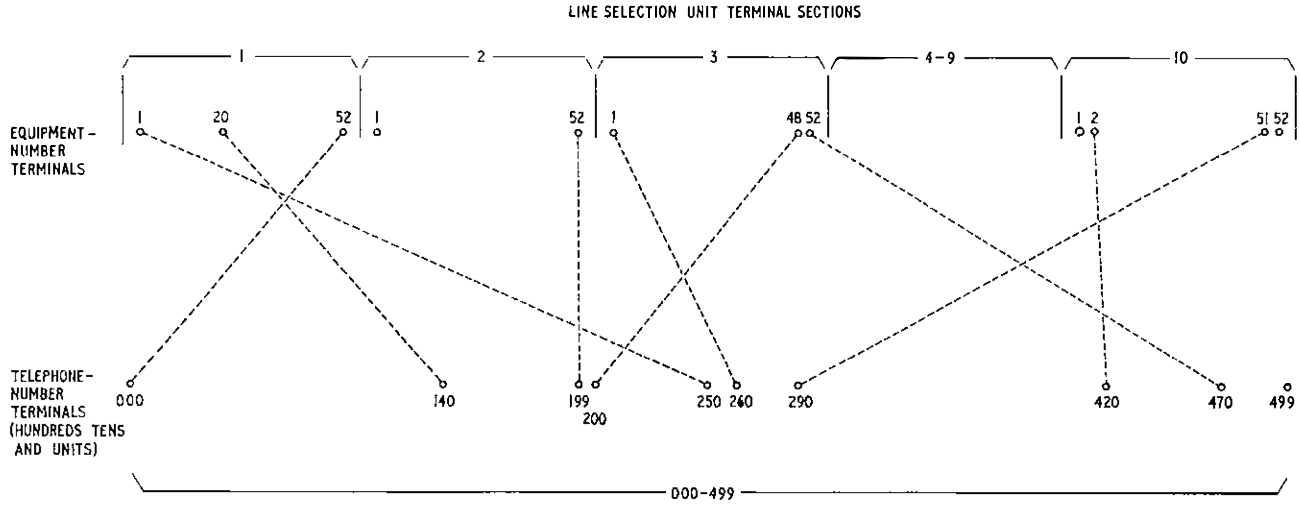


FIG. 9—Principle of the telephone-number-to-equipment-number strapping field

provides flexibility and independence of allocation between called numbers and equipment numbers within the same l.s.u. If, for example, the traffic loading of l.s.u. terminal sections becomes uneven, lines can be moved to other line circuits within the l.s.u., without the need for changing telephone numbers. There are 1,036 line terminations on the low-traffic l.s.u. and 520 line terminations on the high-traffic l.s.u. As only 1,000 and 500 telephone-number tags respectively are provided, the remaining line terminations are available for use for un-numbered lines, such as private-branch-exchange (p.b.x.) lines.

Non-Direct-Dialling-In P.B.X. Working

For normal incoming calls, a p.b.x. group requires only one telephone number. Use can, therefore, be made of the un-numbered line terminations for p.b.x. auxiliary lines. If more than the 20 or 36 line terminations normally available are required, then complete blocks of 100 directory numbers can be shed to other l.s.u.s. Up to 56 p.b.x. groups can be accommodated in each low-traffic l.s.u., and up to 80 p.b.x. groups in each high-traffic l.s.u.

The main advantages of this method of p.b.x. working are that auxiliary lines do not waste directory numbers, and that sequenced numbers do not have to be reserved for the growth of each p.b.x. group. The lines of a p.b.x. are not tested sequentially, and all of the auxiliary lines in a particular p.b.x. group are accommodated in the same l.s.u. Fig. 10 shows the strapping arrangements for a 5-line p.b.x. group, *X*259, to which has been added the facility of night-service working on a particular line. This line, connected to equipment 1/20, can be positively accessed by dialling *X*050. The diode prevents the marking of unwanted lines.

Direct-Dialling-In Private Automatic Branch Exchange Working

The principle adopted for direct dialling-in (d.d.i.) in the U.K. is for private-automatic-branch-exchange (p.a.b.x.) extensions to be allocated numbers within local numbering schemes and, hence, within the national numbering scheme.

In the TXK3 system, recognition of d.d.i. calls is a register-translator function. As own-exchange and incoming-d.d.i. calls are processed in slightly different ways, they are discussed separately. Although a detailed analysis of the treatment of calls to the various types of p.a.b.x. is not dealt with here, the registers and translators are capable of dealing with calls to

(*a*) a very large p.a.b.x. group which has a directory number in the form *A'B'C' XXXX*, where *A'B'C'* denotes the second all-figure numbering (a.f.n.) code allocated to an exchange unit*, the a.f.n. code being allocated to one subscriber,

* The principle of the allocation of two a.f.n. codes to one exchange unit is described in part 1 of this article.

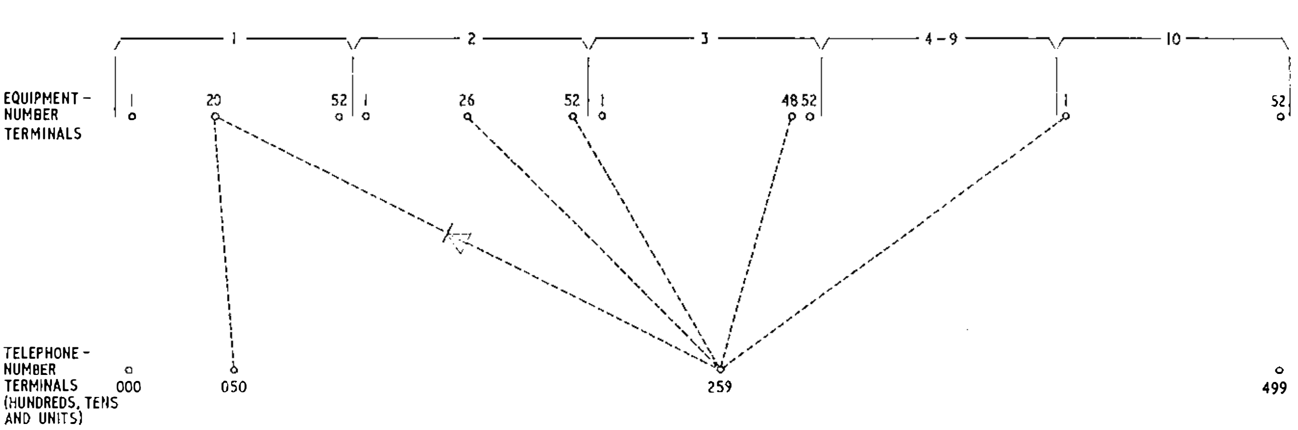


FIG. 10—Use of un-numbered line terminations for p.b.x working, with night-service facility

(*b*) p.b.x. groups with an exchange directory number allocation greater than 1,000 but less than 6,000 in the form *ABC XXXX*, where the a.f.n. code is shared with other subscribers and which, consequently, involve the additional examination of the thousands digit, and

(*c*) small p.a.b.x. groups having directory numbers in the form *ABC NXXX* with the thousands digit shared and which, consequently, involve the further examination of the hundreds digit.

Economic and growth factors have resulted in provision for the allocation of a block of 1,000 or 10,000 numbers if it is foreseen that more than 600 or 6,000 numbers respectively will ultimately be required in a p.a.b.x. group.

A simplified trunking diagram of a TXK3 exchange, illustrating d.d.i. working, is shown in Fig 11.

Own-Exchange D.D.I. Calls

For own-exchange d.d.i. calls, the caller is connected to an originating register, as for a call to a non-d.d.i. subscriber. The own-exchange a.f.n. code is dialled. This may be for a mixed d.d.i. and ordinary-subscriber exchange, or for a large d.d.i. p.a.b.x. where a discrete a.f.n. code has been allocated. For the latter, only the three code digits are required for translation into selection information within the exchange. For a combined d.d.i. and ordinary-subscriber exchange a.f.n. code, examination of the numerical digits is necessary. Examination by the originating translator of the code, plus the numerical digits if required, produces information for routing the call through the originating g.s.u. to an inlet of the incoming g.s.u., via a local-call-timing junctor. Numerical digits, stored in the originating register, are then examined by the local translator. This provides a translation to route the call through the incoming g.s.u. to an outgoing junctor. The appropriate numerical digits are determined by the translator and sent by the originating register, through the outgoing junctor, to the p.a.b.x.

Although this class of call is, in effect, treated as an outgoing junction call, the lines are terminated on the incoming g.s.u. so that access may be gained by incoming traffic.

Incoming D.D.I. Calls

An incoming d.d.i. connexion is determined in a similar manner. If an incoming route is common to two a.f.n. codes, a discriminating digit, added to the translation at the distant exchange, is used to determine which 10,000-line unit is required. If incoming access is via separate routes, or if only one exchange code has been allocated, this digit is not necessary. The incoming register applies to the local translator after the second numerical digit has been stored. The translator then has sufficient information to allow selection of an outgoing junctor. The translator also determines how many digits are to be sent to the p.a.b.x., and indicates to the register that seizure of a 10 pulses/s, loop-disconnect pulse-sender is required. The pulse-sender transmits the numerical digits to the p.a.b.x.

Subscriber-Controlled Transfer

The subscriber-controlled transfer facility enables subscribers to transfer their incoming calls to other nominated lines. Two forms are available: single-line transfer and group transfer. In the Strowger system, the transferring-subscriber's speech and control wires are physically switched in response to 33 kohm loop signals from the controlling subscriber. In contrast, the TXK3 system switches the marking wires, or re-routes the call within the exchange. Switching and restoration of transfer is effected by the use of

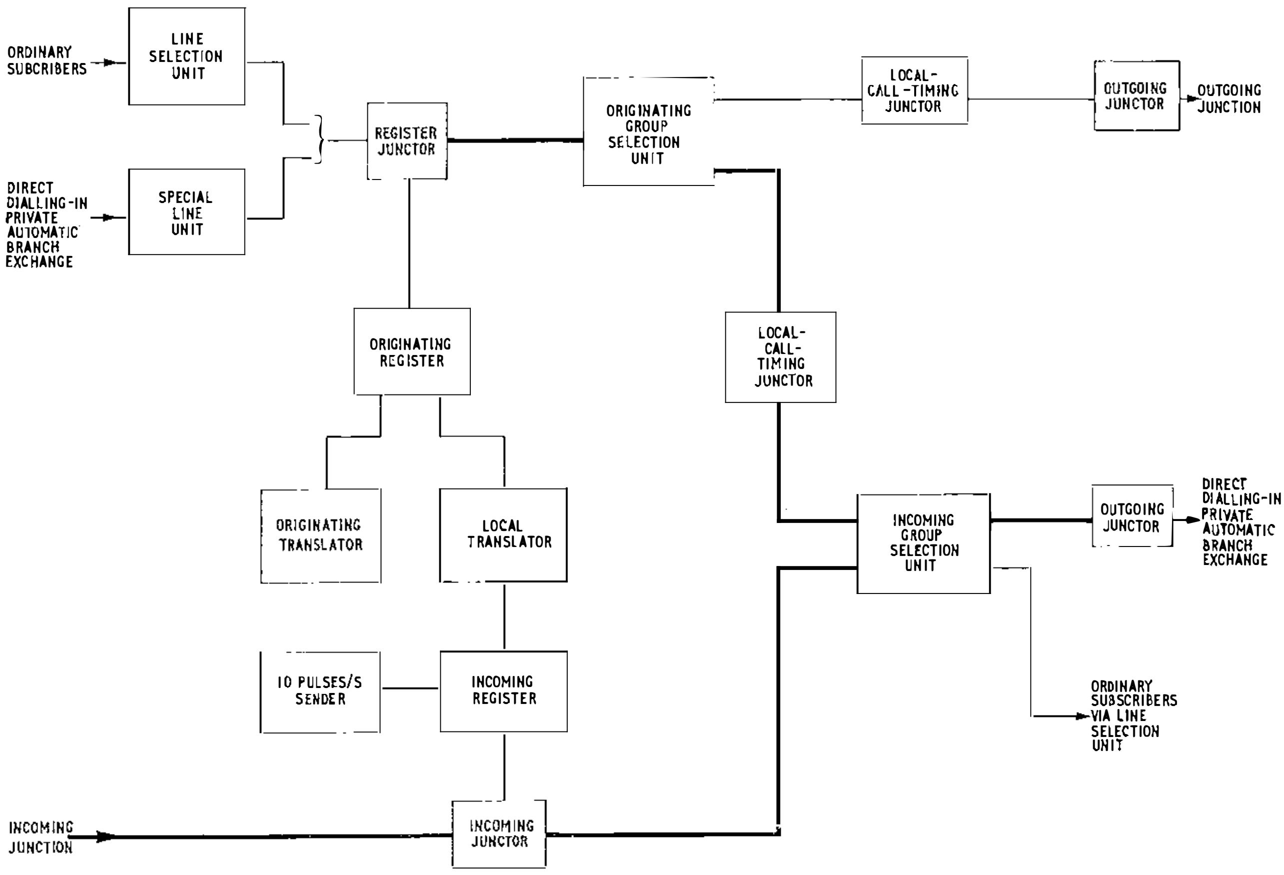


FIG 11—Simplified trunking diagram illustrating d.d.i. working

dial-pulse signals. This method of effecting transfer avoids the need for control equipment to be associated with individual subscriber's lines. The transferring subscriber first dials a special code to route the call to a transfer register, followed by a transfer identity code and either digit 1 to switch, or digit 0 to restore, transfer.

If group transfer is required, the single transfer-switching relay used for single-line transfer is replaced by a magnetic counter. This is a relay device with 10 armatures, one of which is operated at any time, allowing up to 10 subscribers to be associated with a transfer group. A subscriber wishing to transfer his incoming calls dials the special code, his transfer identity code and the appropriate counter-positioning digit of the chosen receiving subscriber. To restore transfer, the same procedure is followed, with the exception that the restoring subscriber dials his own counter-positioning digit. Both subscriber- and operator-controlled transfer facilities are available, with provision for the operator to have over-riding control.

The transfer relay, or magnetic counter, diverts the l.s.u. marking wire to the receiving subscriber's equipment number, if the receiving subscriber is within the same l.s.u. If, however, the receiving number is outside the l.s.u., the marking signal is diverted to a transfer coder. This coder contains the receiving line identity, which it transmits, via a transfer information-path, to the controlling register. The register is instructed to perform a second attempt using the new called-subscriber's identity. If the transferred call is to be handled by the changed-number-interception operator, a signal is returned to the common-control equipment, instructing the controlling register to break down the connexion and to re-route the call through the appropriate g.s.u. to a changed-number-interception junctor.

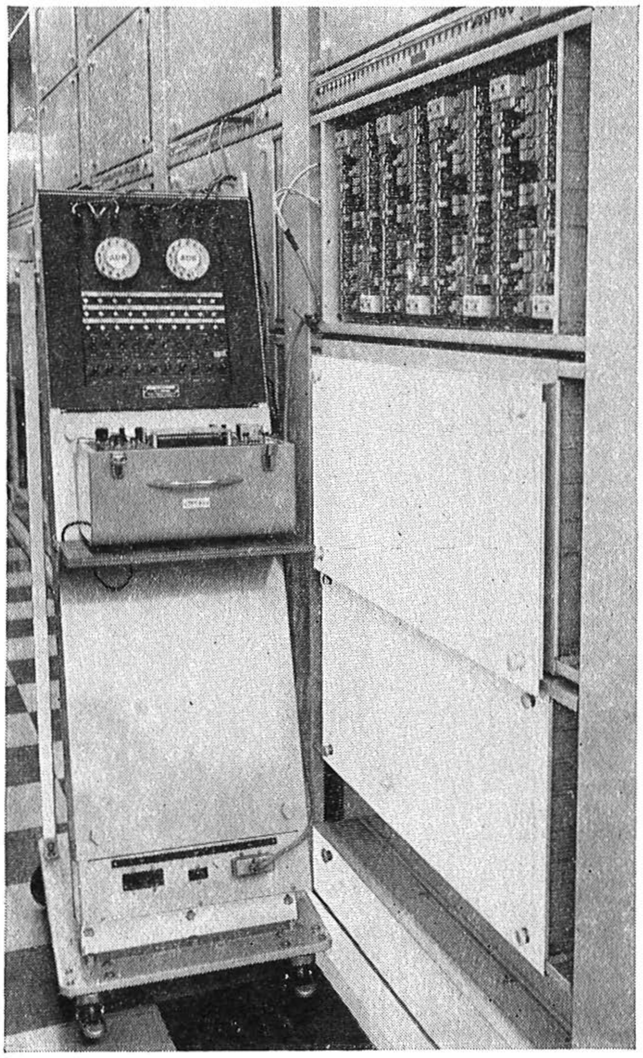


FIG. 12—Typical junctor tester

MAINTENANCE POLICY

The maintenance organization in TXK3 exchanges takes account of the following system features:

(*a*) the simple selection mechanism,
(*b*) the built-in fault-detecting devices,
(*c*) the automatic repeat-attempt facility,
(*d*) the automatic fault-print-out facility, and
(*e*) the increased security derived from the use of alternate and sequential traffic distribution.

Emphasis is placed on corrective- rather than preventive-maintenance techniques. There is, however, a need for some routine preventive maintenance, but the simple and reliable mechanisms used allow inspections to be scheduled at widely-spaced intervals.

Maintenance activities can be classified under three broad headings: (*a*) preventive maintenance, (*b*) functional testing, and (*c*) corrective action.

Preventive Maintenance

Preventive maintenance entails the inspection of multi-switches, relays and magnetic counters. The periodicity of this work varies according to the usage of the circuits and their position in the system. At present, the British Post Office (B.P.O.) has had limited in-service experience of the TXK3 system, and preventive maintenance has been based on manufacturer's recommendations, which include periodic inspections. During the first year of service, the manufacturer recommends a complete check and lubrication of multi-switches, and a check of relays in short-holding-time equipment.

When sufficient data has been obtained to calculate reliability figures, the periodicity of routine preventive maintenance work will be revised.

Functional Testing

Testers, without automatic access, are provided for

(*a*) incoming, outgoing and local-feed junctors,
(*b*) local-call-timing junctors,
(*c*) coin-and-fee-checking junctors,
(*d*) registers,
(*e*) translators,
(*f*) call-tracing equipment, and
(*g*) subscribers' meters.

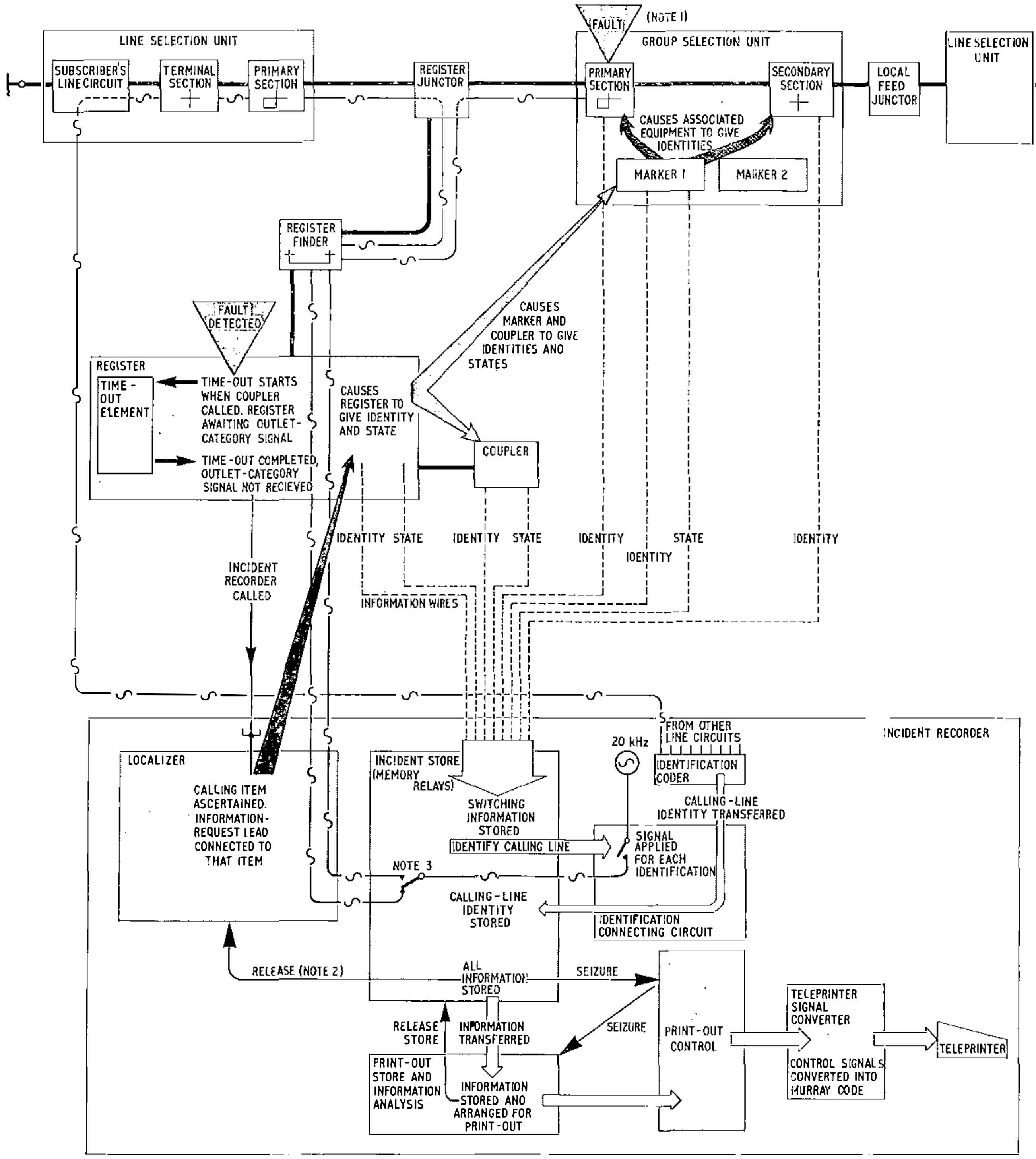
With the exception of the register tester, the above test equipment is manually controlled. Junctor-testing equipment is used, in accordance with a scheduled test program, to detect circuit malfunctions in those areas of the system which are largely outside the scope of the incident recorder and, also, as an aid to the localization of faults.

Fig. 12 shows a typical junctor tester. Additionally, standard test equipment for relay-current, and pulse-speed and ratio checks is used.

Corrective Action

Corrective action includes the localization of faults and remedial work based on information from

(*a*) the preventive-maintenance program,
(*b*) functional testers,
(*c*) supervision devices, such as the centralized display panel and service meters,



Note 1: Assumed fault is the failure to operate the horizontal magnet in the calling primary-section
Note 2: After the release of the localizer, the register makes a second attempt to switch the call
Note 3: Two identification pulses are transmitted, the first to identify the calling subscriber, and the second to identify the called subscriber. In this case, the fault prevents the called-subscriber's identification signal from proceeding beyond the g.s.u. primary section

FIG. 13—The process of recording an incident when the incident recorder is called by a register

(*d*) the incident recorder,

(*e*) subscribers,

(*f*) alarms, and

(*g*) the artificial-traffic equipment, which is currently under development.

FAULT TOLERANCE

The built-in fault-detecting devices, sequential and alternate traffic distribution, duplication of some important circuits, and the automatic repeat-attempt features give the TXK3 system a degree of fault tolerance. Thus, the quality of service given to the customer is not normally degraded by the existence of faults in the system. These features allow maintenance work to be programmed and directed in an efficient manner. It is important, however, that attention is given to service-supervision facilities to ensure that malfunctions of the system are apparent to maintenance staff. A measure of the quality of service of the exchange is obtained from a collective assessment of telephone service observation results, service-supervision devices, fault print-out analyses and artificial-traffic equipment results.

INCIDENT RECORDER

Details of failures to establish a path through the exchange are automatically identified and recorded on a teleprinter operating under the control of an incident recorder.

Certain of the common-control circuits, called *active elements*, are designed to recognize whether a selection process has exceeded a specified time, or if certain other failures have occurred. Common-control circuits without this capability, called *passive elements*, respond to a request from the incident-recording equipment for their identification and phase (or state) of operation. Some common-control circuits are used in either mode.

The active elements are the

(*a*) l.s.u. common relays,
(*b*) special line units,
(*c*) markers,
(*d*) registers, and
(*e*) loop-disconnect pulse-senders.

The passive elements are the

(*a*) l.s.u. and g.s.u. markers,
(*b*) register finders,
(*d*) loop-disconnect pulse-senders,
(*e*) couplers,
(*f*) translators, and
(*g*) information paths.

Fig. 13 illustrates the process of recording an incident. This process takes place in the following stages.

(*a*) When a fault occurs during a particular selection operation, the active element recognizing the fault condition calls the incident recorder.

(*b*) The localizer searches for, and finds, the calling active element.

(*c*) The active element connects its information wires to one of two sets of memory relays, and causes all of its associated passive elements to connect their information wires to the chosen memory relays.

(*d*) Information, giving the identity and the state of the principal phase relays of each element at the time of fault, is passed to, and stored in, the incident store.

(*e*) A 20 kHz signal is applied to the control wires, via the active element, to identify the terminal points of the call.

(*f*) The elements are released, the information stored in the memory relays activates the recorder print-out control, and fault recording takes place.

The following information can be recorded:

(*a*) the date and time of the incident,
(*b*) the identity of the exchange,
(*c*) the identity of the control units involved,
(*d*) the phase of operation of the control units at the time of the incident,
(*e*) the identity of the calling subscriber or incoming junctor, and
(*f*) the identity of the called subscriber or outgoing junctor.

A typical print-out is illustrated in Fig. 14.

Computer Analysis of Print-Out

It is intended to introduce a computer-assisted scheme to analyse fault print-out information. The use of computerized analysis methods reduces the time taken to diagnose faults,

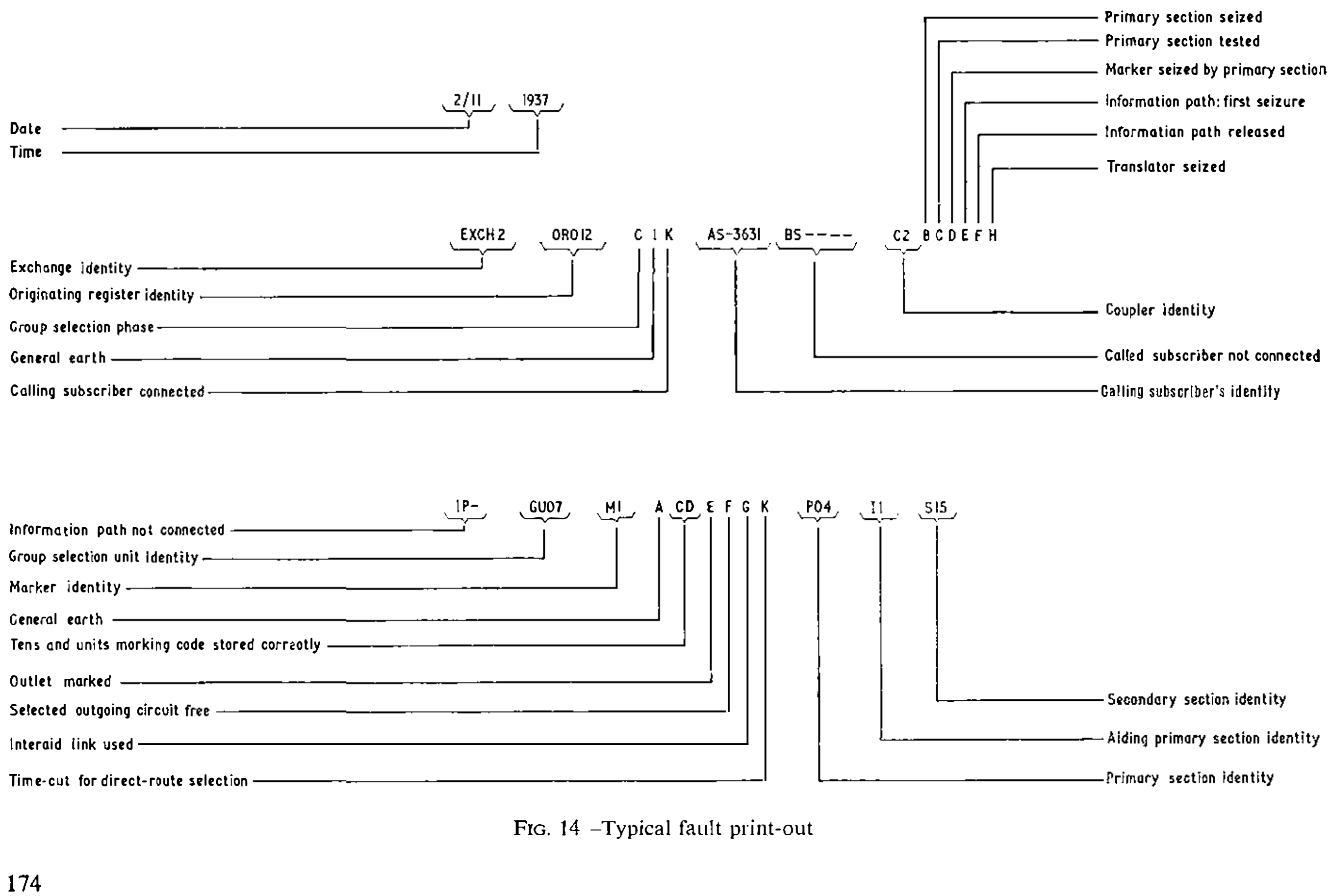


FIG. 14 –Typical fault print-out

and minimizes the need for visual analysis. Visual analysis can be difficult because information relating to similar faults is interspersed with other fault information. It is expected that periodic, off-line batch processing will be used.

Operational Modes

The incident recorder can be operated in either a general or a selective mode. In the general mode, a demand from any active element is dealt with, provided that a free memory exists. Thus, the print-out reflects faults from all areas of the exchange.

However, in certain fault situations, for example, when two or more interrelated faults exist, a confusing fault pattern could result. To assist the analysis of the print-out in such instances, or when certain circuits are suspect, the incident recorder may be operated in the selective mode; that is, the active elements not considered relevant to the fault pattern can be excluded from having access to the monitoring equipment, thus enabling attention to be concentrated on specific groups of circuits.

Parked Lines

Permanently-looped lines undergo forced-release from the register equipment after a period of 24-48 s, and are re-routed to a special junctor with number-unobtainable tone and line-insulation measuring facilities. If a line remains looped for more than 12 s after the application of tone, then the incident recorder, if it is so primed, is used to record the identity of the line and its resistance characteristics. The line is then placed in the parked condition.

To obtain a record of the state of the exchange with regard to the total number of parked lines at any particular time, it is necessary to operate manually a push-button associated with each l.s.u. This causes all lines previously parked to connect to the originating registers, which, after the appropriate delay, re-route the calling lines to the special junctors. The lines are then identified by the incident recorder and parked again, as described above.

Call Tracing

The incident recorder is also used for recording call-tracing information. In order to identify the unknown terminal point of a call, the known junctor or subscriber's termination is associated with the call-tracing equipment by a clip-ended cord, which is connected to the junctor or subscriber's meter bay. The operation of a key on the call-tracing equipment's supervisory panel causes a 20 kHz signal to be fed to the known termination and allows the localizer to search for, and identify, the unknown terminal point. Identification takes place within 350 ms, and the information is printed-out on the teleprinter.

CENTRALIZED DISPLAY PANEL

To assist in assessing the overall performance of the common-control area of an exchange, a centralized lamp-display panel is provided. This panel duplicates the common-control area supervisory lamps, and facilitates the simultaneous observation of similar common circuits. Comparison of the observed lamp signals with the published upper and lower limits for the engaged time for each type of common element provides information on the traffic flow, and can show irregularities due to faults or congestion. In particular, during periods of high traffic, circuits being prematurely released, or not being seized at all, can be identified. The alternate or sequential distribution of traffic, as appropriate, on markers, registers, information paths and translators can also be confirmed.

SERVICE METERS

In order to aid the observation of exchange performance, and to provide traffic-irregularity and fault information, call-count, congestion and fault meters, collectively called *service meters*, are provided. Additionally, on l.s.u.s and g.s.u.s, the number of calls routed via interaid paths is recorded to assist the checking of an even traffic distribution.

The interpretation of service-meter readings for maintenance purposes is based either on trend, or on the comparison of related equipment meter readings, and needs to be considered in conjunction with information obtained from other surveillance devices.

ARTIFICIAL-TRAFFIC EQUIPMENT

Artificial-traffic equipment, developed by the B.P.O., makes provision for automatic call-sending to 96 test numbers from 97 subscribers' line-circuits and 49 incoming junctors.

The receipt of a 400 Hz or 1 kHz test tone, plus a line reversal or metering condition, is recognized as a successful call. A no-tone condition, the receipt of congestion-announcement or the receipt of a supervisory tone is regarded as a call-failure. The equipment can be operated in a hold-and-trace mode or a service-measurement mode. In the latter case, each type of call-failure condition, and the total calls made, are recorded on separate meters in order to facilitate service analysis.

TELEPHONE-SERVICE OBSERVATIONS

A Strowger-type telephone-service-observation equipment is provided at each TXK3 unit. Observation is achieved by monitoring, at the register-junctor equipment, a sample of originating calls. Fifty per cent of the junctors, subject to a maximum of 96 circuits, are associated with the observation equipment. In non-director areas, some of the access circuits are associated with incoming junctors to provide a measure of the quality of the incoming service, as is done for Strowger-type exchanges.

SERVICE SECURITY

The TXK3 system has a number of features, in the form of duplicated equipment, plug-in relays and alternate and sequential distribution of traffic, which give a high degree of service security.

The l.s.u. common-relay circuit is designed so that failure of the magnetic-counter distributor results only in the loss of the sequential-distribution facility for allocating calling subscribers to the marker area.

Plug-in relays are provided in the pulse generator, pulse-distribution circuits and some pulsing and counting elements, in order to facilitate rapid restoration to service in the event of failure.

Marking-relay circuits for switching-block outlets use relays having coils connected in parallel, so that they continue to function when one winding has a discontinuity.

There is no duplication of l.s.u. common relays, or of l.s.u. and g.s.u. marking relays.

CONCLUSION

The maintenance information given in this article should be viewed against a background of limited experience of the TXK3 system in service. Sufficient information is not yet available to give reliable performance indicators, but the maintenance policy currently in use should result in a satisfactory quality of service, with a reduction in operating costs as compared with Strowger exchanges.

ACKNOWLEDGEMENT

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The Circuit Laboratory: 1924–1974

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U.D.C. 621.3.006.2

The following brief account outlines the history and development of the British Post Office Circuit Laboratory since its formation fifty years ago.

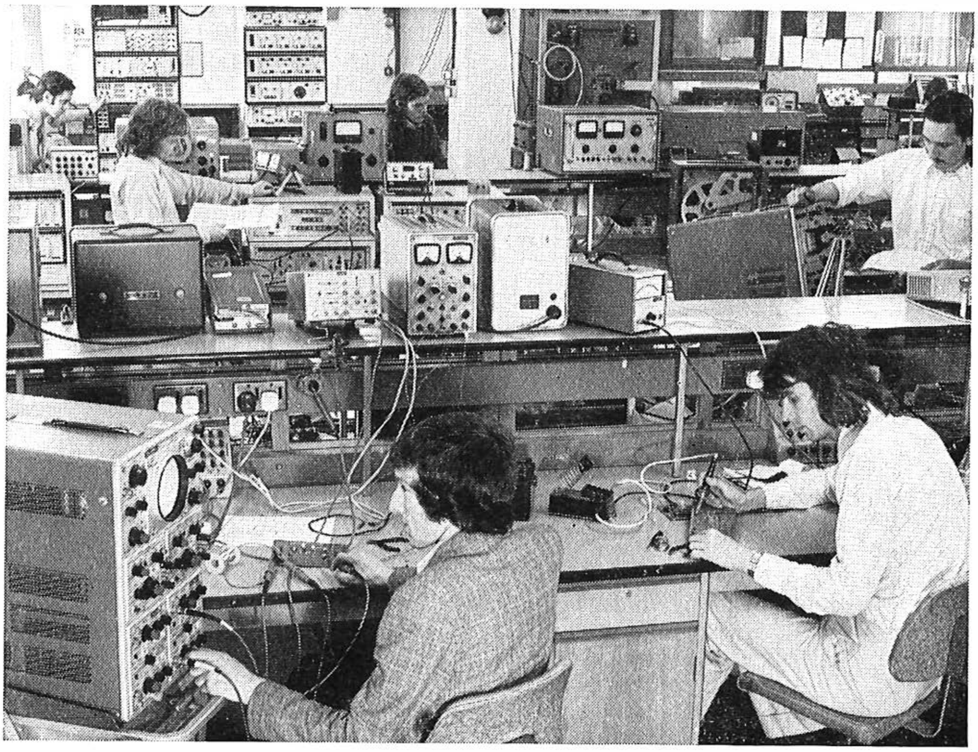

FIG. 1—The a.c. signalling system testing area

INTRODUCTION

Fifty years ago this month, a new section of the Post Office Engineering Department was opened, to be known as the Circuit Laboratory. From a staff of three, in 1924, occupying a part of a floor in King Edward Building, it has grown to a staff of 192, spread over three buildings in the City of London, with a construction unit in North London.

The Circuit Laboratory is part of the Exchange Systems Division of the Telecommunications Development Department, Telecommunications Headquarters (THQ), and is responsible for testing and reporting upon new designs produced within the division, and by the telephone-equipment manufacturers. It also assists the Service Department, THQ, in solving maintenance problems, and can serve other divisions within THQ, particularly when constructional assistance is required.

Since its formation, the Circuit Laboratory has made major contributions in the field of telephone switching systems, and in resolving service difficulties. Over 7,700 complete investigation reports, and 4,600 short reports, have been published, and 17,000 construction projects completed.

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EARLY DEVELOPMENT

Prior to 1922, testing and experimental work on exchange equipment had been carried out as part of the work of the Research Branch, based at the Central Telegraph Office in St. Martin's-le-Grand. When that branch moved to Dollis Hill, in North-West London, this work was transferred to the Automatic Telephone Training School, which had been set up in King Edward Building, King Edward Street, London, for the prime purpose of training exchange-maintenance personnel in the, then, new techniques of Strowger switching. As the complexity of the equipment produced by various manufacturers for the British Post Office (B.P.O.) increased, Mr. B. O. Anson, the Executive Engineer (old style) in charge of the school, requested that a special laboratory be established to accept the manufacturers' automatic telephone-switching equipment for testing, and to provide experimental facilities. This was approved, and in 1924, an area of 550 ft^2 in King Edward Building was allocated for this work, and the Circuit Laboratory came into being.[1]

With the rapid growth of laboratory work, however, expansion became necessary and, in 1929, an additional 3,500 ft^2 of floor space was acquired in King Edward Building. In 1931, the Automatic Telephone Training School moved to the Research Station at Dollis Hill and, since that time, the Circuit Laboratory has functioned as a self-contained unit.[2]

THE WAR YEARS

The war years brought many changes in the nature of the work undertaken, the development of telephone switching systems being, to a large extent, superseded by work directly related to defence. This included such projects as the automatic-control equipment for the London anti-aircraft units, and for calculator racks that were installed at Air Force radar stations to plot automatically, in display form, the positional data of enemy aircraft, for transmission to a control centre.

The increase in the work, and the urgency with which it was required, put a great strain on the resources of the Circuit Laboratory, and much ingenuity, as well as long hours of work under difficult conditions, were required. The achievements of the staff were officially recognized by the honour conferred upon Mr. A. W. Biddlecombe, Assistant Engineer (old style), who became a Member of the Most Excellent Order of the British Empire, and the award to Mr. W. A. C. Blackhall, Inspector, of the British Empire Medal.

POST-WAR DEVELOPMENT

The immediate post-war period involved, as in most spheres, a great deal of adjustment and re-organization. In the Circuit Laboratory, this meant not only the absorption of staff returning from service in the Forces, but also, a resumption of normal development work in place of the work which had been mainly related to defence.

This period of adjustment was made more difficult by the shortages of that time—both of finance and of equipment. There was, inevitably, frustration at all levels, but, although this was perhaps one of the most difficult periods of the Laboratory's history, the rapid re-establishment of an efficient working unit was made possible by the determination of the Laboratory's staff.[3]

During the post-war period, large development programs were being planned for the national trunk switching network, and the subject of one of the first major tasks of investigation and testing in the Circuit Laboratory was that of the terminal switching equipment for trunk mechanization.[4]

At the same time as this work was proceeding, the removal of the Circuit Laboratory from King Edward Building to Armour House, a short distance away in St. Martin's-le-Grand, was being planned and put into effect. The move took place in 1953, and provided an additional 3,000 ft^2 of floor area; the accommodation was described in an earlier article in this *Journal*.[5]

This additional floor space was to prove invaluable during the testing and development of subscriber-trunk-dialling (s.t.d.) equipment.[6] This was the largest program of investigation work undertaken by the Circuit Laboratory, and it involved almost the whole of the Laboratory's effort for more than two years. Within the general framework of the s.t.d. program were other large developments, including the magnetic-drum register-translator, group routing and charging equipment, metering-over-junction equipment, and subscribers' private metering equipment, to mention just a few.

Other important work was the participation in the proving trials for international operator dialling[7] on intercontinental and European circuits and, also, international subscriber dialling.[8]

The trunk-transit network switching system[9] was a later stage in the s.t.d. program. It was during this work that an oscilloscope with display-storage facilities was used for the first time in the Circuit Laboratory to diagnose faults which could not be traced using conventional oscilloscopes.

Work commenced in 1966 on the TXE3 large electronic exchange[10,11], which was another project of importance, being the prototype of the TXE4 production equipment. The task was to build and commission a model electronic exchange in the Circuit Laboratory, in collaboration with design teams in THQ. After commissioning tests had been successfully completed, the exchange was put on a public service trial in 1968, carrying the traffic of 100 subscribers on Monarch (606) exchange. This trial lasted two years, and on only one occasion was it necessary to restore service to the main exchange, and then only for a short time.

The success of this trial can be attributed to the co-operation and teamwork of all involved—THQ designers, the equipment manufacturers, regional maintenance staff, as well as the Circuit Laboratory's staff.

THE CIRCUIT LABORATORY TODAY

Accommodation

During the 1960s, the B.P.O.'s need for office accommodation in central London increased. Much of the accommodation in Armour House is classified for office use and, therefore, when London House—a five-storey, light-industrial building, close by in Aldersgate Street—became available, it was offered as alternative accommodation. This was accepted and occupied in 1969, bringing the total accommodation to over 36,000 ft^2. Figs. 1 and 2 show general views of the testing areas in the Circuit Laboratory, as they are today.

FIG. 2—The life-testing area

Only part of the ground floor of Armour House, unsuitable for use as offices, has been retained, and this remains equipped with Strowger, crossbar, and transit-switching apparatus. Local workshop facilities are available nearby, in Castle House, and the main construction workshops are situated at Manor Gardens, Holloway.

The Circuit Laboratory does not suffer as much as might be expected through having separate premises, and now has the accommodation to enable it to provide the testing and development facilities for present-day needs.

Organization

The Circuit Laboratory is at present administered by two Heads of Group (formerly Senior Executive Engineers), who are each assisted by four Executive Engineers. The work broadly covers specialized switching and signalling systems, tester development, customers' apparatus, endurance testing of components, training and administration. Sixteen Assistant Executive Engineers lead the testing, construction, maintenance and training groups, which are staffed by 161 personnel, including 35 Trainee Technicians (Apprentices) (T.T.(A.)s).

In addition to the normal investigation work for THQ, the Circuit Laboratory is responsible for the mechanical maintenance of magnetic-drum register-translators at s.t.d. exchanges and, also, pre-service tests of transmission and group-delay distortion for type-approval of new exchange equipment. It also administers a driving pool for THQ stores deliveries.

From time to time, work is undertaken which is outside the normal functions of the Circuit Laboratory, mainly because the facilities offered are versatile and there is a fundamental willingness to undertake diversified projects. For example, the Laboratory has been involved in the building of equipment for, and the staging of, two B.P.O. Faraday Lectures on telecommunications subjects, and is, at present, involved in work on display panels for lecturing purposes.

The following sections give a few examples of the present-day work of the Circuit Laboratory. Although only a few aspects are mentioned, they are representative of the wide field covered.

Technical support for the testing groups is given by the construction, special measurements and photographic groups, while other groups deal specifically with testing and investigation work.

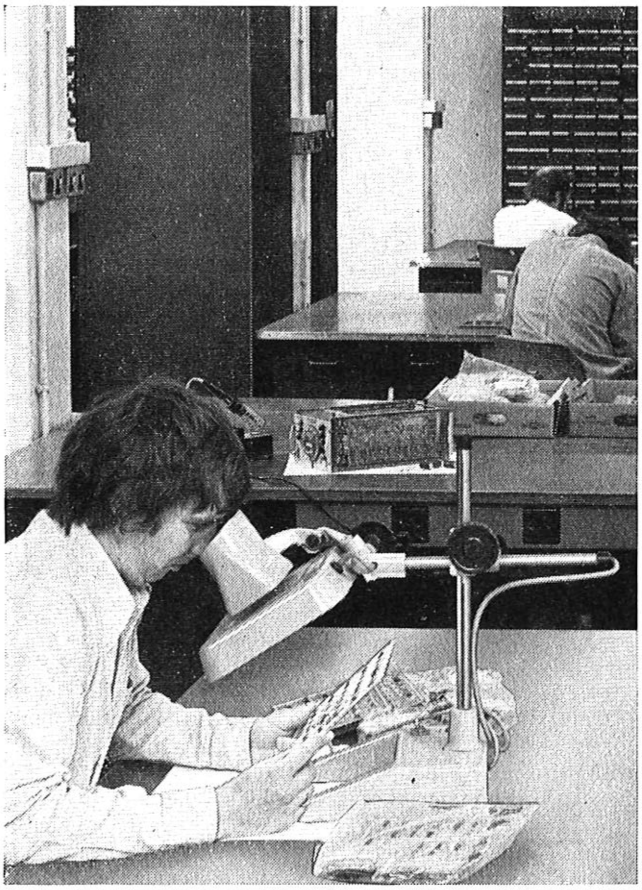

FIG. 3—Printed-circuit board inspection in the wiring shop

Construction

The construction group, consisting of wiring, relay and mechanics workshops, is situated at Manor Gardens, Holloway, and covers 5,000 ft^2 of accommodation. This group is responsible for the manufacture of prototype apparatus, such as maintenance testers and consoles, which may later be tested by the Laboratory. The group is also responsible for specialized items, required by designers for field investigations.

The nature of the work undertaken by the wiring shop has changed with the years, from the typical Strowger-type relay construction, using Type-3,000 relays, of the post-war era, to the present emphasis on miniaturization, employing electronic designs on printed-circuit boards. Flow-soldering equipment has recently been installed, and this is of particular value when large quantities of printed-circuit boards are to be processed. Fig. 3 shows printed-circuit board inspection being carried out in the wiring shop.

Relay construction, although suffering a decline in the quantity of relays demanded, is still important, and stocks are held which enable any standard design to be assembled and adjusted. The coil-winding facilities provide a useful service to the Laboratory for the construction of special-purpose transformers and inductors.

The mechanics workshop, illustrated in Fig 4, is well-equipped with modern machinery. The specialized equipment includes a 16-position hydraulic press, stud- and arc-welding equipment, capstan and metal-turning lathes and surface-grinding equipment. These facilities enable virtually any metal construction work to be carried out to professional standards.

Special Measurements

The special-measurements group is responsible for all test instruments in general use within the Circuit Laboratory, and undertakes the repair and maintenance of apparatus that falls outside the scope of the service provided by the Quality Assurance Branch of the Purchasing and Supply Department, THQ. It provides a calibration service and is responsible for the routine inspection of all moving-coil and digital measuring instruments, and for checking them against precision voltage and current sources.

The anticipation of future trends in the instrumentation field is particularly important. The group ascertains the Laboratory's requirements, and selects and purchases suitable

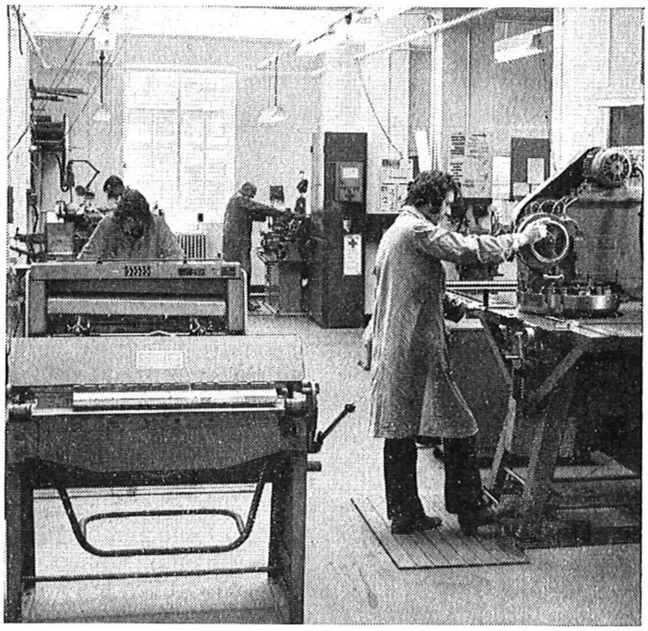

FIG. 4—The mechanics workshop

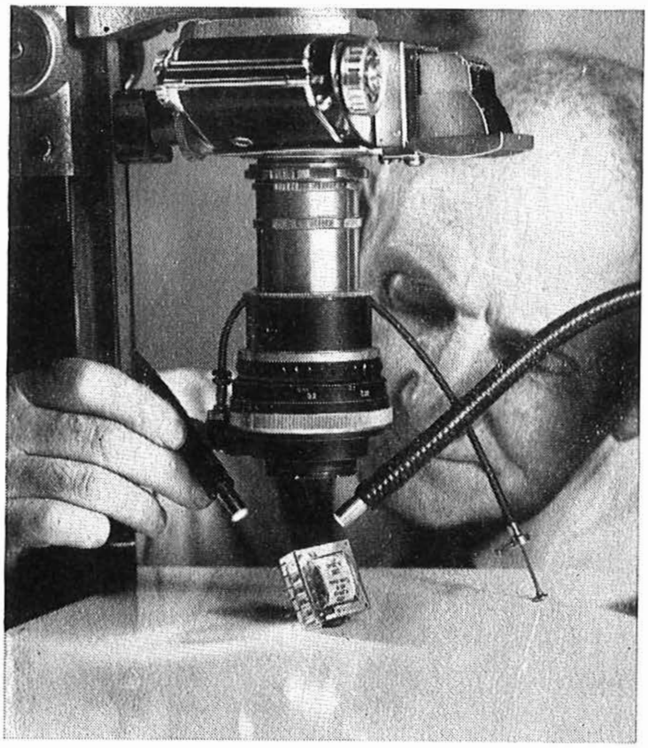

FIG. 5—Photographic equipment for macrophotography

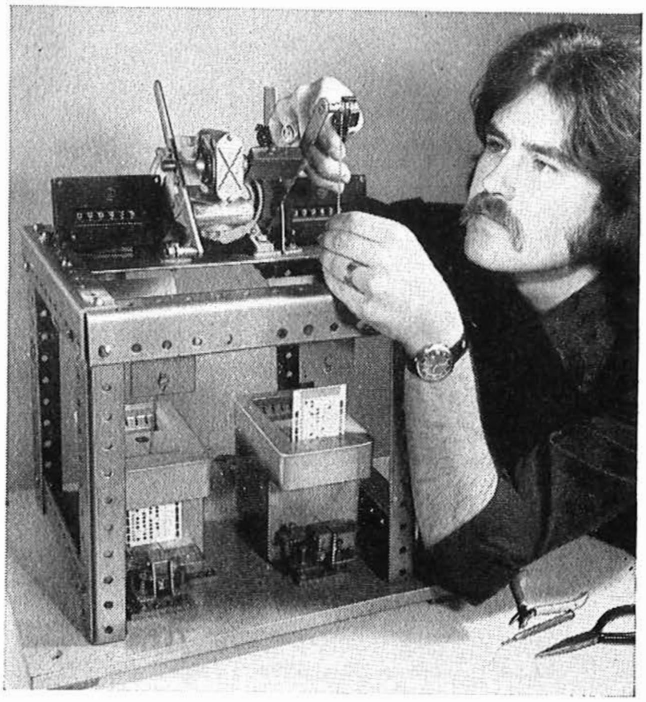

FIG. 6—Preparation of a mechanical life-test for Auto-Dials No. 301A

equipment, where this is available. Recent purchases have included a new generation of storage oscilloscopes, capable of recording single events at a writing speed of 2×10^6 m/s, and a new design of oscillograph, which uses a cathode ray tube, linked to photographic paper by optical fibres, to provide a much improved writing speed over its mechanical counterparts. When suitable commercially-built apparatus is not available, the group undertakes the design of the particular specialized item and arranges for its construction within the Laboratory.

Photography

In step with technological advances, photography has played an increasingly important part as an investigation tool in testing work, and has proved useful for illustrating reports and for general records purposes. The Circuit Laboratory has its own specialized technical-photography group that can undertake this work and which is equipped with a studio and processing facilities. Macrophotography—a technique for producing magnified photographs of small components—is an invaluable aid when it is necessary to compare a test piece immediately before and after an endurance test. Photographic equipment for this work, illustrated in Fig. 5, is available for both black-and-white and colour reproduction, with magnifications of up to 40 times.

High-speed cinematography is a further facility which is available, and has proved to be indispensable as an analytical tool in the investigation of mechanical malfunctions. The camera can operate at speeds of up to 10,000 frames/s and, when photographing non-repetitive events, careful synchronization is required, since the typical running time for a 100 ft reel of film is 1 s. When such a film is projected at the standard speed, movement is slowed by approximately 400 times. A library of some 250 high-speed films has been built up. Recent uses of this technique have included studies of the early failure of incandescent supervisory lamps on Type-4,000 selectors, and investigations into problems experienced with the card-stepping mechanism of the Auto-Dial No. 301A.

Component Endurance Testing

The environmental, electrical and mechanical testing of components is an essential part of the Circuit Laboratory's work and, in the majority of cases, the service conditions have to be simulated as closely as possible. When assessing the performance of components, such as capacitors, resistors and lamps, the relevant B.P.O. or British Standards Institution specifications are used. These may call, for instance, for stress-voltage tests in conjunction with humidity and temperature tests. To simulate extreme environmental conditions, test chambers have been installed which can regulate temperature levels between −70°C and 400°C, with a controlled humidity of up to 99 per cent.

Although the range of components tested is large, electro-mechanical switch-gear, relays, selectors and counters account for most of the work of the group. The life-testing of such components usually takes the form of their repeated operation, and a typical mechanical test-bed is shown in Fig. 6. The tests are usually carried out in cubicles, so as to reduce noise and enable special conditions, such as a dusty atmosphere, to be reproduced. Contact resistance can be monitored during repeated pulsing operations and, if a predetermined value is exceeded, tests can be automatically stopped. Results can be analysed by mechanical, electrical and photographic means, and some life tests may involve up to 10^9 operations.

Customers' Apparatus

Before privately-owned attachments, such as answering and recording machines, and fire and burglar alarms, can be connected to the public exchange network, they must be submitted for approval tests. These include verification of the signalling speed and ratio, measurement of the transmission levels of speech signals and identification tones, measurement of the output impedance, and a check of the mains-protection arrangements for B.P.O. lines. Facsimile and telemetry apparatus require measurements of the harmonic content, and an analysis of the spectrum of the transmitted signal, to ensure that there will be no interference with established B.P.O. a.c. signalling and carrier systems.

Other work includes the acoustical measurements of telephone-instrument characteristics. Fig. 7 shows a section of

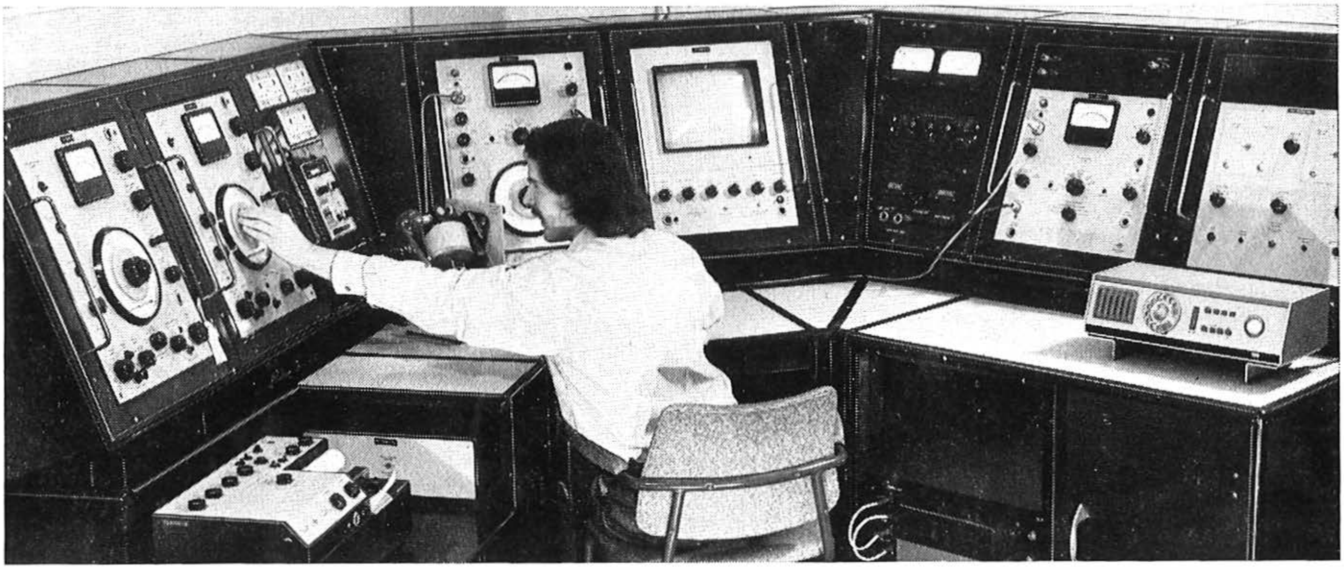

FIG. 7—Section of the acoustical testing laboratory

the acoustical testing laboratory. Sensitivity and frequency-response characteristics are assessed using artificial-mouth and -ear couplers, and tests are conducted in a small anechoic chamber. There is also a reverberant test chamber for use in investigations into the spectrum and loudness characteristics of bell- and tone-callers.

A.C. Signalling

Early in 1970, the Circuit Laboratory, in conjunction with another development group within THQ, embarked upon a program to redesign the signalling system a.c. No. 9[12] terminal equipment, in order to produce a system of smaller size, improved reliability and lower power requirements. Prototypes were constructed using Type-62 equipment practice and, after extensive proving tests in the Circuit Laboratory, the equipment successfully completed a public field trial lasting six months. Manufacturers' pre-production samples are now being assessed and are currently the subject of a further field trial.

Other work, which is being carried out at present, includes tests on the 24- and 30-channel pulse-code-modulation systems, and on B.P.O. and proprietary designs of senders and receivers for signalling system multi-frequency No. 4, for use with push-button telephones.

Miscellaneous investigations are also undertaken on new switching techniques, and on the assessment of new devices.

Training

The foundations for the future of the Circuit Laboratory are being laid now, in the training given to the present T.T.(A.)s. They follow a comprehensive three-year training program, during which their time is divided between block-release courses at technical colleges, training in telephone-areas, and carrying out training projects within a special training centre, which has been set up in the Circuit Laboratory to develop their practical skills and introduce them to laboratory procedures. Their training enables them to join a group on the completion of their apprenticeship, with their skills and technical abilities developed, so that they are able to make a real contribution to the work of the Circuit Laboratory.

CONCLUSION

The preceding summary attempts to show something of the range and variety of the work undertaken by the Circuit Laboratory, but, in spite of all the very considerable technical facilities at its command, the Laboratory could not function without the constant and willing support of all of its staff—technical and non-technical alike.

Although many things have changed in the last 50 years, some things remain the same. In 1924, when the Circuit Laboratory was created, its function was to provide a service to designers. In 1974, it remains the Circuit Laboratory, and it is still providing that same service.

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A New Register-Translator using Stored-Program Control for Director-Area Local Exchanges

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This article describes how the philosophy of stored-program control has been applied to the gradual replacement of common electro-mechanical equipment in Strowger director exchanges, with the result that reduced maintenance costs and improved facilities have been realized.

INTRODUCTION

The new register-translator for director-area local exchanges, described in this article, provides extra facilities over and above those given by the existing electro-mechanical A-digit selector, director and local register. The basic function of the new equipment is to receive all the digits dialled by a customer, and route the call to the required objective exchange, either directly, or via a tandem exchange, sector switching centre (s.s.c.), or group switching centre (g.s.c.).

In the new register-translator, a single common processor is time-shared between a large number of individual interface circuits, called signal-conversion circuits (s.c.c.s). The system is based on the Mark 1c, stored-program-control (s.p.c.) processor, developed by G.E.C. Telecommunications Ltd. As the function of the equipment is governed by a predetermined program of operations, changes to the facilities provided by the equipment can be easily made, in most cases, by modifications to the program.

The physical design uses T 10,000-type equipment practice. Each register-translator unit comprises a pair of cabinets. One cabinet houses the processor, consisting of a data store, a program store, a translator store and the control-logic circuits, whilst the other cabinet houses the s.c.c.s, of which there are 60 on a fully-equipped rack. Each unit is known as a *cabinet-pair*.

The associated maintenance aids include a processor monitor panel with access to the processor's information highway. A teleprinter, used for recording processor fault-information, is provided on a one-per-installation basis. Standard, discrete-component logic circuits are used throughout the processor. A general view of the equipment is shown in Fig. 1.

A typical trunking arrangement at a director-area local exchange, employing the new equipment, is shown in Fig. 2. Traffic from the first code-selectors is offered to all s.c.c.s via the existing A-digit hunters, in such a way that, with the

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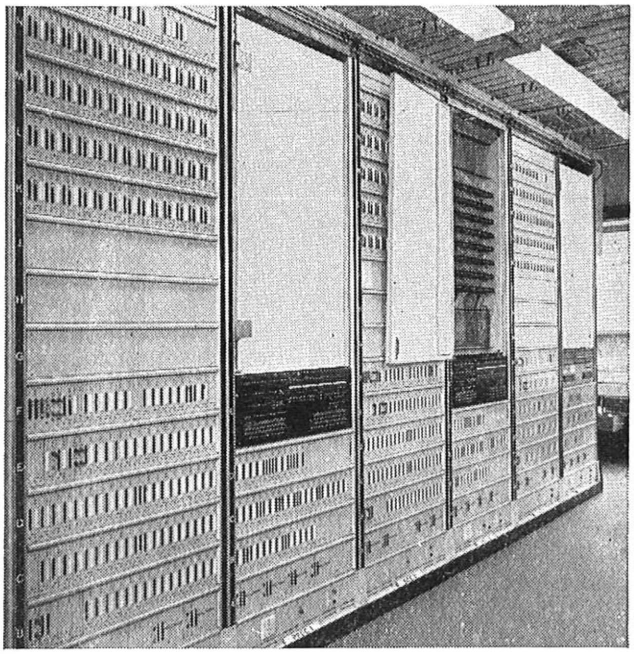


FIG. 1—The installation at Millbank exchange, showing three register-translator units

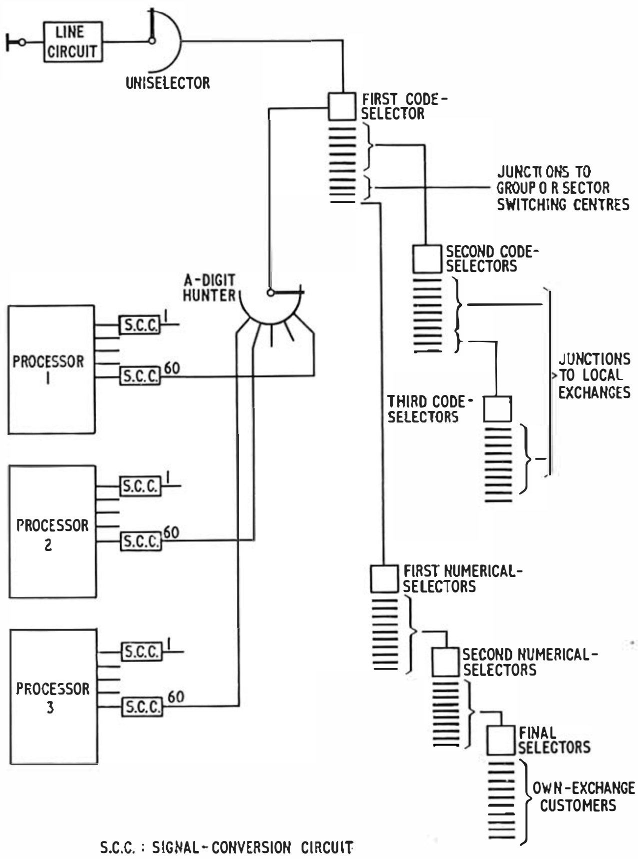


FIG. 2—Trunking diagram for a director-area local exchange with register-translators using s.p.c.

withdrawal from service of any cabinet-pair, the traffic is spread uniformly over the s.c.c.s in those cabinet-pairs remaining in service. For reliability reasons, the minimum size of an installation is three cabinet-pairs, an adequate grade of service having to be maintained with only one cabinet-pair available for traffic.

FACILITIES

The following list is by no means exhaustive, but is intended to illustrate the improvement in facilities given by the use of s.p.c., as compared with conventional electro-mechanical equipment.

Provision is made for

(*a*) eight class-of-service signals on a path-of-entry basis,

(*b*) the receipt of 10 pulses/s loop-disconnect signals, and voice-frequency Keyphone signals when a receiver and the appropriate replacement equipment for the first code-selector are fitted,

(*c*) storage for up to 18 digits,

(*d*) the examination of up to the first six digits for number-length determination and routing purposes, including examination of the fourth digit, where necessary, on home-numbering-group calls, and examination of up to six digits on national-number-dialled calls, for the purpose of directly routing such calls to exchanges in adjacent non-director charging groups over local junction circuits,

(*e*) automatic alternative-routing of calls on receipt of a *group-busy* signal,

(*f*) 4 s and 20 s time-out periods, with normal and forced-release functions, where appropriate,

(*g*) *s.c.c. effective*, *s.c.c. ineffective* and *destination-call-count* metering, and

(*h*) up to approximately 2,000 translations.

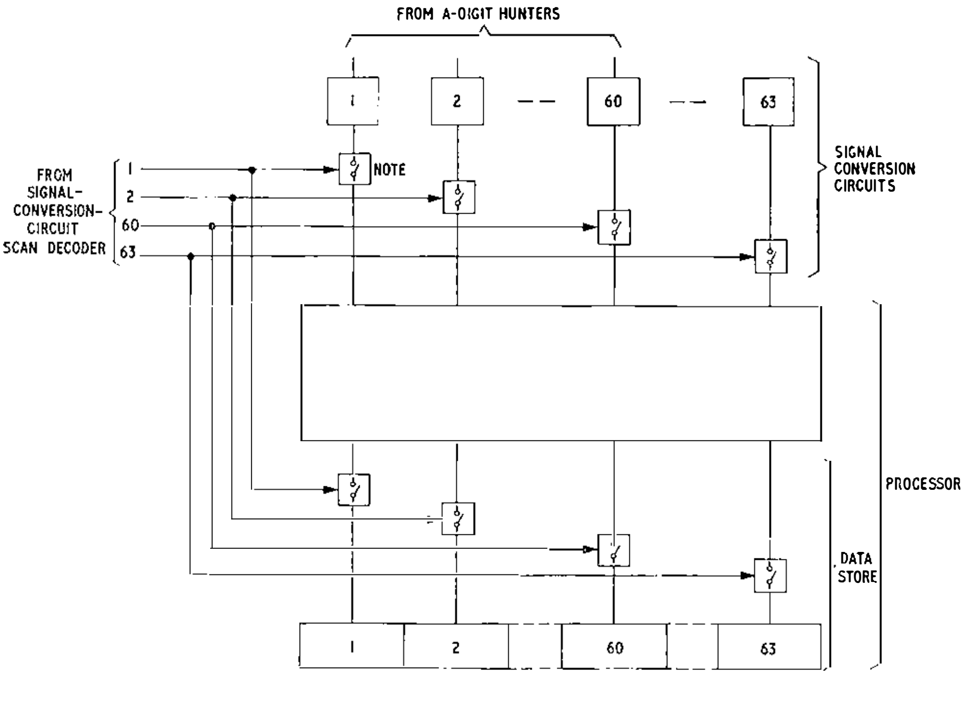
The maintenance facilities include the ability to control manually the processor, so that program instructions can be executed singly. Program instructions can also be simulated, by means of keys on the monitor panel. Indicators show the state of the processor at any instant. Fault information is printed-out on a teleprinter in the form of numerically-coded messages. The information includes the exchange code, the identities of the processor and s.c.c., the nature of the fault, the digits dialled and the state of the processor at the time of printing.

PROCESSOR

The operation of the Mark 1c processor has been fully described in a previous article.[1] The processors used for s.s.c. and director-exchange applications are almost identical. However, the latter application comprises two racks, since no multi-frequency sender-receivers are required, and one program. All incoming and outgoing signalling is in loop-disconnect form. For completeness, a brief description of the processor is given below.

Each processor is capable of processing information from 63 s.c.c.s, of which 60 are available for normal traffic, the other three being used for test purposes. Each s.c.c. has its own section of working space in the data store, comprising 16 words, each of 16 bits; that is, a total of 256 bits per s.c.c. The processor executes the work assigned to it by the s.c.c.s, some of which will be carrying traffic, by scanning each s.c.c. and its respective section of the data store in turn, as illustrated in Fig. 3. The average time taken for the processor to process the information on all 63 s.c.c. positions lies in the range 5–7 ms. The scan is initiated by a clock pulse occurring every 11·1 ms and, thus, the processor is inactive after completing each scan, until the arrival of the next clock pulse, when it returns to the first s.c.c. The clock-pulse interval of 11·1 ms is a factor of the pulsing-out requirements, enabling the processor to initiate timed loop-disconnect pulses by counting scans and operating and releasing the pulsing relay at the appropriate scan times. Fig. 4 shows the basic layout of the processor.[2]

The program is stored in a non-destructive, read-only memory, using Dimond-ring transformer cores. The program controls the progress of each call on the s.c.c.s, and it also



Note: This function is implemented in electronic form

FIG. 3—Signal-conversion-circuit and data-store scanning procedure

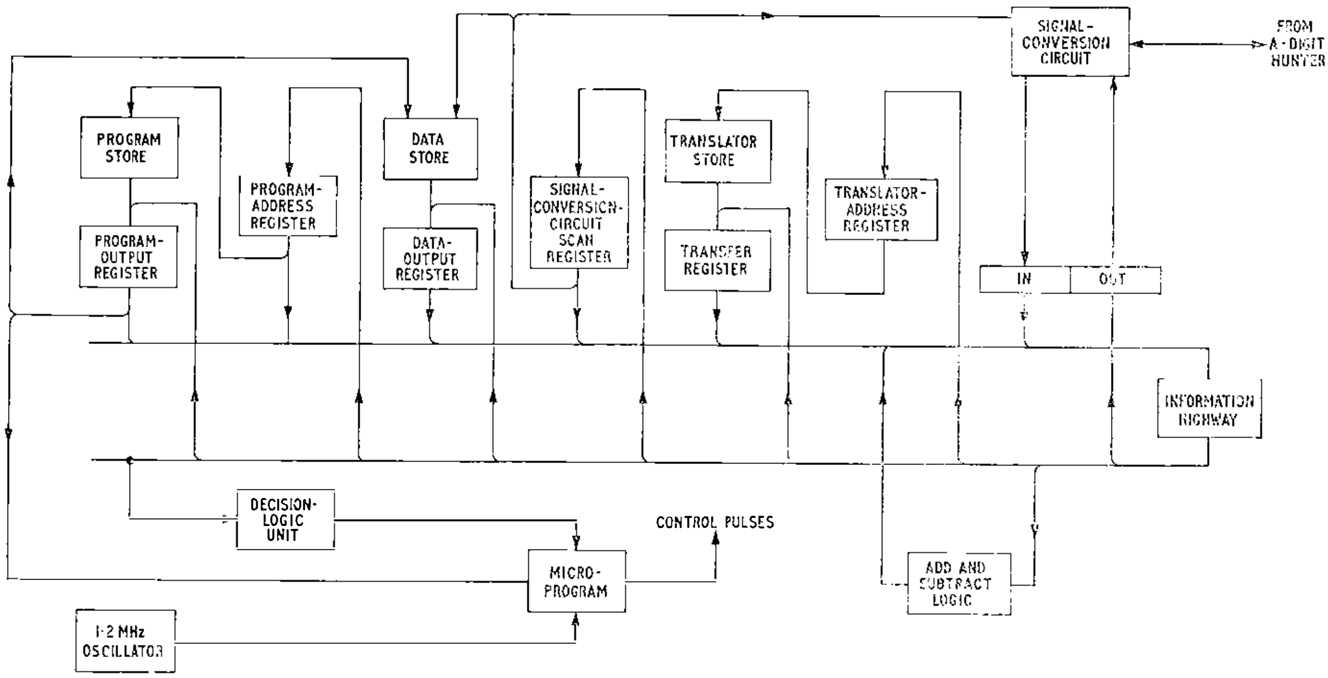


FIG. 4—Simplified block diagram of the Mark 1c processor

controls the scanning mechanism. The capacity of the store is 2,560 words, each of 23 bits. Approximately 1,300 words are used for the register-translator application in director exchanges.

The translator store is a similar read-only memory, also using Dimond-ring transformer cores, and it has a capacity of 2,560 words. The data store is a conventional read/write ferrite-core matrix.

Instructions from the program store are carried out at a basic clock rate of 1·2 MHz, and control the manipulation of information within the processor. The various store and logic units within the processor are gated onto the internal information highway as required, under the control of 17 program instructions.

Security

System security falls mainly into two categories. Firstly, parity bits are used to check the output of the program store, and to predict the parity of the next instruction address, thus verifying that the correct sequence is being followed. Parity checks are also carried out on words from the data store. Secondly, all the processors are connected in a ring through special master-slave s.c.c.s, so that the contents of one translator store may be continuously compared with those of another. If a discrepancy arises, the appropriate slave carries out a programmed self-check to establish which is the faulty processor.

SIGNAL-CONVERSION CIRCUITS

Each s.c.c. is divided into two sections: the signal-conversion relays and the signal-conversion electronics. Each signal-conversion-relay section uses four Type-23 relays and one mercury-wetted reed relay. The two sections are mounted on separate plug-in units, which are both housed in the s.c.c. cabinet.

Fig. 5 shows the elements of the signal-conversion relays and electronics, illustrating how the s.c.c. acts as an interface between the processor and the Strowger equipment. The seizure conditions from the first code-selector, which consist of a low-resistance earth on the P-wire and an earth on the PU-wire, are extended to the signal-conversion electronics over the P and A-leads, via the 20 kohm resistor and impulse-correcting timer, respectively. The level-changers convert these signals into a form suitable for use by the processor hardware by changing the Strowger earth and −50 volt signals into the 0 volt and +12 volt logic levels used in the processor.

Signals from the processor to the s.c.c. are staticized on bistable circuits T1–T4, the outputs of which are used to operate relays via relay drivers A1–A4. For example, on recognition of seizure, the processor operates relay DT by causing input signals to appear simultaneously on the DT, SET and SCAN-DECODE leads. Gates G10 and G2 open to set bistable circuit T1 and, thus, operate relay DT via relay-driver A1. Relay DT extends dial tone to the customer via the first code-selector and operates relay S, a contact of which removes the 240 ohm testing-in resistor, when necessary, as would happen in an A-digit selector. The processor releases relay DT, on recognition of the first BREAK pulse from the first code-selector, by causing input signals to appear simultaneously on the DT, RESET and SCAN-DECODE leads. Gates G9 and G1 open to reset bistable circuit T1, which releases relay DT.

Earth-disconnect signalling pulses, from the first code-selector, are repeated to the signal-conversion electronics via the impulse-correcting timer. The timer is designed so that the processor ignores break periods of less than 16 ms and make periods of less than 6 ms; this arrangement overcomes problems associated with contact-bounce and spurious pulses. Outgoing loop-disconnect pulses are repeated to line by relay P, which is operated by the processor for the duration of each outgoing break pulse.

When all digits have been sent, the processor operates relay R. This releases relay S, and disconnects the P-wire to give normal release conditions to the first code-selector, which then switches the call through.

The processor can cause the s.c.c. to force-release a call; for example, when dialling-in is delayed, or when a spare code is dialled. The processor operates relay FR, which applies an earth to the FR-wire, and then operates relay R, which disconnects the P-wire, in order to fully release the first code-selector. Long junction-guard forced-release is given

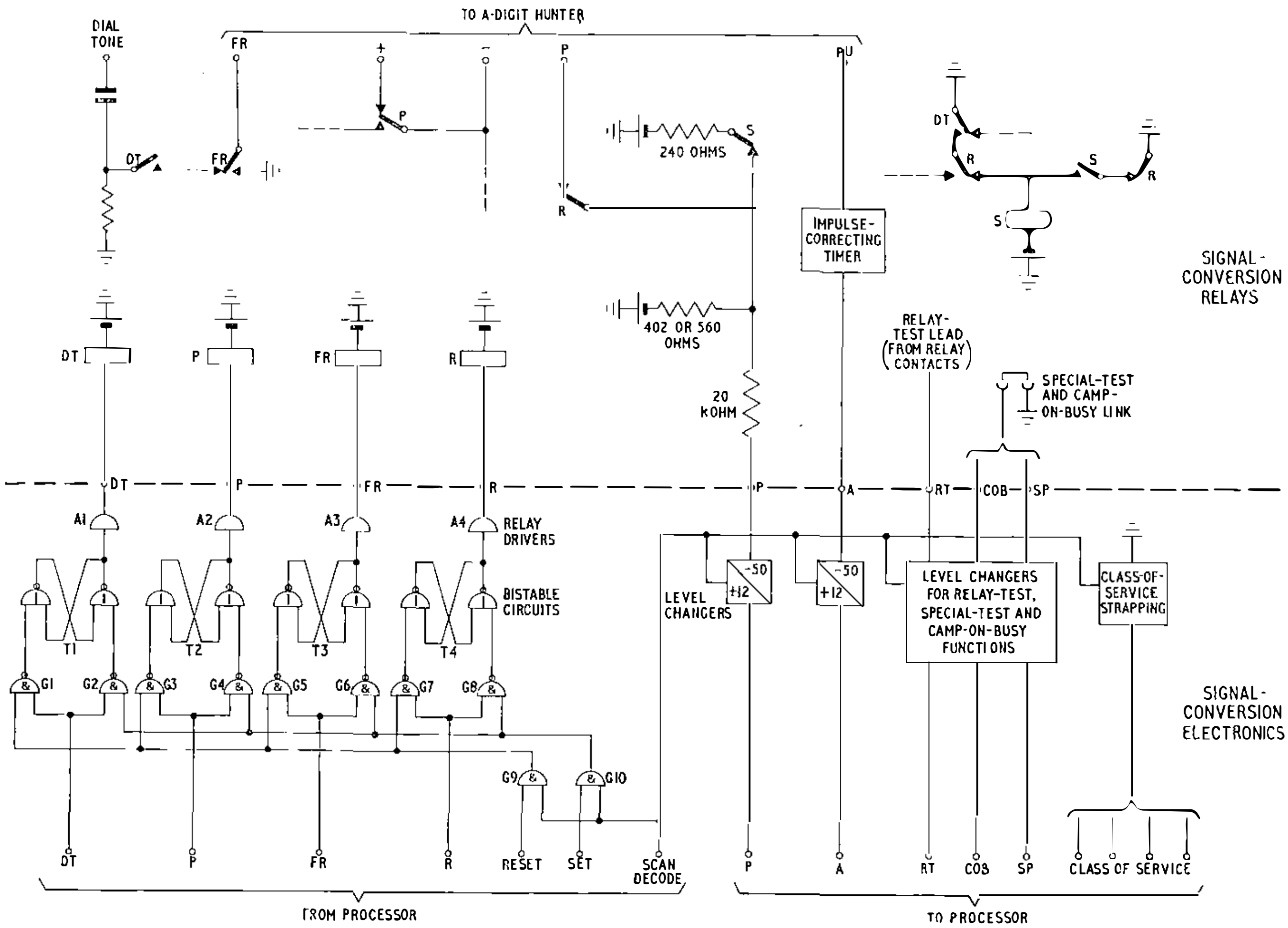


FIG. 5—Interface elements of the signal-conversion relays and electronics

where necessary, by the operation of relay P for 800 ms before the operation of relay FR.

When the processor recognizes the release of the first code-selector, all the signal-conversion relays are released.

Test Facilities

A relay-test facility is provided for the s.c.c.s, and is carried out by the processor

(*a*) upon detection of a permanent calling condition,

(*b*) on all ineffective calls, except those which are abandoned,

(*c*) at the end of every call on every s.c.c., if the appropriate key is operated on the monitor panel, and

(*d*) on an s.c.c. which has been selected by the manual insertion of a special link.

The relay test consists of the operation and release of various relays in the s.c.c. by the processor, which checks for the correct conditions. A failure causes the s.c.c. to be "frozen," that is, locked out of service, and a fault print-out to be given.

An s.c.c. can be placed in the camp-on-busy condition under the control of a manually-inserted link. This allows the s.c.c. to deal with any call in progress and, then, become unavailable to traffic when that call has been processed.

TYPE APPROVAL

The type-approval exercise for the Mark Ic processor, in its director-area, local-exchange application, was carried out in the following three basic stages.

(*a*) All the documents required for production were approved. Environmental testing and facility checking were carried out at the manufacturer's premises, and at Belgravia exchange, on a single, fully-equipped cabinet-pair.

(*b*) All of the remaining documentation was approved, the main part of which consisted of service diagrams.

(*c*) Finally, all of the facilities, including the security aspects, were checked at a complete installation.

A schedule of tests was drawn up by the British Post Office (B.P.O.), to ensure that

(*a*) the components used were acceptable,

(*b*) the circuit design was acceptable,

(*c*) there were no undue fire hazards,

(*d*) all of the diagrams conformed to B.P.O. standards,

(*e*) the flow charts conformed to the facility schedule,

(*f*) the program followed the flow charts,

(*g*) the real time used by the processor, in any single scan, did not exceed 11·1 ms,

(*h*) the processor functioned correctly under adverse environmental conditions, such as excess electrical interference and high temperatures,

(*i*) the equipment interworked satisfactorily with approximately 40 different types of first code-selector,

(*j*) the master-slave testing arrangements were satisfactory, and

(*k*) the equipment provided the facilities laid down in the facility schedule.

Many of the tests were carried out at the manufacturer's premises and at Belgravia exchange, where the field-trial was held. Final type approval was not given until a full installation was available, enabling tests on the master-slave arrangements, fault-recording arrangements, traffic meters and power supplies to be completed, which could not have been carried out on a single cabinet-pair.

SOFTWARE

Telephone control software is a comparatively new discipline in telephone switching, and it brings some unusual design considerations and problems. The following observations are applicable to the Mark 1c processor.

Real Time

It was decided that the type-approval exercise should include some measurement of the actual processing time (or real time) for a scan within the allocated 11·1 ms clock-pulse period, and the effect of variation of the real time, known as *jitter*, upon calls in progress.

Depending on the number of instructions to be processed for any particular s.c.c., the actual processing time taken for that s.c.c. varies between the orders of tens to hundreds of microseconds. Typically, a free s.c.c., when processed, causes the processor to pass down an *s.c.c. waiting* path in the program, which consists of a certain number of instructions. However, an s.c.c., which has just been seized, causes the program to pass down the next *state-of-call* path, consisting of a different number of instructions. Therefore, the sum of the varying processing times for s.c.c. Nos. 1–63 constitutes the total operating time of the processor (or real time) within the 11·1 ms clock-pulse period, as illustrated in Fig. 6. The next real-time period would differ from the previous one because some of the calls on the s.c.c.s would have progressed to their next state-of-call. Hence, the real time varies from scan to scan, although successive scans always commence at 11·1 ms intervals.

In practice, the real time averages from 5–6 ms for 60 working s.c.c.s. This figure increases to 6–7 ms during busy periods. Measurements of real time were made, under varying load conditions, to ensure that adequate care had been taken during the writing of the program. Considering a typical scan, lasting about 6 ms, it may be appreciated that, of a maximum of 60 traffic-carrying s.c.c.s, only a small percentage will have actually detected or originated a change of state, such as a seizure condition or the operation of a pulsing relay, during the scan. The probability of an s.c.c. being in a waiting (or time-out) state is high and, in general, the time-out state is the most popular area of the program. It should, therefore, be the intention of the programmer to arrange that time-out paths in the program comprise very few instructions, typically three to six. Unpopular paths of the program, such as unusual release-failure conditions, may be up to 20 or 30 instructions long.

The overall aim of the programmer is to ensure that any particular real-time period has a very low probability of exceeding the allocated 11·1 ms clock-pulse period. If this probability were high, then the use of software scan-counts for timing purposes would become invalid. In practice, the real scan-time exceeds 11·1 ms, on fully-provisioned cabinet-pairs in busy installations, once every few weeks.

Jitter

If consideration is now given to successive scans, it is evident that, although for s.c.c. No. 1 the period between two successive scans is 11·1 ms, for s.c.c. No. 63 this is not the case. If, for example, in scan N, s.c.c. No. 63 is scanned 7 ms after s.c.c. No. 1 and, in scan $N+1$, s.c.c. No. 63 is scanned 5 ms after s.c.c. No. 1, then the scan interval for s.c.c. No. 1 is 11·1 ms but, for s.c.c. No. 63, it is 9·1 ms. If, in scan $N+2$, s.c.c. No. 63 is scanned 6 ms after s.c.c. No. 1, then this scan interval becomes 12·1ms. However, when the scan interval for s.c.c. No. 63 is observed for a sufficiently large number of scans, the interval will average 11·1 ms. The variation in the length of the scan interval, for a particular s.c.c., is known as jitter.

The effect of jitter on a call is minimal. A call on s.c.c. No. 60 will be the worst affected, and even then, only the shortest time-out periods will show any measureable difference. For example, during pulsing-out, if the processor commences to time the make period of a pulse on scan N at, say, 7 ms after the arrival of the 11·1 ms clock pulse, and terminates it on scan $N+3$ at, say, 5 ms after the 11·1 ms clock pulse, the make pulse will have existed for 31·3 ms instead of 33·3 ms, which is the standard value and which always applies for s.c.c. No. 1 (see Fig. 7). For longer time-out periods, the same amount of jitter has a reduced effect. For example, a break pulse, in the above conditions, would exist for 64·6 ms, instead of 66·6 ms.

Extensive tests, under live-traffic conditions, on s.c.c. No. 61 showed that there was a 99 per cent probability of the jitter being less than 0·5 ms. The tolerance on a make pulse would, therefore, be 1·5 per cent. This figure is overshadowed by the tolerance on the 11·1 ms clock pulse, which is 4 per cent.

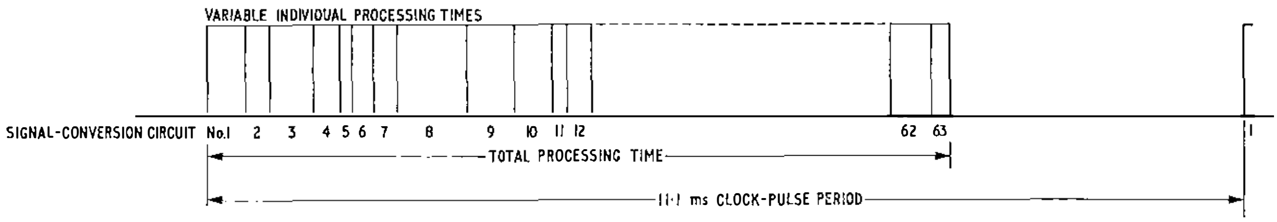


FIG. 6—Variability of real time

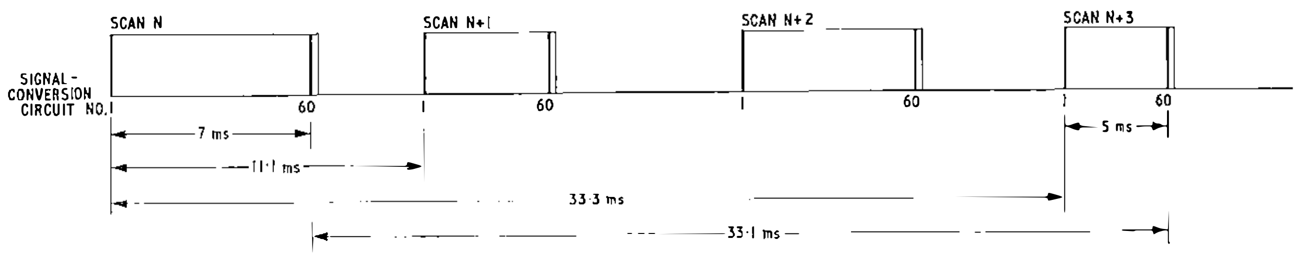


FIG. 7—The effect of jitter on timing for the make period of a pulse

Interface Software

A common problem associated with the design of new electronic equipment is that of interfacing it with electro-mechanical equipment. As electronic components have much faster switching times, and operate at comparatively high impedances, this makes such equipment very sensitive to timing, sequencing, relay-race conditions, noise and contact bounce found in electro-mechanical systems. As described above, the hardware interface in the s.c.c. successfully eliminates noise and contact bounce on the PU-wire. However, it becomes costly to eliminate timing and sequencing signal errors using hardware circuits, and these problems are more easily overcome in the software. A simple example may be found in the validation of the seizure signal on the P-wire against contact bounce, where interrogation of the P and PU-wires takes place on two successive scans before the call is allowed to proceed. In general, interfacing the traffic program to the signals from the s.c.c. is complex, and the problem is aggravated by the 40 different first code-selectors with which the equipment is required to work.

The majority of program changes made during the system testing at Belgravia exchange, the service trial and subsequent installations, have been in the interface-software area of the program. The possibility of more modifications being required cannot be significantly reduced until the equipment has been observed to be operating satisfactorily in every scheduled installation.

A possibility, as yet mainly unexplored by the B.P.O., is the use of the processor to diagnose faults in associated Strowger equipment. It is feasible for an s.c.c. to be modified by the addition of tone detectors, so that information may be printed, giving the destinations of calls and their degree of success. The release and forced-release programs could be expanded to give more-detailed information about faults in the A-digit hunters or first code-selectors. This is an area where the flexibility of the machine may offer savings in maintenance costs outside its particular application.

Software Documentation

Software documentation basically takes three forms. The first is a flow chart, to the agreed B.P.O. notation, derived from the facility schedule. This is essentially the facility schedule in flow-chart form, and is system-orientated only to a small degree. The second form of documentation is the state-of-call flow chart, where the original flow charts are converted to machine-code instructions, arranged within the housekeeping* instructions. The third consists of numerous pages of computer print-out, giving the binary equivalent of the instructions in address sequence and, also, the wiring code. The print-outs are generated by a general-purpose computer working to a compiler program, which also calculates the parity bits for each instruction. An example of the software implementation of a sub-routine has been given in a previous article.[1] Other documents are mainly informative, and give details of program and data-store allocations.

MODIFICATIONS

The modifications to the interface software have arisen over a period of two years, from system testing in Belgravia exchange to installations that have been working for some months. The following examples illustrate the sort of problems likely to be encountered in Strowger environments, and their solution by means of changes to the software.

Pulsing

It was discovered that, in the worst case, standard pulsing on routes to s.s.c.s and g.s.c.s was unacceptably distorted by the metering-over-junction relay-set. It was decided that pulses sent by the s.c.c. should be negatively distorted,† in order to counteract positive distortion† introduced by the relay-set. The associated software was, therefore, modified to give a break-to-make period ratio of 8 : 1 on this type of call, under the discrimination of a class-of-service signal.

P-Wire Resistance

Observations at two installations showed that ageing Strowger equipment was causing the progressive freezing of s.c.c.s. It was found that excessive P-wire resistance between particular types of first code-selectors and the s.c.c.s was preventing the recognition of a seizure condition by the level-changer in the signal-conversion electronics. The equipment had originally been programmed to recognize this as a fault condition on the s.c.c., force-release the call, freeze the s.c.c. to traffic, and give a fault print-out.

The problem could have been rectified by modifications to the Strowger equipment, the s.c.c.s or the program. In this case, the advantage of changing the program, rather than modifying the hardware, is that such changes are simple to carry out, being similar to translation changes, and effectively modify the operation of 60 s.c.c.s.

The problem was overcome by changing the program to enable this particular condition to be recognized. Instead of force-releasing the call, the program was arranged to operate relay S, which increases the resistance of the P-wire within the signal-conversion relays. The effect of this is to reduce the P-wire voltage at the level-changer and, thus, enable the level-changer to recognize the condition. Then, seizure is detected by the program, and the call proceeds successfully. In the event of a fault condition existing in the s.c.c., forced-release is arranged as before.

OPERATIONAL EXPERIENCE

The purchase of proprietary, computer-type equipment for use in general telephone switching has given rise to some interesting points relating to the documentation, installation and maintenance aspects.

Although the software gives a unique flexibility in the design of the equipment, the B.P.O. documentation series does not allow the possibility of the local modification of programs to suit specific installations. Control of the program by Telecommunications Headquarters enables future facility changes to be incorporated in the equipment, and allows the most efficient use of the program and data stores.

To date, experience in both commissioning and maintenance have shown that teething troubles are likely in the first few weeks of service, mainly due to the bedding-in of components. After this period, the equipment requires little attention. The performance to be expected for 120 s.c.c.s might typically be one fault per month and, perhaps, between 5–10 fault print-outs per week, mainly caused by unusual conditions in the associated Strowger equipment.

MAINTENANCE AIDS

A special maintenance aid is provided on s.c.c. position No. 61, which allows a suspect signal-conversion-electronics or signal-conversion-relay section to be mounted at a convenient height for maintenance. This s.c.c. position is not available for carrying traffic. A software test is possible under key control.

An inlet tester was developed by the B.P.O., which simulates, under manual control, the conditions between

* The housekeeping instructions provide the scanning, 11·1 ms timing and state-of-call jump functions.

† Negative distortion is an increase in the break-to-make period ratio from the standard value of 2 : 1 (derived from $66\frac{2}{3}$ ms : $33\frac{1}{3}$ ms); positive distortion is a decrease in this ratio.

the first code-selector and the s.c.c. This allows the maintenance engineer to pass valid calls through the s.c.c., or to simulate typical faults in the first code-selector. New translations, or some program modifications, can be tested, using s.c.c. No. 61, before the processor is allowed to carry live traffic.

A spare cabinet-pair has been allocated to each of four telecommunications regions for maintenance purposes. In the event of a fault on a cabinet-pair, the faulty unit will be replaced by a spare, in order to minimize the out-of-service time of the processor. The faulty unit will then be tested in its working position on the maintenance cabinet-pair. As fault-finding on units in this manner will be time consuming, it was decided that the spare processors would be more efficiently employed if they were reprogrammed and modified to operate as diagnostic testers, so that a faulty unit could be logically tested, as a peripheral device, in a few seconds. The software and hardware design of the diagnostic tester is well under way, and it is expected to be available at the beginning of 1975.

CONCLUSIONS

The replacement of the existing electro-mechanical register-translator equipment, in director-area local exchanges, results in savings in floor space, and gives considerable economies in maintenance costs, as well as producing a quieter working environment. In addition, the ability to directly route local national-number-dialled calls will result in economies in line plant, since metering-over-junction circuits to the g.s.c. or s.s.c., as well as the g.s.c. or s.s.c. equipment itself, will not be required for the routing of this traffic. Also, number lengths of eight digits will be possible within the London director-exchange area. Furthermore, alterations and additions to facilities can be achieved by changing the system software with, possibly, minimal modifications to the hardware.

ACKNOWLEDGEMENTS

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The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*.

Letters of sufficient interest will be published under "Notes and Comments". Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will only be possible to consider letters for publication in the January issue if they are received before 18 November 1974.

Letters intended for publication should be sent to the Managing Editor, *P.O.E.E. Journal*, NP 9.3.4, Room S 08A, River Plate House, Finsbury Circus, London, EC2M 7LY.

Selling Price of the Journal

The Board of Editors regrets that, from January 1975, the price of the *Journal* will be increased to 30p per copy, 45p per copy including postage and packaging (£1·75 per year, $4.50 Canada and the U.S.A.). The price increase is due to heavy increases in costs, particularly in the cost of paper.

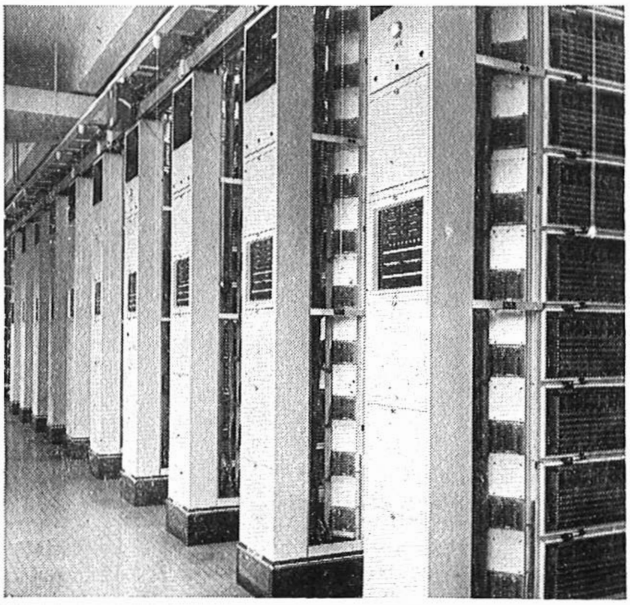
The price to Post Office staff remains unchanged.

Regional Notes

SOUTH EASTERN REGION

New TXK1 Group Switching Centre at Hastings

The new Hastings switching complex was brought into service in two stages. Firstly, at about 06.15 on Saturday 30 March, a time of low traffic density, the new TXK1 group switching centre (g.s.c.)—the largest of its kind in the U.K.—was switched into service. It replaced a temporary Strowger g.s.c., installed by local labour using equipment recovered from Brighton (Withdean) exchange, which had been in operation since late 1969. To cope with an ever-increasing traffic load for the Hastings and Rye charging group which it served, this temporary installation had undergone several extensions since 1969, the last of which was completed only months before the change-over.



General view of Hastings TXK1 unit

(By courtesy of G.E.C. Telecommunications Ltd.)

The first stage included the partial introduction of a new cordless switchboard system (c.s.s.) No. 1 and a repair service centre (r.s.c.) for the area surrounding Hastings. This enabled one of the three existing manual switchboards to be closed, thus releasing operators to staff the new auto-manual board. Lines which were connected to a mobile non-director exchange, and temporary out-of-area lines, were transferred to the new TXK1 exchange.

The second stage took place on 24 April, with the provision of full automatic working for Hastings itself, involving the final closing down of the two remaining manual switchboards and the old r.s.c. Between the two stages, 110 public telephone kiosks were converted to pay-on-answer working. Prior to this, some 250 renters' coin-collecting boxes had been converted and modified with voice-frequency adapters, to enable them to work temporarily to the manual exchange.

The 22-volt manual exchange had served Hastings since 1930, when it opened with 2,320 subscribers. During the second world war, it escaped serious damage, although its windows were shattered by the blast from an aerial torpedo. When it closed on 24 April 1974, it was the largest remaining manual exchange in Western Europe.

Work on the foundations for the new building started in September 1968. To secure a firm foundation, 520 piles were driven to a depth of about 60 ft. The new installation consists of a TXK1 g.s.c., using 5005 crossbar equipment, with a local multiple capacity of some 18,000 connexions, a 38-position c.s.s. No. 1 auto-manual switchboard, 14 office-type director-enquiry positions and an r.s.c. Some 2,500 junction and main-network circuits provide s.t.d. access to about 3,000 exchanges. The installation includes 327 crossbar-equipment racks and 96 Strowger-type racks.

The equipment was installed by G.E.C. Telecommunications Ltd., and was accepted for service just before Christmas 1973, after successfully passing a 42-part call-sending program, this being completed in less than two weeks. There then followed an intensive program of modification and testing, by British Post Office personnel, to bring the installation and its out-station equipment to a state of readiness for the first stage of the opening. The total cost of the project was around £3M.

The exchange is now handling nearly 1-million calls a week and, after two months' service, shows every sign of settling down to give a high quality of service.

J. W. G. HAWARD

SOUTH WESTERN REGION

Exeter (Rougemont) Exchange Ductwork

The provision of a new switching centre in the heart of a city is a once-in-a-lifetime operation and, when that centre needs a 74-way main duct, with a 54-way duct down the centre of the main street, then that operation needs to be timed, planned and executed with care. Exeter is an ancient city, and not one noted for its wide streets. Consequently, the operations involved the closing of two main streets while the work was in progress. Alternatives had been considered, including that of tunnelling, but these had been rejected for various reasons.

A further problem was that the main duct-way had to cross a railway line, and there was insufficient space within the bridge's structure to accommodate all of the ducts. This problem was overcome by building a steel-pipe bridge immediately beside the road bridge, the pipe being filled with plastic duct-ways. The pipe was conveyed to the site in two parts, assembled on the footpath, and the whole was lifted over the parapet, to be seated on to a previously-erected, lattice-steel, centre support, and into receptive excavations in the abutments at each side.

The estimated weight of the cable and duct to be accommodated within the pipe was 8,954 kg, and the length of the span was 18·3 m. The pipe was constructed of welded steel, with a nominal inside diameter of 0·9 m, and was embedded into each abutment wall for a distance of 0·9 m. Expansion joints were provided between the pipe and the reinforced-concrete cradles in which it was embedded. To allow for drainage, a fall of approximately 60–70 mm was specified over the line of the pipe. The work was scheduled for Sunday 3 February, which coincided with industrial action by train drivers and, consequently, the work was undisturbed by the normal rail traffic.

Meanwhile, the main ductway and manhole construction work had commenced on 28 January. The planning team had had the foresight to hold meetings with the City Council, the police, representatives from undertakers of other services, the public transport company and the Chamber of Trade. Work which involved the complete closure of roads had to be timed to follow the Christmas-shopping period and precede the summer-holiday-traffic season, and strict adherence to a program was, therefore, essential. Before the event, opportunities were taken to seek publicity through the medium of the local press and, as soon as a firm starting date was known, a letter, showing the phasing of the road closures with estimated dates, was sent to all of the affected frontagers.

The operation involved the construction of several large, non-standard manholes, two of the largest having a floor area of 9·1 m × 3·1 m each, and being 5·2 m deep. The whole project went according to plan, and the contractors were able to finish the work three weeks earlier than anticipated.

The public showed great interest in the operations and, for a few weeks, a busy main street became a pedestrian shopping precinct and a jaywalker's dream.

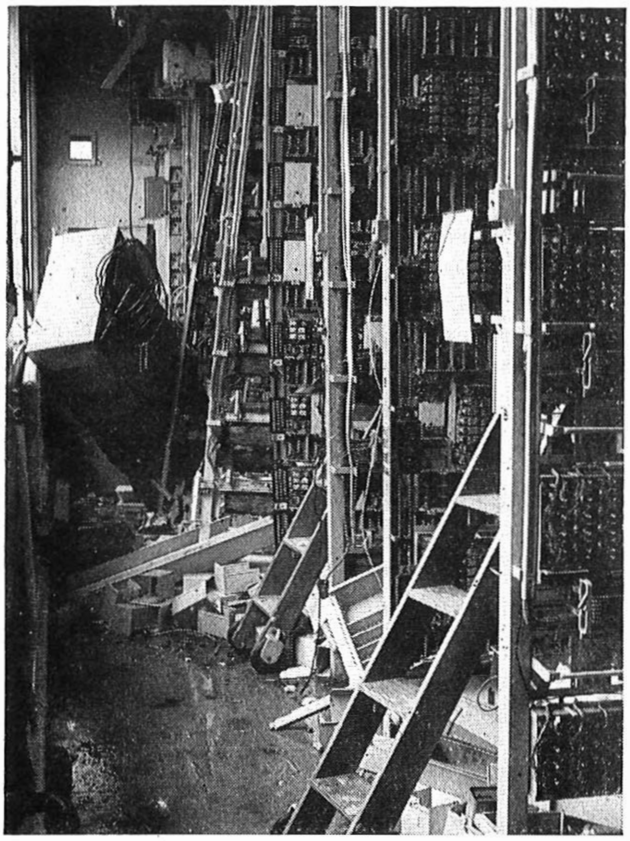
C. F. W. CONDOR
D. P. MOSS

NORTHERN IRELAND

Dungannon Remote Non-Director Exchange

On Friday 2 February 1973, armed terrorists placed bombs inside Dungannon remote non-director exchange, badly damaging the building and putting the exchange out of action.

As a first step towards restoring service, emergency subscribers were connected to other exchanges via the junction cables. A 400-line mobile non-director exchange (m.n.d.x.) was transferred to Northern Ireland by the Operational Programming Department, Telecommunications Headquarters, and installed adjacent to the wrecked building, using the original main distribution frame (m.d.f.), which had survived the explosion. The pulse-code-modulation and repeater equipment, housed on the first floor of the building, was not seriously damaged, and was soon available for the provision of junction circuits. The m.n.d.x. was brought into service on Monday 26 February 1973, having been modified by installing a group-selector rack and 100 additional uniselectors.



Dungannon exchange, after the explosion

It was obvious that, even if it was decided to re-use the bombed building, a temporary exchange of some 2,000-lines' capacity would be required, as an interim measure, until a new exchange could be installed and made ready for service.

The planning of the temporary exchange was immediately put in hand, and it was decided that it would consist of a mobile tandem exchange (m.t.x.) and five m.n.d.x.s, with a Type-BI timber building to house an m.d.f. and test set, and provide accommodation for maintenance staff.

The m.n.d.x.s were earmarked from those in service in Northern Ireland and due to be released at a suitable date, and those due for delivery within the next six months or so. The m.t.x. came from Telecommunications Headquarters' stock.

Eventually, it was decided to install this exchange within the perimeter of an Army Centre, some 0·75 mile from the original site. To inter-connect the original and mobile-exchange m.d.f.s, it was necessary to lay 0·75 mile of 2,000-pair cable, with ducts. Ducts were also laid between the mobiles, the new m.d.f. and a stand-by generator.

One of the greatest problems was to prevent congestion, and in an attempt to overcome this, a list was prepared by the Belfast Telephone Area traffic staff, showing subscribers whose accounts, including rental, amounted to

(*a*) under £16 per quarter, and
(*b*) over £16 per quarter.

It was assumed that subscribers having accounts of £16 and over (later amended to £15) were heavy users and required to be connected to a uniselector, whilst the others could be connected to 50-point line-finders. Care had to be taken in respect of private branch exchanges, where the costs appeared on one line only.

The temporary exchange was brought into service on Friday 16 November 1973, 41 weeks to the day after the destruction of the original exchange—no mean feat, bearing in mind the conditions existing in this part of the U.K. at the time. The new permanent exchange will be on a nearby site, and it is hoped that it will be in service in 1978.

J. H. Johnston

WALES AND THE MARCHES

Swansea Power-Plant Fault

The power plant at Swansea exchange consists of two 1,500 amp rectifiers and the associated batteries. The exchange has a minimum load value of approximately 350 amps and a busy-hour load which rises to 2,300 amps. The load on rectifier No. 1 is near to, or at, its maximum value for twelve hours a day.

During a recent inspection in the busy-hour period, three busbar joints, immediately above the rectifiers, were found to be outside the resistance limits laid down in Specification PT 1105. The bolts on the negative busbar joint, above rectifier No. 1, were loose, and the joint was extremely hot. Tightening the bolts did not noticeably reduce the temperature. It was necessary, therefore, to remake completely the three joints; a task not normally required to be undertaken by maintenance staff. There were practical difficulties. Firstly, the horizontal busbar, teeing the two rectifier outputs, could not be isolated from the exchange and, secondly, the close proximity of adjacent busbar joints left little room for working—or error!

With the precautions of fitting copious amounts of rubber sheeting over nearby exposed metal parts and using plastic spanners, the first joint was loosened, and the short copper busbar between rectifier No. 1 and the aluminium teeing busbar was removed without mishap.

On inspection, the wooden spacers inside the busbar clamp were found to be severely charred, and the surface of the copper busbar was oxidized for almost its complete length. The aluminium busbar was oxidized and pitted in the area of the joint. Draw-filing of the copper bar revealed a small area of aluminium migration, thus accounting for the pitting in the aluminium busbar.

The renovating procedures laid down in Specifications PT 1105 and PT 1027 were then carried out on each busbar. The capacitors in rectifier No. 1 were re-charged in order to avoid current surges, and the joints were reassembled, using new spacers and clamps. The same procedures were applied to the other two faulty joints. These showed none of the severe oxidization present in the first joint, but required a lot of draw-filing before meeting the specified limits.

There were no obvious reasons for the poor joints, but possible causes are

(*a*) vibrations, causing the nuts to work loose, and
(*b*) shrinkage of the laminated-wood spacers.

The maintenance staff involved are to be congratulated for their enthusiastic approach to a difficult job, which was successfully completed without any interruption to service.

A. J. Pallot

Associate Section Notes

Cambridge Centre

The Cambridge Centre has been fairly active during the first half of 1974. In January, we were narrowly beaten by Aylesbury in the first round of the Regional Land-Line Quiz. We have visited the local Police Headquarters and the Kodak colour-processing laboratories, and Mr. B. A. Pearce has presented a lecture on international subscriber dialling.

At the annual general meeting, the following officers and committee were elected.

President: Mr. A. E. Patterson.
Chairman: Mr. R. S. King.
Vice-Chairman: Mr. L. A. Salmon.
Treasurer: Mr. M. Burdett.
Secretary: Mr. P. Young.
Assistant Secretary: Mr. L. G. Stewart.
Members: Messrs. S. L. Hurt, A. Meek, B. V. Lee, B. P. Matthews, and B. Cole.

The program for the future includes visits to Peterborough parcel-sorting office and the B.B.C. Television Centre. The complete program for the 1974–75 session has yet to be finalized, but will be distributed to members as soon as possible.

P. Young

Dundee Centre

The annual general meeting of the Dundee Centre took place on Tuesday 16 April, when 20 members sat down to dinner in the Royal Centre Hotel. Mr. E. A. W. Page, our retiring area liaison officer, introduced his successor, Mr. D. Neave. The following office-bearers and committee were elected.

Chairman: Mr. R. L. Topping.
Vice-Chairman: Mr. D. Moore.
Secretary: Mr. R. T. Lumsden.
Treasurer: Mr. A. J. Vaughan.
Assistant Secretary: Mr. A. W. Smart.
Committee: Messrs. J. Chisholm, A. Dowie, J. Duncan, J. C. Howe, I. J. McBean, R. C. Smith and M. Williamson.

Lively discussion followed the reports, and the suggestions for next session's program promise a worthwhile and entertaining syllabus.

R. T. Lumsden

Inverness Centre

The annual general meeting (a.g.m.), held in the Queensgate Hotel on 5 April, concluded an excellent year for the Inverness Centre. This year, for the first time, we held the a.g.m. in conjunction with a buffet and dance, and the evening was an unqualified success.

The following office-bearers were elected to serve for the 1974–75 session.

President: Mr. J. Lough.
Chairman: Mr. R. H. Inglis.
Vice-Chairman: Mr. I. C. MacLeod.
Secretary: Mr. D. A. Ross.
Treasurer: Mr. A. J. Ross.
Committee: Messrs. D. Watson, L. Robertson, W. G. Smith, G. Stables, F. McInnes, and Mr. K. D. MacCallum, who has also agreed to undertake the duties of assistant secretary.

One of the highlights of the 1973–74 session was our trip to the British Aluminium Reduction Works at Invergordon. On Friday 26 October, 23 of our members were very ably conducted round the smelter by Mr. Donachie, the public relations officer. We then travelled to Tain and, after high tea, were shown round the Glenmorangie Distillery by the manager, who then invited us into his office to sample the end product.

D. A. Ross

Oxford Centre

The summer program began on 30 May, when 20 members visited the Fire Brigade's training centre at Moreton-in-the-Marsh. This proved to be an excellent visit and is highly recommended to other centres within travelling distance.

We are pleased to report the success of two of our younger members, who entered the International Apprentice of the Year competition. Adrian Buck won the semi-final in the electrical engineering section, and will be competing against the winners from abroad in the final, to be held in Lisbon, and Steve Emmett came second in the electronics section. The centre feels extremely proud of these achievements, and warmly congratulates both candidates. We wish Adrian the very best of luck in the forthcoming final.

D. Green

Stirling Centre

Our 1973–74 session ended on 28 May with the annual general meeting, attended by 14 members. This was followed by a talk on winemaking, presented by Mr. J. Rodgers, Technical Officer, and what better way to conclude than by tasting various home-brews, contributed by members, in the form of a cheese-and-wine party—a most enjoyable finish to the session.

The office-bearers for the 1974–75 session are as follows.

President: Mr. T. S. Young.
Chairman: Mr. W. Burns.
Vice-Chairman: Mr. A. Moffat.
Secretary: Mr. J. Hannah.
Treasurer: Mr. R. Henderson.
Committee: Messrs. W. McGregor, G. Nicol and J. Niven.

We look forward to the next session, and a new program which, we hope, will encourage more members to participate. Our best wishes go to all other centres for the 1974–75 session.

J. Hannah

Worthing Centre

During the 1973–74 session, the centre has enjoyed various visits, including the Royal Air Force Museum at Hendon, the Royal Mint, H.M.S. Belfast and the Central Electricity Generating Board's power station at Bolney, in Sussex. Last year's visit to Dungeness power station is to be repeated this year, and visits to the National Maritime Museum, Greenwich, and the Armoured Fighting Vehicles Museum, Bovington, are planned.

Mr. J. Thompson accepts the Bray Trophy from the quiz team. From left to right: Eric Davison, Alan Newnham, Mr. J. Thompson, Fred Stanford, Dave Rudram (Captain), Tony Rainford, and Peter Wells

On 9 May, a luncheon was given at Grenville House in honour of Worthing's National Technical Quiz Competition team, who brought the Bray Trophy to the South Eastern Telecommunications Region (S.E.T.R.). The lunch was attended by Mr. J. Thompson, Regional Director, S.E.T.R., and Mr. K. Burling, General Manager, Brighton Telephone Area. The members of the team were introduced to Mr. Thompson, who formally accepted the Bray Trophy on behalf of the S.E.T.R.

A. J. Bonsall

The Associate Section National Committee Report

The annual conference was held at the Technical Training College, Stone, in May. There were many propositions, some of which were very controversial and needed much discussion, but all of which contributed to a lively and interesting conference.

A change has been made in the structure of the committee. The chairman, general secretary and treasurer will, from now on, be elected annually by the delegates to the National Committee, and will hold office for the following year as non-voting members of the Committee. They will, therefore, not become involved as regional delegates and can devote all their time to the National Conunittee.

A pleasant duty was the creation of a new post—that of vice-president—and the unanimous decision of the committee was to elect our former chairman, John Dow, to fill this important position. John had been the chairman of the National Committee since its inauguration and, indeed, was concerned in its conception. Recently, John has spent a lot of time touring the country, giving talks on the subject of the Associate Section National Committee, and has been very successful in increasing our membership. We trust that, should centres and regions require a representative from the National Committee, or a person to make presentations, they will remember our vice-president.

The following officers were elected to serve on the committee for the 1974–75 session.

Chairman: Mr. T. H. Hopkins, Northern Ireland Directorate.

Vice-Chairman: Mr. J. Hannah, Scotland Directorate.

General Secretary: Mr. P. L. Hewlett (telephone 01-261 4569).

Assistant Secretary: Mr. S. McDonald (telephone 0266 6123).

Treasurer: Mr. P. G. White (telephone 04536 2943).

Editor: Mr. C. F. Newton (telephone 094 34 2361).

Quiz Organizer: Mr. K. Marden (telephone 0204 27560).

Project Organizer: Mr. E. W. H. Philcox (telephone 0234 61561).

Visits Secretary: Mr. B. Hickie (telephone 035 281 3190).

Any centre wishing to contact the new vice-president is invited to do so via the general secretary.

Cotswold Trophy

The Cotswold Trophy was awarded, this year, to Otley Centre. The committee was pleased to make this award in the light of the continued efforts of the members of this small North-Eastern Region centre, in producing the *National News*, our very much appreciated little journal. Otley has produced the *National News*, under the leadership of our editor, Colin Newton, since the very beginning, and has maintained a high standard.

National Museum

Such has been the enthusiastic response to the National Museum project, that Eric Philcox, the organizer, has been inundated with offers of exhibits and suggestions for furthering the project from all over the country. So much so, in fact, that the main Institution Council has become interested and has set up a Museum Committee to investigate ways and means of gaining further support and sponsorship for the project.

The committee's first meeting was held at Stone, and a friendly, co-operative atmosphere was established. Ideas were exchanged which could ultimately result in a fine museum being set up, and the general feeling was that one of the first priorities must be to find storage space for all of the potential exhibits. A report is being prepared by the chairman, Mr. A. Ness.

In the meantime, our members can rest assured that a lot of progress is being made towards a museum of which the Associate Section can be proud.

P. L. HEWLETT
E. W. H. PHILCOX

Institution of Post Office Electrical Engineers

Essay Competition, 1974–75

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 prizes totalling £40 for the five most meritorious essays submitted by Post Office engineering staff 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.

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, EC2V 7AG.

Competitors may choose any subject relevant to engineering activities in the Post Office. A4-size paper should be used, and the essay should contain between 2,000 and 5,000 words. A one-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, EC2V 7AG

by 15 January, 1975.

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

Election of Members of Council, 1974–75

The results of the recent elections of Members of Council are given below, the names being shown in the order of votes counted.

Grade Representation

Members in the British Post Office Headquarters Departments holding posts in Bands 9 and 10:

Mr. F. BATESON, returned unopposed.

Members in the London Regions holding posts in Bands 9 and 10:

Mr. K. B. HINCHLIFFE, returned unopposed.

Members in Provincial Regions, and in the Factories Division (Provinces), holding posts in Bands 9 and 10:

Mr. J. FARRAND,
Mr. J. T. CROCKER,
Mr. J. STOREY,
Mr. S. B. WATKINS,
Mr. P. J. O'DOHERTY.

Inspectors of the British Post Office Headquarters Departments and the London Regions:

Mr. D. V. GASSON, returned unopposed.

Draughtsmen and above, and Illustrators and above, but below the senior salary structure, of the British Post Office Headquarters Departments, and of the London Regions:

Mr. K. J. B. POTTER,
Mr R. O. G. CLARKE.

Draughtsmen and above, but below the senior salary structure, of Provincial Regions, and of the Factories Division (Provinces):

Mr. G. W. WARNER,
Mr. P. H. HARRISON,
Mr. H. EDWARDS,
Mr. M. J. POYNER,
Mr. M. A. H. MATHEWS,
Mr. G. S. GORST,
Mr. G. P. GREENE,
Mr. R. E. WILLIAMS.

Constitution of the Council

The constitution of the Council for the year 1974–75 will, therefore, be as follows:

Mr. J. F. P. THOMAS—Chairman.

Mr. D. WRAY—Vice-Chairman.

Mr. T. PILLING—Vice-Chairman.

Mr. R. T. MAYNE—Honorary Treasurer.

Mr. H. BANHAM—Representing the members holding posts in Bands 5 to 8 of the senior salary structure of the British Post Office Headquarters Departments, and of the London Regions.

Mr. A. NESS—Representing the members in the Provincial Regions holding posts in Bands 5 to 8 of the senior salary structure.

Mr. F. BATESON—Representing the members in the British Post Office Headquarters Departments holding posts in Bands 9 and 10 of the senior salary structure.

Mr. K. B. HINCHLIFFE—Representing the members in London Regions holding posts in Bands 9 and 10 of the senior salary structure.

Mr. J. FARRAND—Representing the members in Provincial Regions, and of the Factories Division (Provinces), holding posts in Bands 9 and 10 of the senior salary structure.

Mr. J. C. FLETCHER—Representing the members of the British Post Office Headquarters Departments, and of the Factories Division (London), listed in Rule 4(*a*), with the exception of those in Groups 14 and 15.

Mr. M. S. ARMITAGE—Representing the Executive Engineers and Assistant Regional Motor Transport Officers of the London Region.

Mr. D. L. STEVENSON—Representing the Executive Engineers, Assistant Regional Motor Transport Officers, Experimental Officers and Scientific Officers of the Provincial Regions, and Factory Executive Engineers and Factory Overseers of the Factories Division (Provinces).

Mr. M. G. Grace—Representing the Assistant Executive Engineers, Technical Assistants, Senior Scientific Assistants, Assistant Experimental Officers, Third Officers, Fourth Officers, Third Engineers, Fourth Engineers, Electrical Engineers and Assistant Technical Costs Officers of the British Post Office Headquarters Departments, and Assistant Factory Foremen of the Factories Division (London).

Mr. T. AUSTIN—Representing the Assistant Executive Engineers and Technical Assistants of the London Regions.

Mr. D. W. SHARMAN—Representing the Assistant Executive Engineers, Technical Assistants, Senior Scientific Assistants and Assistant Experimental Officers of the Provincial Regions, and Assistant Factory Foremen of the Factories Division (Provinces).

Mr. D. V. GASSON—Representing the Inspectors of the British Post Office Headquarters Departments and the London Regions.

Mr. B. A. B. WOOD—Representing the Inspectors of the Provincial Regions.

Mr. K. J. B. POTTER—Representing the Draughtsmen and above, and Illustrators and above, but below the senior salary structure, of the British Post Office Headquarters Departments, and of the London Regions.

Mr. G. W. WARNER—Representing the Draughtsmen and above, but below the senior salary structure, of the Provincial Regions, and of the Factories Division (Provinces).

Mr. A. J. BARKER—Representing the Corporate Members holding non-engineering posts in the British Post Office (Rule 11(a)).

Mr. E. C. OFFORD—Representing the Affiliated Members of the British Post Office Headquarters Departments and the London Regions.

Mr. R. B. LLOYD—Representing the Affiliated Members of the Provincial Regions.

A. B. WHERRY
Secretary

London Centre Program, 1974–75

Meetings will be held at Fleet Building, Shoe Lane, London, E.C.4, commencing at 17.00 hours.

Tuesday 15 October:
Management Sciences in Telecommunications by T Lomas.

November (date to be announced):
The Home Office Police Computer Unit by G. H. Atherton of the Home Office.

Wednesday 15 January:
Plastics in Telecommunications by J. D. Austin.

Tuesday 4 February:
Estimation of Long-Term Demand for New Telecommunication Services by A. A. L. Reid.

Wednesday 26 February:
Aluminium Alloy as a Conductor for Local-Network Cables by J. Pritchett and D. W. Stenson.

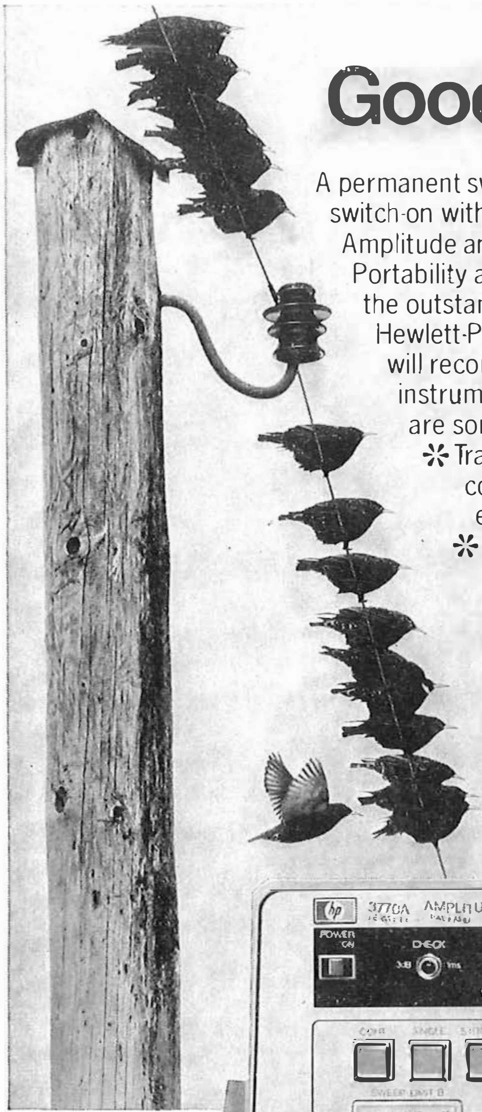
Tuesday 11 March:
Local Distribution—A Time for Change? by A. G. Hare.

Wednesday 16 April:
Teletraffic Engineering by A. G. Leighton.

Tuesday 29 April:
Semiconductor-Device Development within the Post Office by S. O'Hara.

The annual general meeting of the Institution will preceed the last meeting of the 1974–75 session, to be held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, commencing at 17.00 hours.

Wednesday 14 May:
Annual general meeting, followed by *Global and Regional Satellite Communications—The Evolving Scene* by J. K. S. Jowett.



Good news for data line users

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- Measures group delay and attenuation distortion using CCITT approved principles.
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- Absolute level measurements from +10 dBm to −50 dBm from 200 Hz to 20 kHz.
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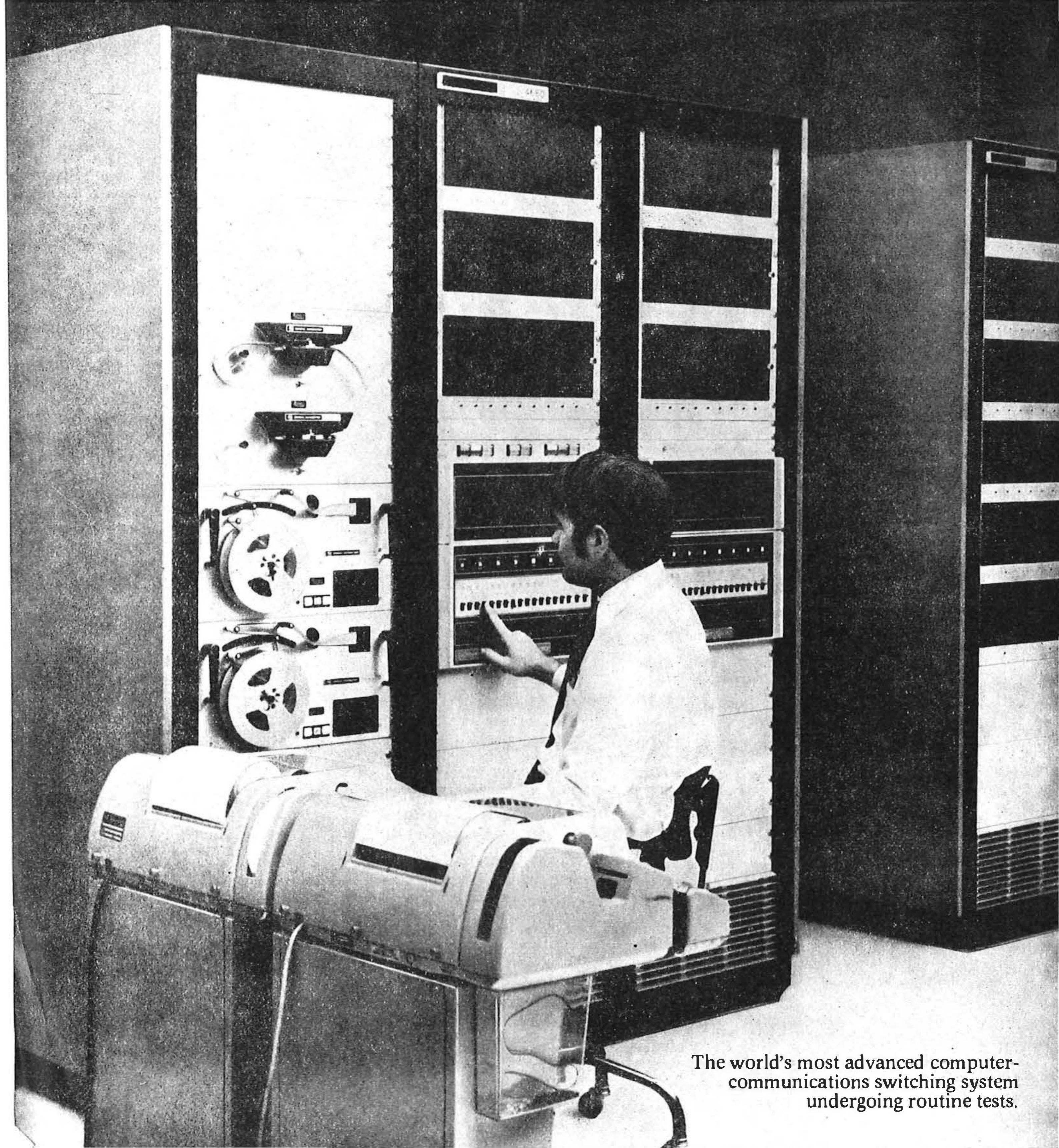


The world's most advanced computer-communications switching system undergoing routine tests.

Plessey System 4660

Not so much an exchange as a computer that can take all the requirements of a telex network in its stride. There are no crosspoints in the conventional sense—the signal path is routed through the computer core memory.

Here are some of the things it can do: if an addressed line is busy it can hold the message until it is cleared; it can send a message to a required number of addresses in one operation; it can store messages until low tariff periods commence; it can select alternative/optional routes . . .

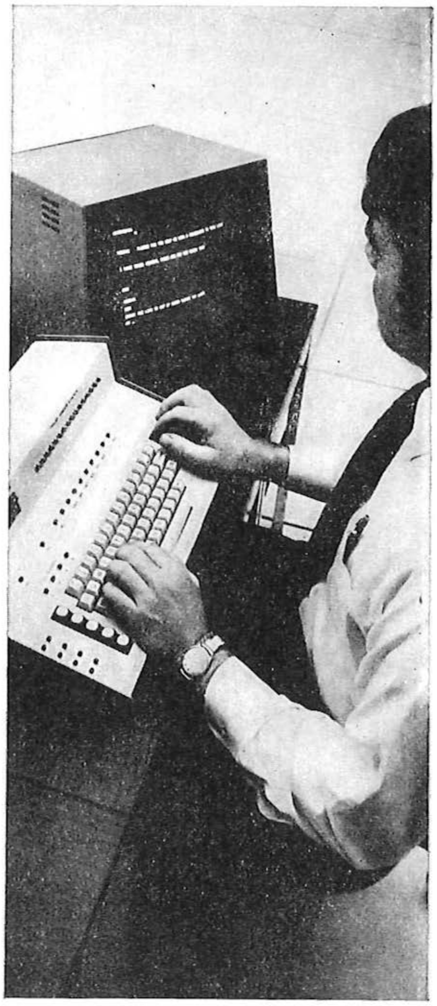
These are merely some of the sophisticated extras System 4660 can offer, but they indicate the advanced technology of its design. The terminal equipment, for example, includes operator consoles with c.r.t. display, print-out or magnetic cassette.

Sizes: systems can range up to 32,000 lines.

Features include: *High traffic capability · Modular design · CCITT compatibility · Economy and low cost · Speed and code conversion · Ease of maintenance · Automatic message accounting · Self diagnosis and fault indication · Space saving · Solid state reliability · Flexibility and speed of installation.*

There is a full spares and after sales service.

For further information about System 4660 please write or telephone: Plessey Telecommunications, Major Systems Marketing, Edge Lane, Liverpool, England L7 9NW. Telephone: Liverpool (051) 228 4830. Telex: 62267.



Cordless Switchboard Operator position handling assistance call with CRT Visual Display.

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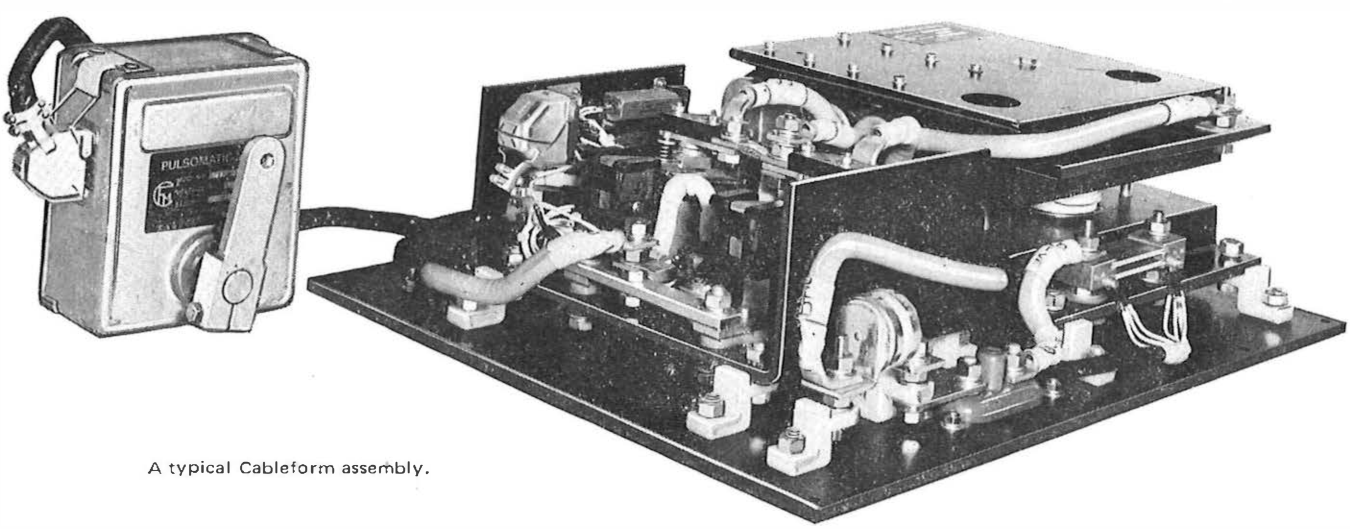

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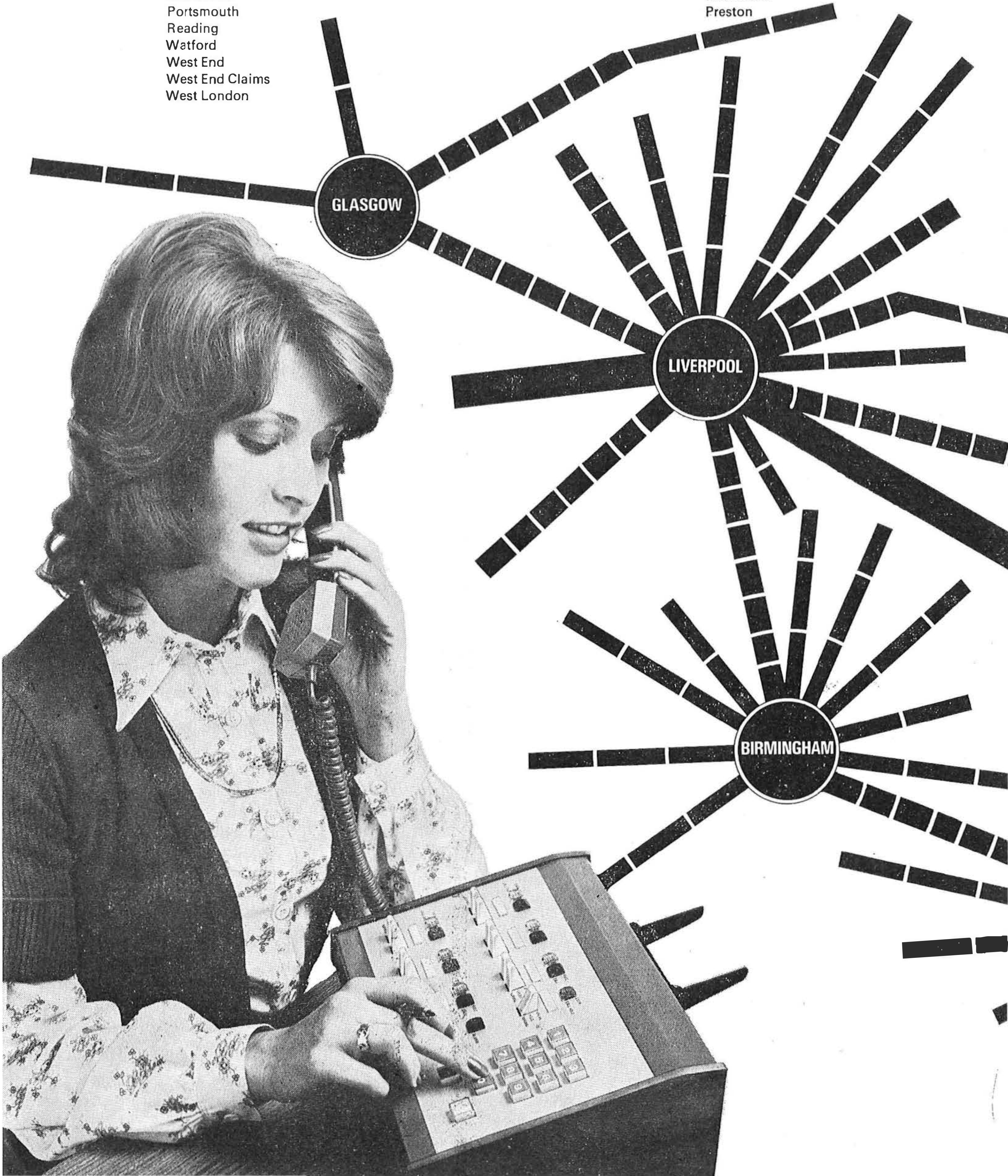


The Spider's Web

Telephone network by Pye Business Communications Ltd. links head offices and branches of Guardian Royal Exchange Assurance Group.

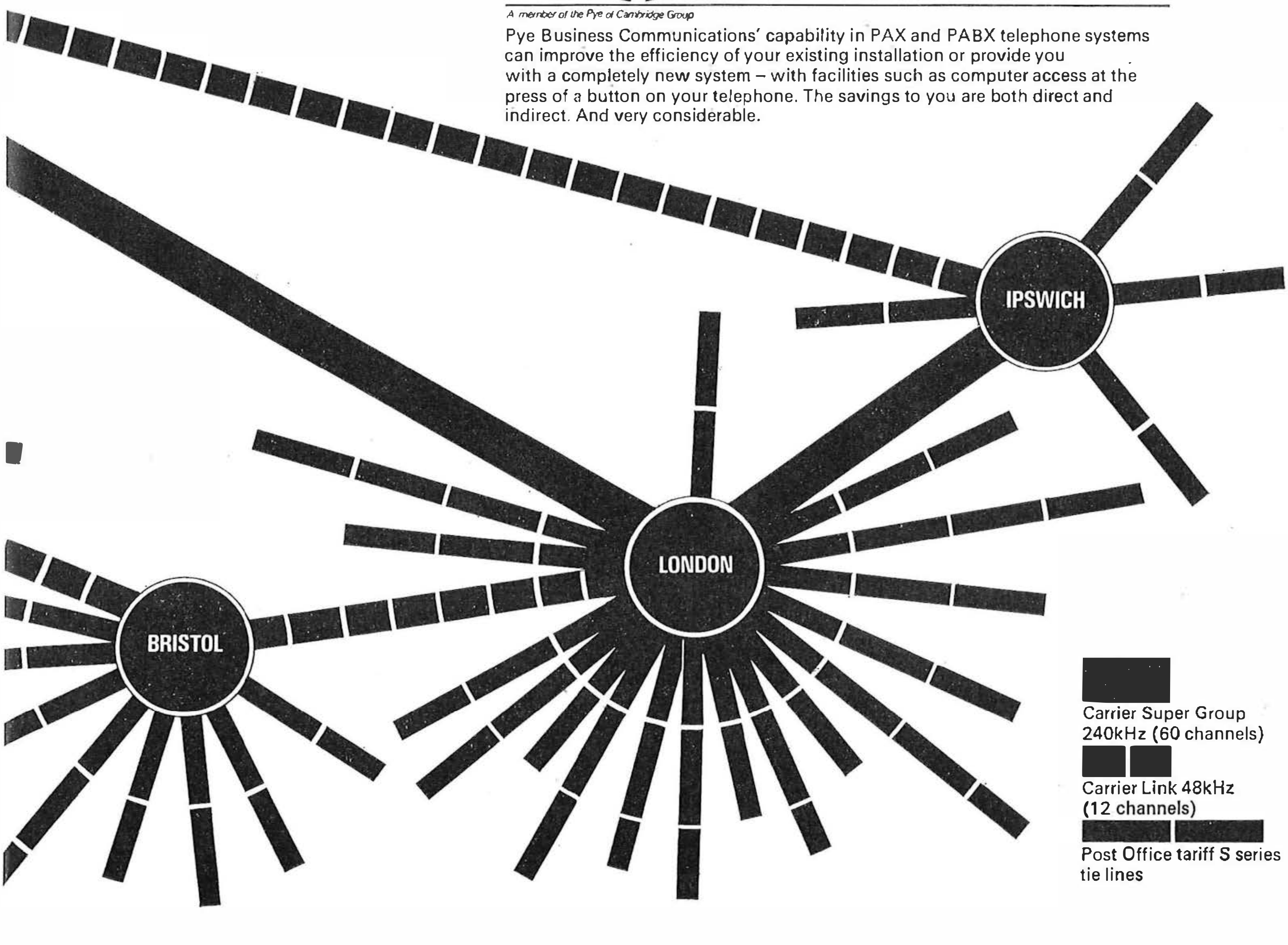
The new fully-automatic private telephone network for the Guardian Royal Exchange Assurance Group was conceived and designed by communication consultant C. J. W. Macaulay. The equipment, engineered, supplied and installed by Pye Business Communications will provide efficient, economical communication between GRE head offices and branches in the United Kingdom.

This highly advanced system, designed to pay for itself within a few years, comprises a main network of wideband carrier links (with sufficient spare capacity for data transmission), and simple private wire links to peripheral offices. A universal 5-digit numbering scheme is employed, accessed by a single digit from the Philips high-speed push-button telephones. Now, for GRE, calling Edinburgh from Ipswich is as simple as a five-finger exercise.

Pye Business Communications Ltd
Cromwell Rd. Cambridge CB1 3HE
Tel: 0223 45191 Telex 81547

A member of the Pye of Cambridge Group

Pye Business Communications' capability in PAX and PABX telephone systems can improve the efficiency of your existing installation or provide you with a completely new system – with facilities such as computer access at the press of a button on your telephone. The savings to you are both direct and indirect. And very considerable.



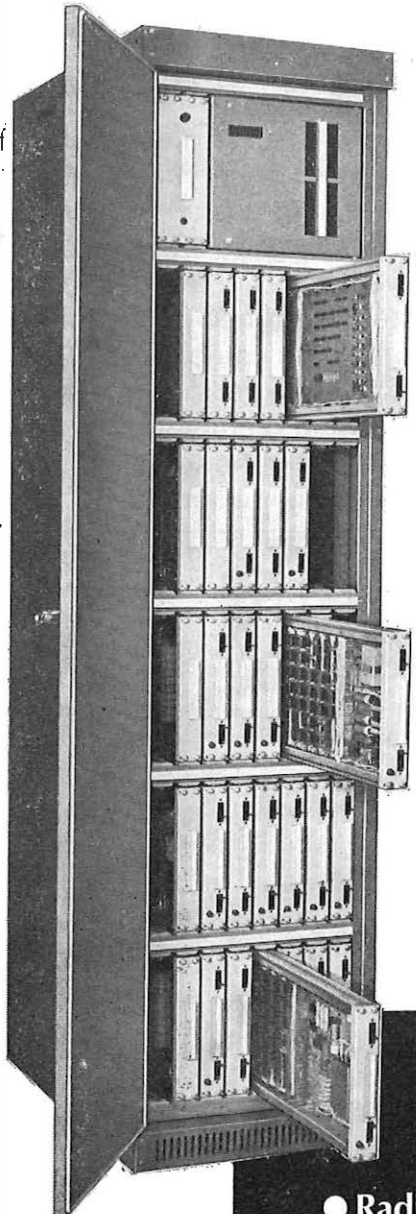
Now you can give your small subscribers a big-user complex

The GTEX 100 is a brand new electronic branch exchange that opens up–at low cost–a wide range of sophisticated telephone communications for small subscribers.

Now the smaller user, with 25 or 50 telephone extensions, can get all the benefits of a big-user exchange to improve his communications and overall business efficiency.

The GTEX 100 incorporates advanced features like 'Wait on Trunks', 'Call forwarding', 'Ring Back When Free', 'Transit Switching' and many more time-saving programmes, in a compact, free-standing unit the size of a filing cabinet. You can use dial or key instruments, and to extend the capacity to 75 or 100 lines all you need is a second cabinet. And the GTEX 100 works in blissful silence.

The special light-emitting diode (LED) busy/free display gives the operator at-a-glance recognition of line status, including indication of Internal/External Call, Class of Service Identification and, internally, Calling Line Identification. This electronic line status display also acts as a built-in scanner to diagnose faults. The miniaturised plug-in distribution frame enables the most unskilled user to allocate or re-allocate extension numbers to users, and plug-in slides allow quick replacement of a faulty circuit which can then be checked out later at a central depot.

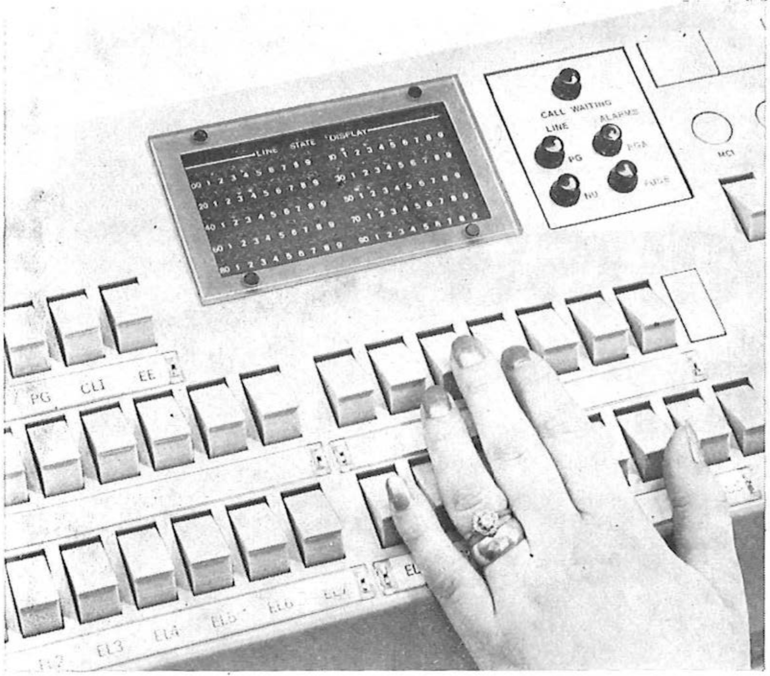


SPACE DIVIDED PRECIOUS METAL SPEECH PATH

The GTEX 100 PABX was developed by GTE International at its international Switching Development Laboratory at Rochester in Kent. The system uses a space divided precious metal speech path with distributed control, organised round an electronic TDM data highway. The switching matrix has a single stage non-blocking array which allows almost unlimited expansion to cope with heavy traffic, or to provide specialised requirements for heavy trunking. Because of TDM control, only two wires are switched through the matrix. This improves efficiency of crosspoint division and, together with miniaturised,

The following telecommunications products are being supplied by GTE International to U.K. customers:

- **Radiolink Systems for TV and Telephony**
- **Space Communications Equipment**
- **Echo Suppressors**
- **Supervisory Equipment utilising MOS LSI Techniques**
- **FDM Multiplex**
- **Large Electronic PABX**
- **Data Modems**
- **In-Band Signalling Equipment**
- **House Telephone Systems**



high reliability relays, produces a low-cost yet completely reliable switch. Standardised components streamline stocking and purchasing – for example, there are only six types of miniature relays.

SUBSCRIBER GETS ALL MODERN PABX FEATURES ON A SMALL UNIT

The GTEX 100 gives subscribers the latest PABX features.

Wait-on. If an extension finds all trunk lines busy, he dials a special digit and hangs up. The extension can then continue to receive and make calls in the usual way. But, as soon as a trunk line and the extension are both free, his telephone is automatically rung and the extension connected to that free circuit. This benefit also applies to tie-line working.

Ring when free. If an extension dials an internal call and receives a busy tone, he dials a pre-arranged digit to put the call in waiting on the wanted number. He then hangs up. The PABX continuously monitors the TDM free highway. When the wanted extension is free, the GTEX 100 automatically rings the calling extension and, when it answers, automatically rings the wanted number. A series of numbers in one group can also be handled in the same way.

Call forwarding. If an extension wants to arrange for incoming calls to be received on another telephone, he simply dials a given digit into the GTEX 100, followed by the number to which he wants calls transferred. All incoming calls are then automatically routed to the second instrument. This feature can also be used to aid staff location. Dialling the same number of the telephone in the empty office puts the call through to the temporary location or the owner of that extension.

Extension group search. By dialling the first number in a group of sequentially numbered extensions, the equipment can be programmed to ring the first free extension in that group.

Line Lock out. If an extension remains off-hook without dialling, or after an incomplete PABX number, that line will be 'parked'. This ensures that registers are available for other calls. The line is released from park when the extension goes on-hook.

BIG USER BENEFITS AT SMALL USER COSTS

These and other advanced features of modern PABX design are often barred to smaller subscribers because of cost. Now with GTEX 100, they too can transform their telephone systems into a highly effective business tool, streamlining operations, saving time and money and improving working conditions.

If you would like to see a system working with the GTEX 100, or require more information on any of our range please write to or 'phone: Chris Gannon, GTE International, Central Way, Feltham, Middlesex. Telephone: 01-890 1455. Telex: 934830. Or, GTE Telecomunicazioni S.p.A., Via Turati 27, 20121 Milan, Italy; GTE International, 1 Stamford Forum, Stamford, Connecticut, USA.

GTE INTERNATIONAL

In addition GTE International can offer:

- **Batteryless Keyphones for Decadic Signalling Exchanges**
- **Subscribers Carrier Equipment**
- **Trunk Connected Telephones**
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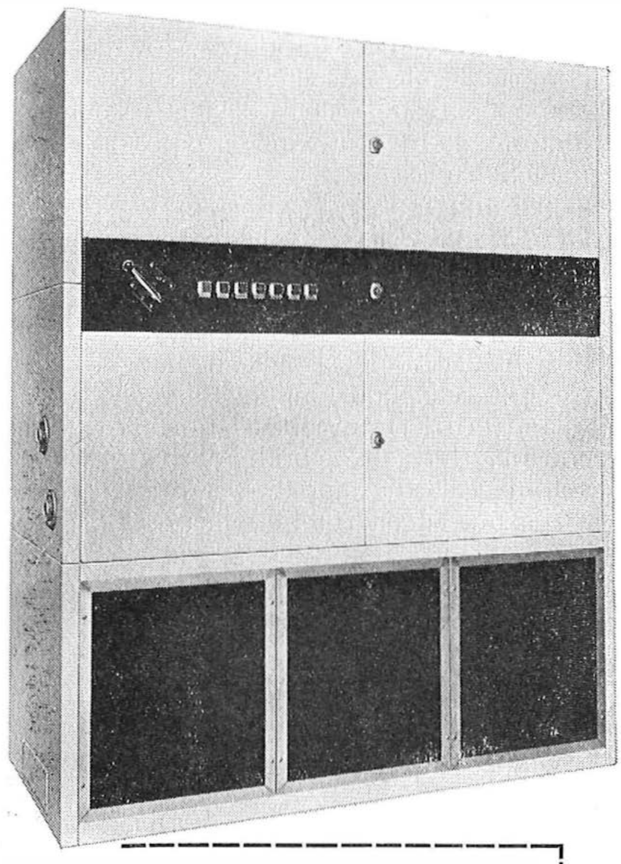

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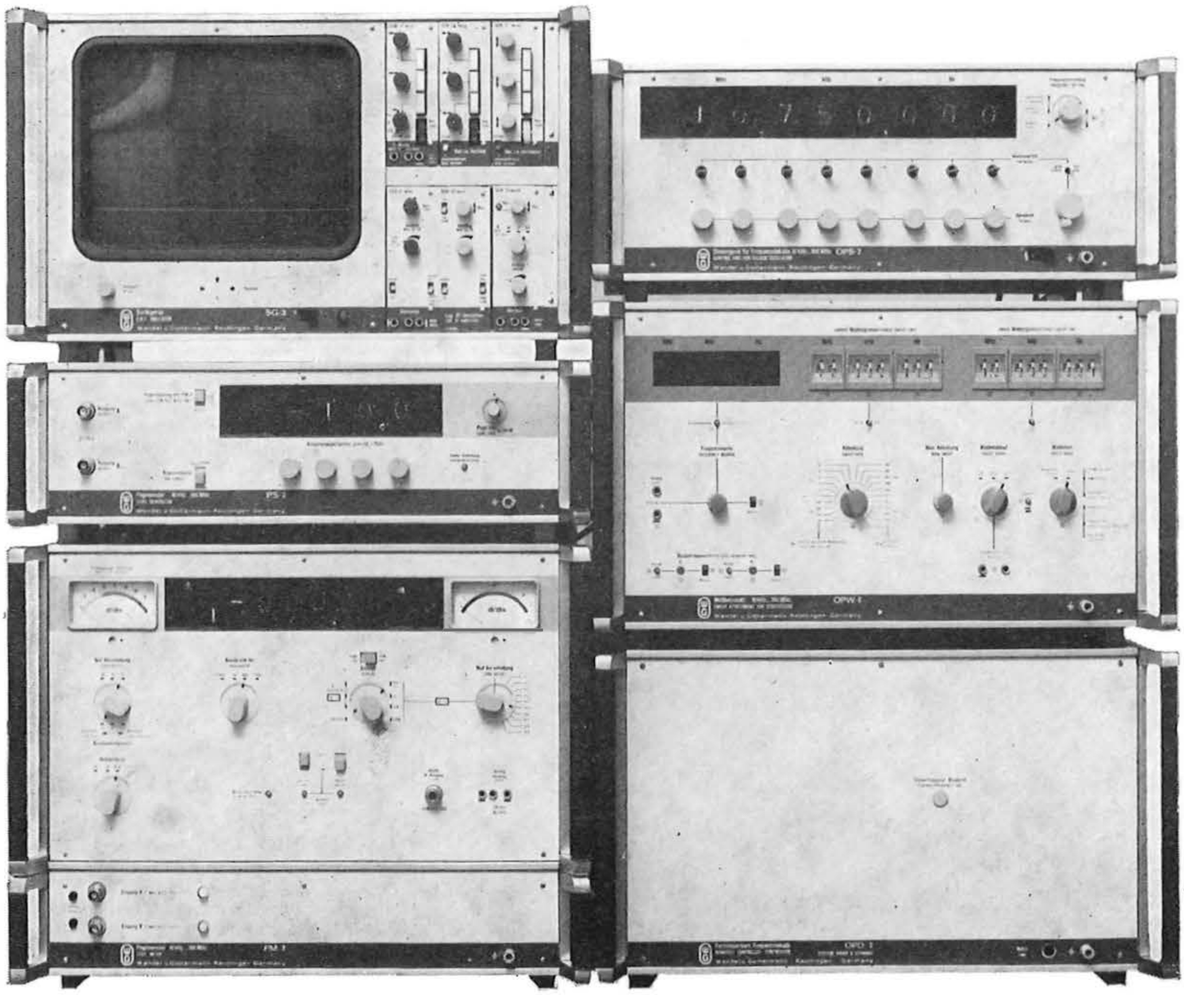

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