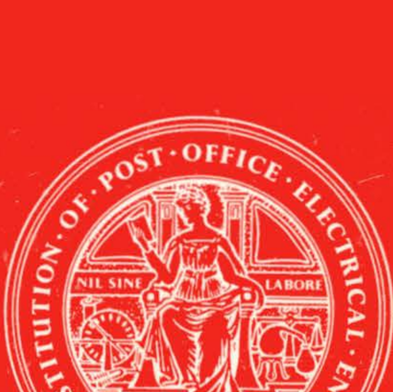
The Post Office Electrical Engineers' Journal

VOL 70 PART 1 APRIL 1977



THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

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Contents

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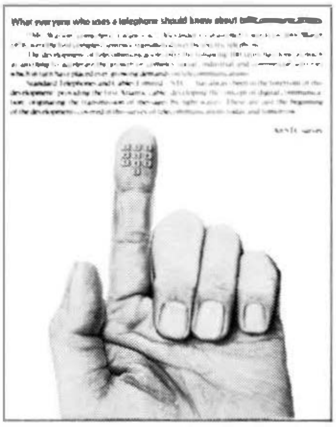
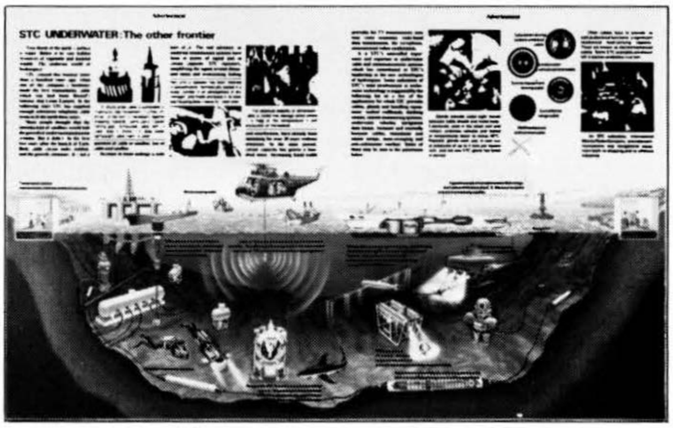
Why STC took in the Sunday

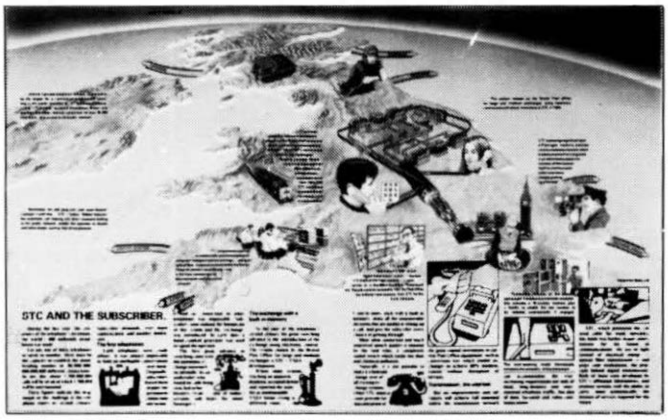


It occurred to us that although a lot of people to whom we speak, speak the same language as we do, many others don't.

These are people who, intelligent and successful in their own fields, may not know the difference between MHz, Mbaud and Mbit/s.



The people who can get a bit lost when we, at STC, talk about jitter reducers and dependent regenerative repeaters and multiplex-demultiplex equipments.



And not only when we do. When you do, as well.

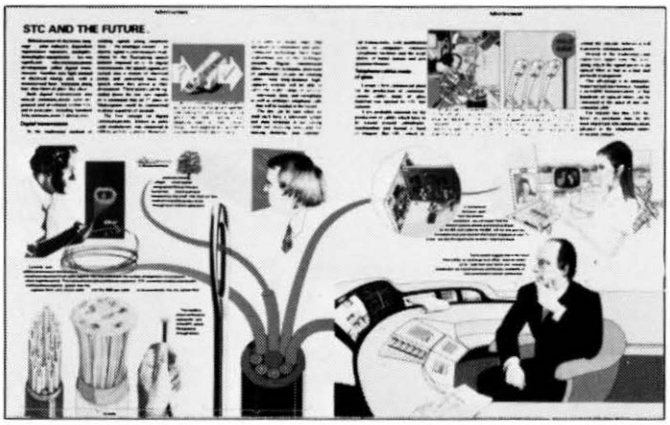
But they do make up a responsible audience. Responsible, quite often, for the wielding of immense influence and weight of

8 colour pages Times.

approval on the recommendations of people more technically sophisticated.

So it seemed a good idea to give them some kind of illustrated glossary.

It appeared, the other Sunday. Rather like we hint at here.

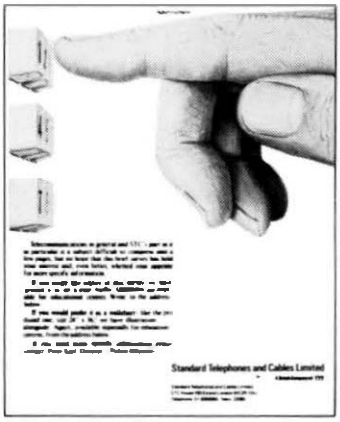


You probably saw it.

Or if you didn't, we would like to think that someone who did has already mentioned it to you.

If you'd like a copy of it, or a wall-chart version, please let us know.

And also let us know how useful it's going to be for you.



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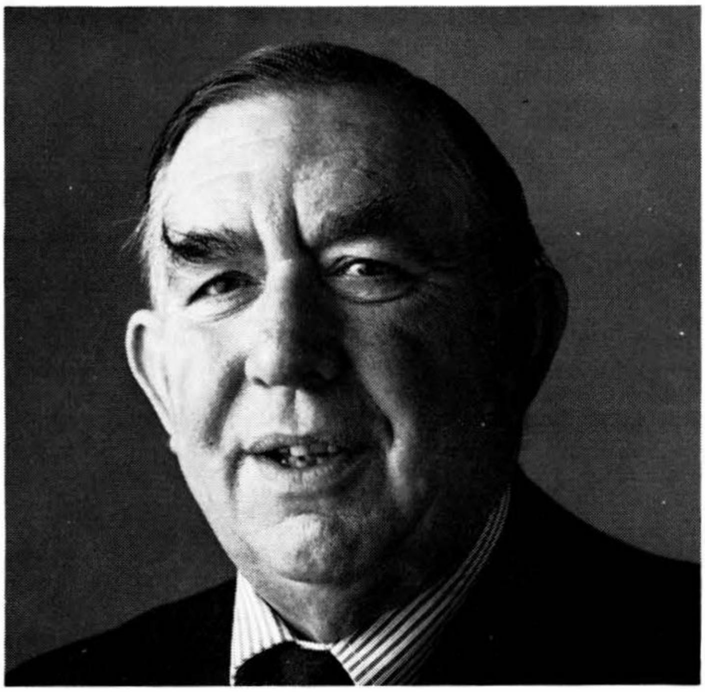

AVION CASE, CB, CBE, MBIM, General Secretary,
Hospital Saving Association.

A personal message to all HSA Contributors

The Hospital Saving Association's Standard Scheme (5p a week), to which many thousand members of the Post Office belong, was set up over 50 years ago to bring financial security to ordinary working people during times of sickness.

With the passage of time and with the recent onset of inflation, the Benefits that it is possible to pay under the Standard Scheme have become entirely inadequate for your needs.

The Hospital Saving Association's alternative CROWN PLAN, introduced a few years ago, provides much greater and a larger range of Benefits – Benefits that are in tune with your circumstances today.

For example, should you or your wife (or husband) become an In-Patient, CROWN PLAN pays out £21 a week; should you both be in Hospital at the same time, £42 a week is payable up to a maximum of £546 in any one year. Moreover, both husband and wife may enjoy separate memberships, and so by both claiming, benefit entitlement is effectively doubled.

Two new CROWN PLAN Benefits have been introduced from 1st January, 1977, a Dental Treatment Benefit, and a Recuperation at Home Grant which is payable after 14 nights or more in Hospital with an acute illness. There are also numerous other Benefits protecting you and your family which contribute towards the costs of Spectacles, Home Help and Maternity etc, etc.

Clearly, it is in your interests to transfer your membership NOW to the CROWN PLAN as 15,000 of your Post Office colleagues have already done, provided that you are eligible by health and age to do so; the 65 age limit will unfortunately preclude most Post Office Pensioners from eligibility to join CROWN PLAN.

The HSA Executive Council has, therefore, decided that Standard Scheme Group payroll deduction facilities should cease as soon as practicable, and all those Contributors who are willing to do so should transfer into the CROWN PLAN with an immediate entitlement to all CROWN PLAN Benefits from the date of transfer. Deductions from pay will then be at the CROWN PLAN rate only (25p a week or £1.08 a month). New payroll deduction mandates will be necessary.

Arrangements are being concluded with your HSA Honorary Group Secretary for this block transfer of Post Office Standard Scheme Groups to the CROWN PLAN. Not all Groups can be actioned immediately, and you will be receiving a personal notification of the arrangements for your Group in due course, together with full details of the CROWN PLAN. In the meantime, you may, of course, contact your HSA Honorary Group Secretary to arrange your individual transfer to CROWN PLAN as soon as you like.

If you wish to opt out of your Group transfer to the CROWN PLAN and remain in the Standard Scheme, you may do so by becoming a Direct Contributor to the HSA Head Office. All you need to do is contact your HSA Honorary Group Secretary and complete a Transfer Form sending it to the HSA Head Office with your annual contribution of £2.60, and cancel your HSA deduction authority.

I hope that all Post Office HSA Contributors will wish to join CROWN PLAN and enjoy the better benefits and security that it brings.

Avion Case.

HOSPITAL SAVING ASSOCIATION

30 LANCASTER GATE LONDON W2

The non-profit-making Benevolent Association bringing help in time of sickness.

The Post Office Electrical Engineers' Journal

EDITORIAL

The IPOEE has a new President. Professor J. H. H. Merriman, who has recently retired from the British Post Office (BPO), relinquishes the presidency in favour of Mr. J. S. Whyte. Brief biographies of Professor Merriman and Mr. Whyte appear on page 62 of this issue. On behalf of the *Journal* readership, best wishes are extended to Professor Merriman for a long and happy retirement.

A change in the management of the *Journal's* advertising business occurs with the publication of this issue. The position of Advertisement Manager, previously filled from within the IPOEE membership, has now passed to an advertisement agency, the Kemps Group.

In this issue are the final parts of two 3-part articles: the review of the BPO microwave radio-relay network is concluded with description of the equipment used in microwave radio-relay systems, and the article on the TXE4 electronic exchange system is concluded with a description of the system security and maintenance features.

The history of the BPO Research Department at Dollis Hill and the design of the new research centre at Martlesham have featured in articles published in recent issues of the *Journal*. Included in this issue is an interesting article that considers the human aspects related to the transfer of some 1400 research staff and their families from the London area to Suffolk.

The desire of the Board of Editors to publish more articles from authors in Areas and Regions has been well publicized in a past editorial and within the *Journal*. At the risk of being accused of repetition, the editors would again appeal for such contributions. All articles and contributions to Regional Notes must be approved as suitable for publication at organizational level 5 (Head of Division (THQ)/Controller/General Manager). However, if an author would first like to discuss the content of a proposed article with the editors, perhaps with a view to seeking advice from a specialist THQ duty, or to establish the suitability of a proposed topic, then the editors will be very pleased to help. Acceptance of an article for publication would, of course, still be subject to authorization being received at the appropriate level.

The Evolution of the INTELSAT V System and Satellite

Part 1—System Description

R. J. EATON, C.ENG., M.I.E.E., and R. J. KIRKBY, B.SC.†

UDC 621.396.946

The latest generation of commercial communications satellites—the INTELSAT V series, now under construction—introduces major advances in both transmission techniques and spacecraft design. Part 1 of this article describes the factors leading to the specification of the communications requirements and outlines the general features of the system. Part 2 will concentrate on the spacecraft; its construction, launch and operation.

INTRODUCTION

The global communication-satellite system established by the International Telecommunications Satellite Organization (INTELSAT)[1] has grown rapidly during the 1970s, both in respect of the number of telephone circuits carried and the number of earth stations in operation. By 1976, the membership of INTELSAT was 95 countries, of which 78 were actively participating with their own earth stations.

To keep pace with traffic demands, successive generations of satellites have had to be developed, each series having a substantially increased telephone circuit capacity compared with its predecessor. The INTELSAT III satellites, used to set up the first global system in 1968, have been superseded by INTELSAT IV satellites, and these are being replaced, where necessary, by INTELSAT IVA, a modified version of INTELSAT IV with increased circuit capacity.

In 1979, INTELSAT V will be introduced; this article describes the events and considerations that influenced the design of this satellite, and outlines the main features of its communications equipment.

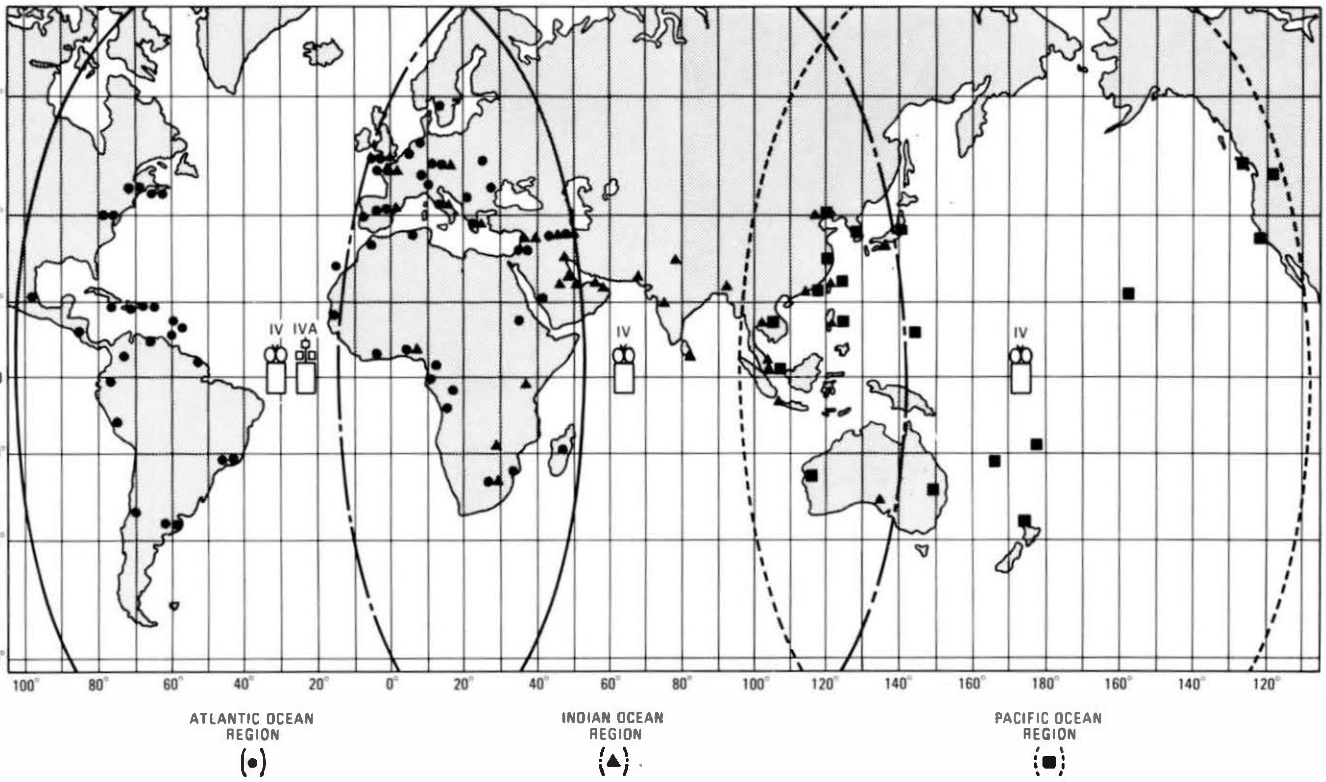

FIG. 1—Earth stations in the INTELSAT global system (1976)

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† Telecommunications Development Department, Telecommunications Headquarters

PRESENT STATUS OF THE INTELSAT SYSTEM

The present status of the INTELSAT system is illustrated in Fig. 1 which shows the locations of earth stations carrying international telecommunications services in the 3 coverage regions: the Atlantic, Pacific and Indian Ocean regions. The Atlantic region, with 63 major earth stations, carries by far the heaviest traffic load and, since 1970, has been covered by 2 satellites. One of these, designated the *primary* satellite, serves virtually all the participating earth stations in the region and provides the main interconnecting facility; the other is known as the *major-path* satellite and carries, for the most part, heavy traffic streams between countries that are able to justify the provision of additional aerials for this purpose.

At the beginning of the 1970s, the INTELSAT IV series of satellites, with a 7 year design life and a capacity of about 7000 telephone channels, were introduced into the system.[2] These satellites were brought into use first in the Atlantic region, and then gradually over a period of a few years in the Pacific and Indian Ocean regions. Planning estimates at that time indicated that the Atlantic primary traffic could be carried by an INTELSAT IV satellite until about 1975, when its saturation capacity would be reached. Since, at that stage, the early INTELSAT IV satellites would also be nearing the end of their design life, it was clear that an early decision was needed on the INTELSAT IV "follow-on" policy to allow sufficient time for possible development of a new satellite.

Methods of Increasing System Capacity

There are 3 basic ways in which the capacity of a communication satellite system can be increased: the number of working satellites can be increased; the effective use of existing satellites can be increased by improved modulation methods, for example, digital time-division multiple-access (TDMA)[3]; or a new design of satellite of inherently higher circuit capacity can be introduced.

The first method, increasing the number of satellites, is the simplest and most straightforward from the *space segment** point of view, but its success depends on the willingness of participating countries to build the additional earth-station aerials to work to the new satellites. This situation arises because the funding of earth stations in the INTELSAT system is not the responsibility of INTELSAT, but is entirely a matter for the individual countries concerned. Provision of a second satellite, the major-path satellite, proved a satisfactory solution for the Atlantic region in the early 1970s, but this was only because the larger European countries (UK, France and Germany), and North-American countries (Canada and the USA) had sufficiently large mutual traffic to justify the provision of additional aerials. An added attraction to these large countries was the ability to divide their heavy traffic streams between the 2 satellites, and thus protect against total interruption of a route in the event of a satellite or earth-station failure. However, further extension of the system by increasing the number of satellites would require many of the smaller countries to provide second aerials and the larger countries third or even fourth aerials. Planning on the basis of increased numbers of aerials is unreliable in the case of the INTELSAT system because of the independent financing of the earth stations. It is also a costly solution for the space segment as well as the earth segment.

The second way of extending system capacity, replacing the existing frequency-division-multiplex (FDM)/frequency-modulation (FM) mode of transmission by more efficient methods, such as TDMA with digital speech interpolation (DSI), is even more attractive in terms of the space segment, which requires no modification at all. Once again, however, the financial burden falls on the earth-station owners, who would have to re-equip for the new modulation method. To gain maximum satellite capacity advantage from this approach, virtually all operators would need to change to the new modulation method, even small users of the system. A further point, which reflects on the time scale of such a change-over, is that it is normal to precede the introduction of new techniques with a field trial, over a period of a year or two, to resolve any equipment or operational problems before embarking on full-scale implementation.

The third solution, a new generation of satellites, gaining more capacity by making more effective use of the bandwidth allocation at 6/4 GHz‡ or through the introduction of allocated bands at higher frequencies, still involves some earth-station investment; for example, installation of new 14/11 GHz stations and modification of existing 6/4 GHz stations for dual-polarized** operation, but the major part of the cost is borne by the space segment which is directly under the control of INTELSAT. However, a lead time of some 4–5 years is required to allow for design and contractual procedures, plus time for the manufacture of the satellite.

INTELSAT IVA Decision

After detailed studies within the INTELSAT organization, including system capacity calculations and cost appraisals, it was decided that the 1975 saturation problem should be resolved by taking up an offer, by the Hughes Aircraft Company of America, to provide an INTELSAT IVA satellite, an uprated version of INTELSAT IV capable of carrying about 11 000 telephone channels and 2 television programmes. The extra capacity, relative to that of INTELSAT IV, was achieved mainly by re-using the 6/4 GHz frequency bands in the east and west coverage areas by means of directional aerial beams.[4] Because the basic spacecraft structure of INTELSAT IVA was almost identical to that of INTELSAT IV, a significant amount of development work was avoided, and delivery of the first satellite was completed in less than 2 years. In all, a total of 6 INTELSAT IVAs were ordered for general use within the system. Two are already in orbit.

INTELSAT IVA Follow-on Studies

At the high rate of traffic growth prevailing, it was clear that INTELSAT IVA would solve the Atlantic capacity problem for only a few years before it too reached saturation. Soon after the decision on the procurement of INTELSAT IVAs, the studies of ways of coping with increased capacity requirements were taken up again. The 3 approaches referred to earlier were again considered in detailed studies, the first 2 being re-evaluated on the basis of using INTELSAT IVA satellites. The third option concentrated on designs for a new higher-capacity satellite, INTELSAT V. The ultimate outcome of these studies was a decision to proceed with contract negotiations for a series of INTELSAT V spacecraft, the first to be delivered in 1979.

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* For administrative purposes the INTELSAT system is divided into 2 segments, the *space segment*, comprising the satellites and their monitoring and control stations, and the *earth segment*, comprising the communicating earth stations

‡ The frequency bands at present in use in the INTELSAT system comprise 500 MHz allocations at around 6 GHz and 4 GHz. The higher frequency is used for the up-link from an earth station to the satellite, the lower frequency is used for the down-link; the satellite is thus said to operate in the 6/4 GHz band

** The topic of dual-polarization techniques, applicable to communication satellites, will be the subject of a future article in this *Journal*

FIG. 2—Artist's impression of INTELSAT V spacecraft
(Photograph by courtesy of the Ford Aerospace and Communications Corporation)

INTELSAT V Proposals

Studies were made of INTELSAT V designs with various arrangements of aerial beams and, in 1974, a tentative design was presented to the INTELSAT Board of Governors. The basic design comprised 2 semi-global beams (generally known as *hemispheric* or *hemi* beams), shaped to cover the east and west land masses of the Atlantic region and re-using the frequency bands at 6/4 GHz, as in INTELSAT IVA; and, superimposed, 2 narrow *spot* beams at 14/11 GHz covering high-density traffic areas in West Europe and North-Eastern America. Estimated traffic capacity was about 24 000 telephone channels if provision of a substantial number (11) of 14/11 GHz earth stations was assumed. The 6/4 GHz section, however, being virtually the same as for an INTELSAT IVA, provided little improvement in capacity in itself. The INTELSAT Board of Governors, unwilling to rely solely on the provision of 14/11 GHz earth stations for the increased traffic capacity because INTELSAT could have no direct control over the provision of these, asked that the INTELSAT V design be reconsidered with a view to increasing the 6/4 GHz capacity. This resulted in a completely new proposal from the INTELSAT Management Services Contractor (COMSAT) for an all 6/4 GHz INTELSAT V, using multiple spot-beams of about 0·7° diameter in several clusters, each cluster using the whole of the allocated 6/4 GHz bands. To generate these spot beams, a very large reflector, some 10 m in diameter, illuminated by a vast and complex array of multiple feeds, was proposed. Although the use of a 6/4 GHz only satellite was attractive, it was felt that the provision of such a complex satellite was too big a risk at the current state of technology; failure of one aerial feed could impose severe restrictions on the use of the whole satellite. Also, since the satellite aerials were tailored to cover only the specific earth-station groups in being at the time, the arrangement was considered too inflexible, and several other features made this type of satellite operationally undesirable. The proposed multiple-beam INTELSAT V was, therefore, rejected by the INTELSAT Board of Governors.

During the time that the multiple-beam INTELSAT V was being evaluated, studies were being carried out in the British Post Office (BPO) on an INTELSAT V communications package that contained a limited amount of polarization re-use at 6/4 GHz. In 1974, a UK document was submitted to the INTELSAT Technical Committee proposing a modified version of the INTELSAT V design with 2 *zone* beams providing frequency re-use in the east and west high-density traffic areas. In addition to providing increased capacity in the Atlantic and Pacific regions, a feature of this design was the ability to switch the zone beams to new optimum positions in the Indian Ocean region where coverage is required of a large central land mass, and the division into clear-cut east and west zones no longer applies. As in the earlier INTELSAT V design, two 14/11 GHz spot beams were included but, in the BPO version these were to be powered as alternatives to the zone beams.

At about the same time, a similar study was being carried out by a small team in COMSAT and the outcome of this was a proposal on very similar lines to that of the BPO, the essential difference being that the COMSAT version proposed simultaneous operation of zone and spot beams, through a reduction in the number of spot transponders. After some modification in the INTELSAT Technical Committee, this design became the basis of the INTELSAT V communications package specification.

After the submission of tenders and their evaluation, a contract for the development and supply of 7 INTELSAT V satellites was approved by the INTELSAT Board of Governors. An artist's impression of the spacecraft is shown in Fig. 2.

COMMUNICATIONS ASPECTS OF THE INTELSAT V SYSTEM COVERAGE PATTERNS

The planned coverage patterns of the INTELSAT V aerials for the 3 ocean regions are shown in Fig. 3. In the Atlantic coverage, Fig. 3(*a*), it is seen that the 6/4 GHz hemi beams encompass practically all the earth stations operating in the region. The reverse-polarized zone beams provide additional coverage for the higher-density traffic areas in North and Central America, Europe and the Middle East.

In the Pacific region, Fig. 3(*b*), the same aerial patterns fit the east and west land masses quite conveniently, but in the Indian Ocean region, Fig. 3(*c*), the geographical situation is quite different and the zone beams are redirected to cover more of the large central land mass. This redirection of beams will be achievable while the satellite is in orbit, by remote switching of aerial feeds.

The 14/11 GHz spot beams are derived from gimballed, steerable, dish aerials, so that they can be directed, as required, to areas of very high traffic density; for example, in the Atlantic region, to Western Europe and North America.

Frequency Re-use

The 2 hemi beams, as well as being shaped to cover the east and west land masses, are designed to have a very sharp fall-off of gain outside their coverage areas. By this means, it is possible to use the same 6/4 GHz frequency bands in both beams with minimal interference. Similar spatial frequency re-use is possible between the zone beams, and a further doubling of all the available 6/4 GHz spectrum is obtained by the use of opposite senses of polarization in the zone and hemi-beam coverages.

The spectrum at 14/11 GHz is used twice, once in each spot beam, through a combination of spatial and cross-polar isolation. No within-beam cross-polar frequency re-use is provided at 14/11 GHz as there is insufficient spacecraft mass margin available to accommodate the additional transponders‡ that would be required. In any case, the 14/11 GHz

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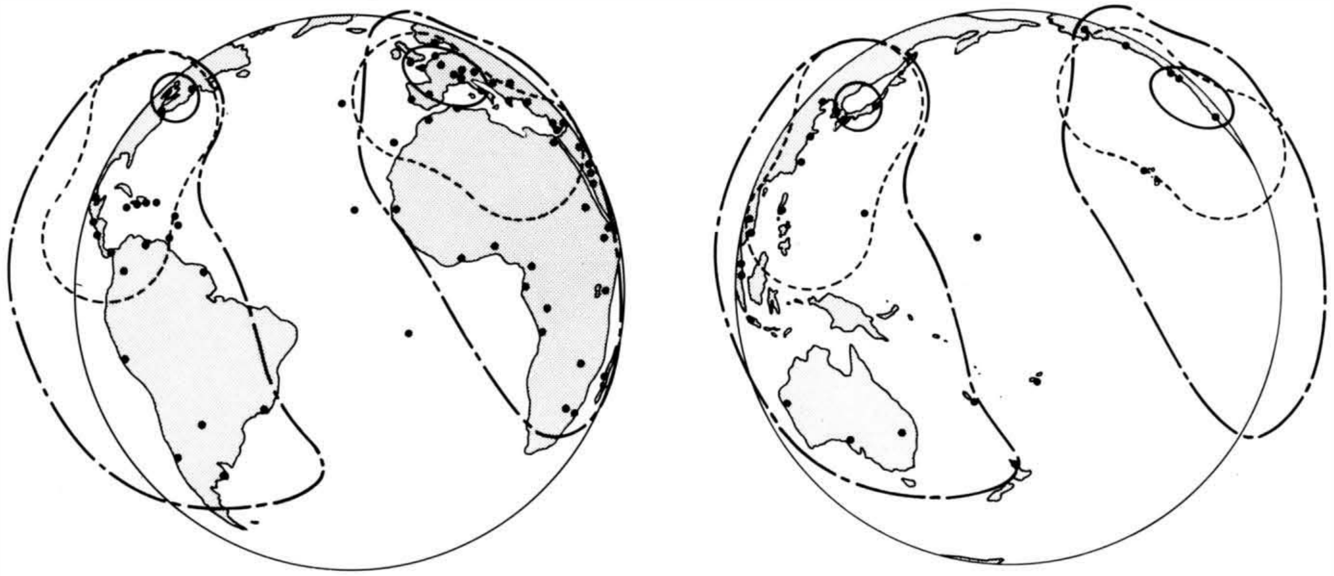
‡ The term *transponder* has been widely adopted to describe a wideband communication-satellite channel. The strict interpretation of the word transponder stems from the field of radar, where the term describes a receiver, frequency changer and transmitter.



(a) Atlantic coverage

(b) Pacific coverage

(c) Indian Ocean coverage

FIG. 3—Approximate aerial beam coverage of INTELSAT V

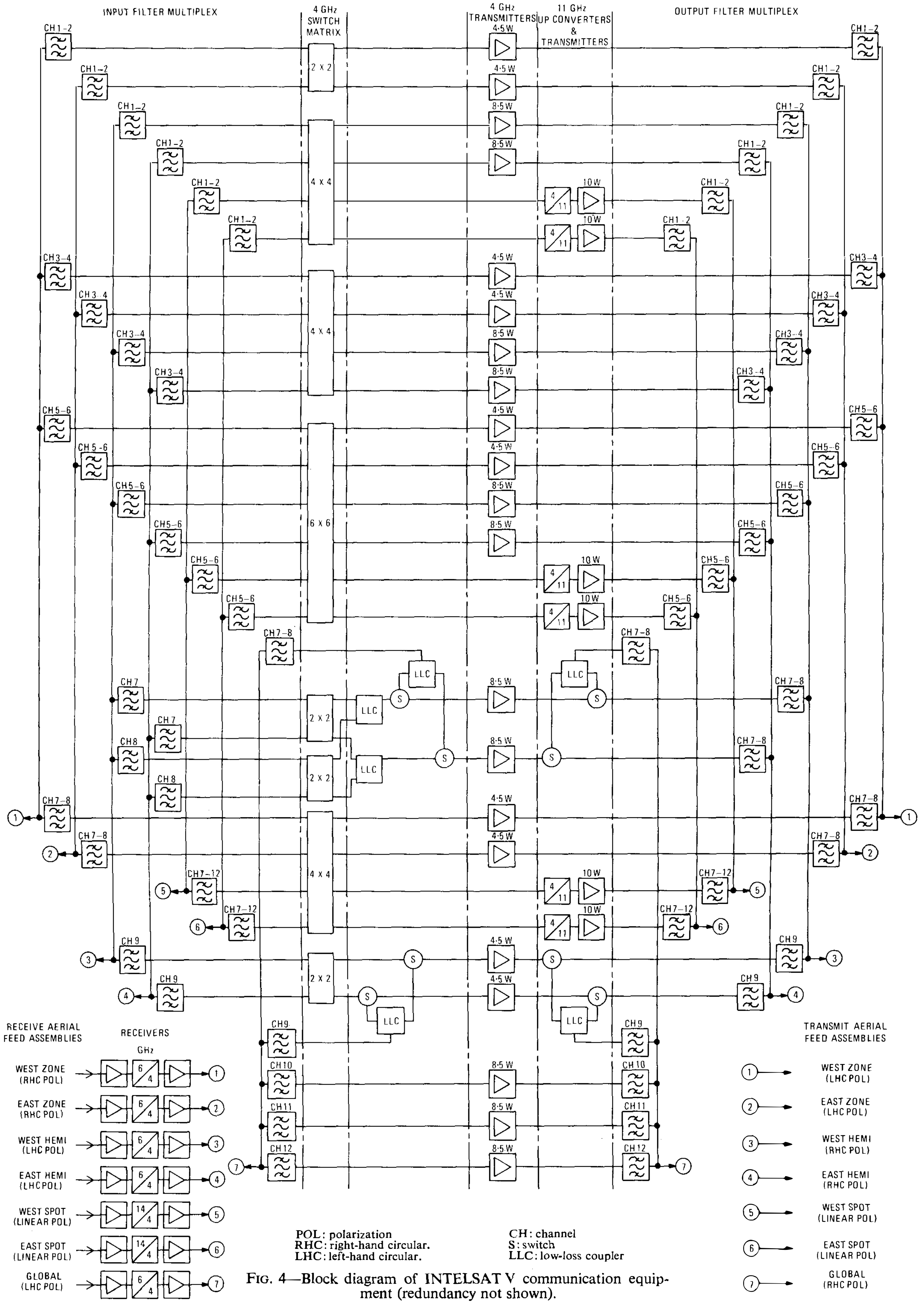
facilities already provided should be adequate for the first generation of INTELSAT V satellites. Later versions could have the added facilities built-in if more mass margin becomes available through the development of new spacecraft materials and techniques, or as a result of a more powerful launch capability.

Cross-Connexion Facilities Between Frequency Bands

To obtain maximum capacity from the additional frequency bands at 14/11 GHz, a system of cross-connexion is provided in INTELSAT V (generally termed *cross-strapping*). This means that transmissions from high-frequency earth stations at 14 GHz can be frequency translated to 4 GHz for reception at standard earth stations. Similarly, in the reverse direction, 6 GHz carriers from standard earth stations can be frequency translated to 11 GHz for transmission to the high-frequency stations. These interconnexions can be introduced as required by remote switching of the transponders.

Outline of INTELSAT V Communication Package

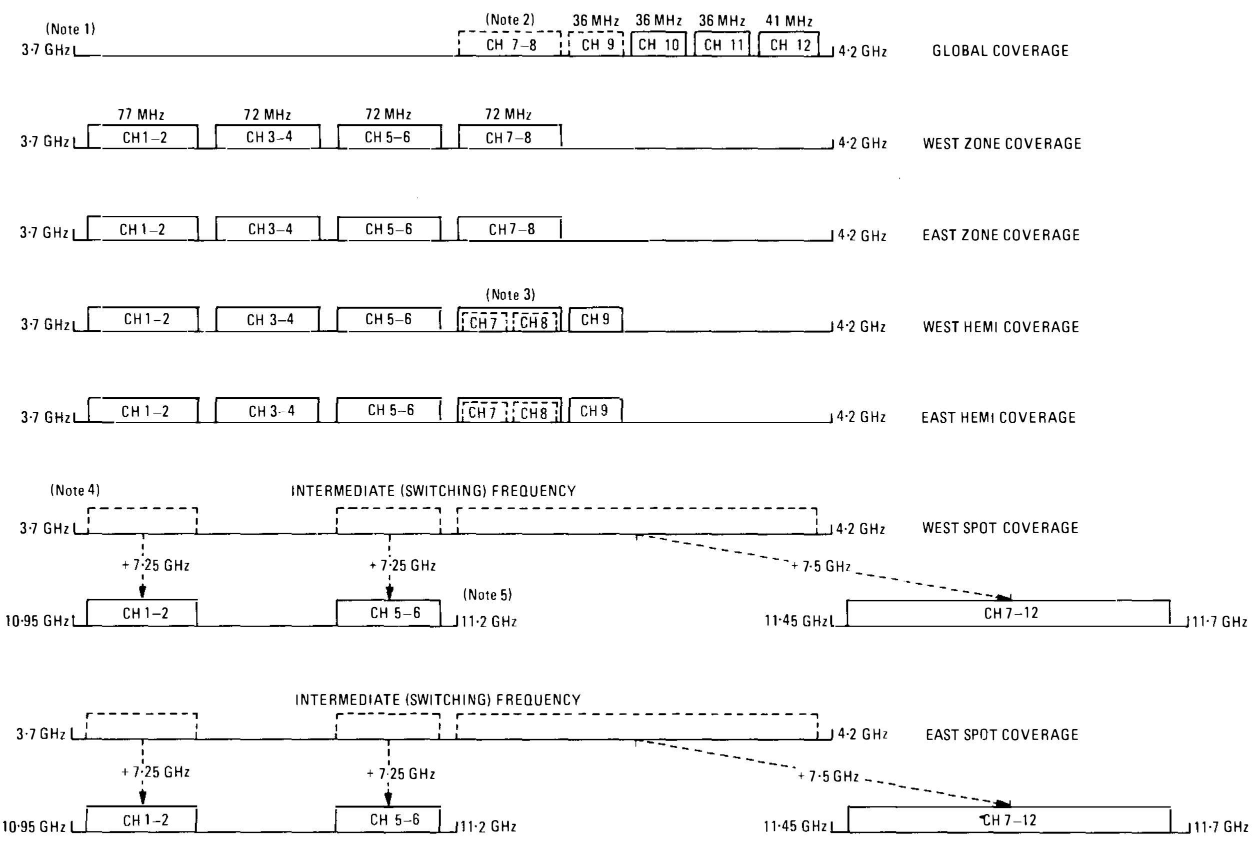
Fig. 4 shows a block diagram of the INTELSAT V communications equipment. The 7 receiving aerials, east and west hemi aerials, east and west zone aerials, global aerial at 6 GHz, and east and west spot aerials at 14 GHz, are each connected to a wideband receiver, with a built-in frequency changer to translate the incoming signals at 6 or 14 GHz to a common frequency band at 4 GHz. The outputs of the receivers are then filtered into the various transponder bandwidths and fed into the interconnexion switch matrix which is switchable under ground control. The transponder numbering retains the original 12-channel nomenclature of INTELSAT IV and IVA, which is based on 36 MHz bandwidth units; thus, the first transponder of INTELSAT V, approximately twice the bandwidth of the IV and IVA transponders, becomes channel (1–2), the second transponder becomes channel (3–4), and so on. The complete channelling plan is shown in Fig. 5. From the main switch matrix, the signal paths are taken through gain-adjustment attenuators to the output travelling-wave-amplifiers (TWAs), which have saturated output powers of 4·5 W and 8·5 W at 4 GHz, and 10 W at 11 GHz. As with other INTELSAT satellites, the output TWAs are normally operated "backed-off" from the saturated output condition to reduce intermodulation components when loaded with multiple carriers.[5] The outputs for the 11 GHz TWAs have to undergo an up-conversion from



POL: polarization
RHC: right-hand circular.
LHC: left-hand circular.

CH: channel
S: switch
LLC: low-loss coupler

FIG. 4—Block diagram of INTELSAT V communication equipment (redundancy not shown).



Notes 1: Input frequency band to 6 GHz receivers is 5·925–6·425 GHz, the output frequency band is 3·7–4·2 GHz
2: Channels (7–8) and 9 can be routed to global coverage, using paralleled TWAs
3: Inputs to channel (7–8) hemi coverage comprise 2 independently switched 34 MHz channels
4: Input frequency band to 14 GHz receivers is 14–14·5 GHz, the output frequency band is 3·7–4·2 GHz
5: Frequency band 11·2–11·45 GHz is not allocated for satellite use

FIG. 5—INTELSAT V channelling plan

4 GHz before passing to the gain adjustment attenuators and output TWAs. From the TWAs, a multiplex of filters is provided to feed the 7 transmit aerial beams covering the same areas as the receive beams. A high degree of flexibility is provided by the 4 GHz switch matrix. The 6 transponders (1–2) can be routed to any combination of spot and hemi aerial coverages; transponders (3–4) can be routed to hemi or zone coverage, and transponders (5–6) are switchable to various combinations of hemi, spot and zone use. Transponder (7–8) has a wide variety of switching options which can be broadly summarized as either

(*a*) global coverage only (using paralleled output TWAs), or

(*b*) hemi–hemi, and zone-zone coverages (not interconnectible), or

(*c*) hemi–hemi, together with cross-strapped zone–spot operation using the lower 72 MHz of transponder (7–12).

When used in the hemi receive mode, the input to transponder (7–8) is divided into 2 separate 34 MHz bands which can be independently switched as required.

All hemi, zone or spot transponders are capable of being switched to either east or west beams as desired, but not more than one transponder of a given frequency and polarization can, of course, be used in a coverage at any one time.

Transponder 9 can be switched to either global coverage (using paralleled TWAs) or to separate hemi coverages. Transponders 10, 11 and 12, at 6/4 GHz, are all permanently allocated to global use. Transponder 12, with its slightly greater bandwidth (41 MHz), will normally carry 2 television transmissions.

Only 3 transponders are provided in each 11 GHz spot beam because of overall mass and power constraints. In the lower part of the band, transponders (1–2) and (5–6) are separated by the bandwidth normally occupied by transponder (3–4) to ease filtering requirements. In the upper half of the band an extra-wide bandwidth transponder (7–12), is provided, but without any corresponding increase in TWA power. It is envisaged that only about half the bandwidth of this 241 MHz transponder would normally be used and that the carriers in it could be optimally spaced to reduce the effects of intermodulation. As a result, a reduction in TWA "back-off", and hence an improvement in operating efficiency, will be obtained in this transponder.

Impact on Earth-Station Design

The introduction of new frequency bands at 14 GHz (up-path) and 11 GHz (down-path)[5] and the introduction of cross-polar frequency re-use are major advances in the INTELSAT system evolution. In the 14/11 GHz bands, transmission through the earth's atmosphere is subject to considerable attenuation during heavy rain, unlike the presently used 6/4 GHz bands where the effect of rain is quite small. Although no satellite emissions have been available at these high frequencies until very recently, for several years data have been collected in the UK on the statistical distribution of fading, first with radiometer measurements using the sun as a source of radiation, and later through the measurement of sky noise which can be directly interpreted in terms of attenuation. The cumulative results of UK measurements at 12 GHz taken during the period 1972–75 are shown in Fig. 6. Other countries have made similar measurements and it has thus been possible to predict the fading depths likely to occur for small percentages of the

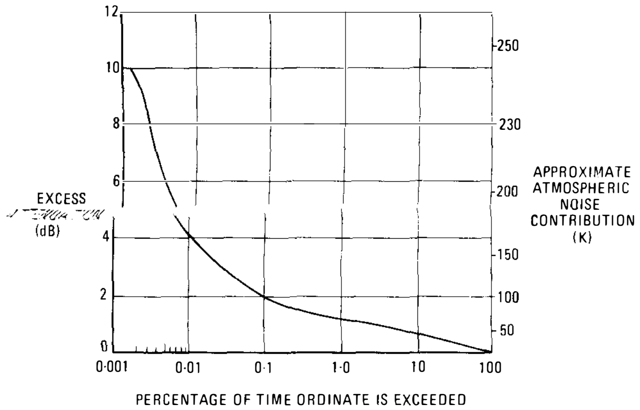


FIG. 6—UK attenuation statistics at 12 GHz

time in the countries intending to operate in the 14/11 GHz bands. On the basis of this information, the achievement of a reasonable balance between the INTELSAT V parameters and the required earth-station gain/noise temperature (*G*/*T*) characteristics was possible. However, the required rain margins vary considerably from country to country, and it has been necessary to specify the earth-station *G*/*T* requirements in such a way that they take account of this variation. The INTELSAT Technical Committee has recently derived performance standards for the 14/11 GHz stations based on an effective *G*/*T*; that is, a value which takes into account the atmospheric noise temperature and excess path loss, in addition to the basic *G*/*T* of the station itself. This effective *G*/*T* must be not less than 39 dB for all but 10% of the time in any year. In addition, a small-percentage-of-the-time effective *G*/*T* criterion has to be met, the figure varying according to whether the station is served by the east spot beam or the west spot beam, there being a difference of 3 dB in the respective spacecraft aerial gains.

The actual values required are, for all but 0·017% of the time, for the east beam, 32·5 dB, and for the west beam, 29·5 dB.

Calculations indicate that these standards can be met, at least for the earth stations to be provided in Europe, without the need for diversity pairs of stations. It may also be possible to avoid the use of diversity for the stations in the USA and Canada, but these countries have not yet made their decisions on this point. The aerial diameters required are expected to be generally in the range 16–20 m, the actual figure being dependent not only on the rainfall margin required, but also on the noise temperature of the low-noise amplifier chosen. This can range from about 170 K for an uncooled parametric amplifier to 50 K for a cooled one.

In addition to the requirement for new 14/11 GHz stations in the earth segment, the introduction of cross-polar operation to the 6/4 GHz bands will entail extensive feed modifications at practically all the existing earth stations to bring them to the required standard of 27 dB minimum isolation between the opposite senses of circular polarization. Any new stations will be required to meet 30 dB isolation.

TRAFFIC CAPACITY

The first of the INTELSAT V satellites to be brought into use will continue to use the multiple access FDM/FM transmissions of standard telephone channel capacities, currently used in the INTELSAT IV and IVA systems. The satellite is also designed to be compatible with TDMA/DSI operation, but this will probably not be introduced on a large scale until towards the middle of the 1980s.

A typical FDM/FM channel loading plan for one 72 MHz transponder is shown in Fig. 7. Here it is seen that the configured capacity, that is, the maximum number of telephone channels obtainable with the carrier sizes allocated, is 1236, while the actual number of channels assigned to operation is 1020. This shortfall of assigned capacity, which can vary from 10–20%, is a factor that has to be borne in mind when evaluating saturation capacities of satellites using FDM/FM.

If all of the 22 wideband transponders were loaded in a similar fashion to the example in Fig. 7, their total capacity would be about 22 500 telephone channels. In addition, there could be a further 5 narrow-band transponders (36 MHz) for telephony use, (transponder 12 would normally be used for television), and assuming a similar density of traffic loading, these would add a further 2500 telephone channels, giving a total capacity of 25 000 channels (12 500 telephone circuits) plus television. This of course is a hypothetical case, and assumes, optimistically, that all the transponder destinations (east and west hemi, zone and spot) will have traffic

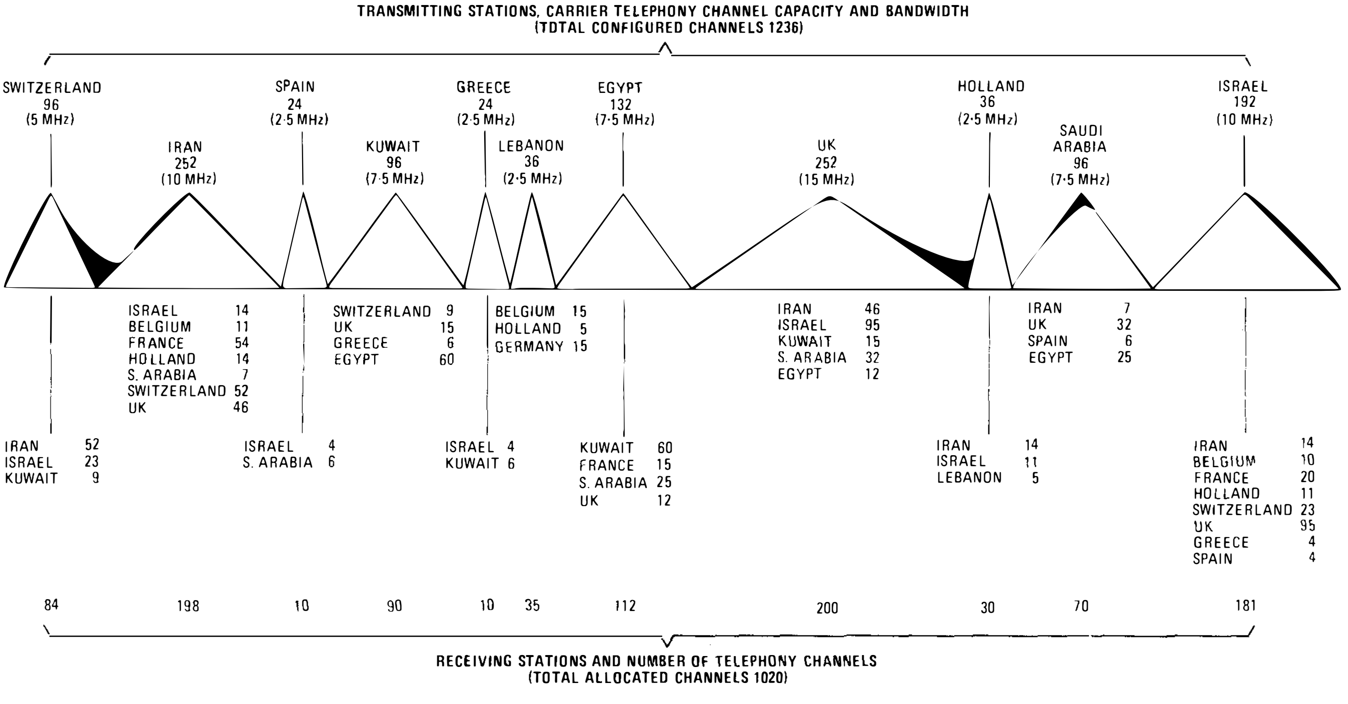


FIG. 7—Example of 72 MHz transponder loading

requirements that match the capacities of the transponders available to them. On the other hand, the assumption that all transponders will be loaded in the same way as the example chosen may well be a pessimistic one, and in practice there will probably be some transponders loaded with a few large carriers that will use the spectrum more efficiently and provide a higher total capacity. It will, therefore, be appreciated that the saturation capacity of INTELSAT V can vary considerably according to the circumstances of its use. A saturation capacity of between 20 000 and 25 000 telephone channels should generally be attainable, provided that a reasonable number of 14/11 GHz stations are in operation. In this context, it is expected that the USA and Canada, and the UK, Germany, France, Italy and Spain will be equipped for 14/11 GHz operation in the early 1980s.

CONTRACT STATUS AND IMPLEMENTATION PLANS

The INTELSAT V contract with the Ford Aerospace and Communications Corporation was signed on 21 September 1976. The Corporation will head an international team comprising Aerospatiale (France), Messerschmitt-Boelkow-Blohm (Germany), Mitsubishi (Japan), Selenia (Italy), and Marconi (UK).

The contract calls for delivery of 7 flight spacecraft, the first of which is scheduled for delivery by mid-1979, with subsequent deliveries to be made at intervals of about 3 to 5 months thereafter.

The first 2 spacecraft will be used as the Atlantic region primary satellite and its in-orbit stand-by satellite. If present traffic trends are continued, the next 2 spacecraft will be required in the Indian Ocean region, as worker and spare, in 1980. An allowance of one in 4 satellites is made for launch and satellite failures, leaving a probable 2 satellites for implementation as Atlantic region and Indian Ocean region major-path satellites. At present predicted traffic growth rates, a single working INTELSAT IVA should be able to cope with demands in the Pacific Ocean region until the mid-1980s.

The contract provides for an option of further spacecraft orders up to 1981, by which time it will be clear how the programme is progressing.

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Book Review

Telecommunications: A Systems Approach. G. Smoll, B.SC., PH.D., C.ENG., M.I.E.E., M. P. R. Hamer, M.A., and M. T. Hills, B.SC., PH.D.,C.ENG., M.I.E.E. George Allen & Unwin Ltd. 270 pp. 125 ills. £8·50 (hardback); £4·25 (paperback).

In these days of specialism within the field of telecommunications, the authors of this book and the Open University, for which this is a study book, are to be congratulated. They have produced a book that emphasizes to students the common threads of technology running through telecommunications, linking together such aspects as the hierarchical structure of telephone switching systems, analogue and digital transmission and the subtleties of the shadow-mask colour-television tube.

The book starts with a review of telecommunication principles, drawing on commonplace things, such as a baby alarm, to illustrate the fundamental components of telecommunication systems. The book is then devoted to what the authors refer to as extended case studies, firstly of switching systems and then of television systems. The authors' claim perhaps underestimates the scope of the material covered. In particular, the study of switched telecommunication systems initally provides the fundamentals of the hierarchy of telephone systems, and then introduces the problems of numbering schemes for local, national and international purposes. It then covers modern techniques in switching and signalling. Still under the heading of switched telecommunication systems, the book deals very adequately with the principles of transmission over cables and radio systems, and introduces both frequency-division and time-division multiplex transmission. A welcome inclusion is a section on design and planning, introducing concepts of dimensioning systems, and including the economic considerations of capital costs, maintenance costs and equipment-replacement expenditure (depreciation). At the conclusion of this section, the reader has been given a very good appreciation of the main characteristics of the British switched telephone network and, at times, a comparison between this network and those in other countries.

The next 2 equally substantial chapters are devoted to television systems. After briefly reviewing the transmission principles involved in broadcasting picture information, the book deals in some depth with the design of television receivers. This is followed by a final section on colour-television systems. Here again, the basic factors involved in the colour receiver are explained very adequately, leading up to a discussion of NTSC, SECAM and PAL, and the reader is given an appreciation of the reasons for the choice made by the UK.

The book is described as being aimed at undergraduate students, where I am sure it will be welcomed. However, mathematics is used sparingly in the book and only where necessary, and the presentation of the various subjects is very readable and logical. For these reasons, the book will, I am sure, commend itself to a much wider readership.

Specialists in the reliability field may quarrel with the definitions on page 112, which are in everyday terms rather than in the terms now emanating from the British Standards Institution and the International Telegraph and Telephone Consultative Committee. However, the world-wide agreements on such reliablity definitions are only slowly spreading into technical literature.

On page 116, the traffic-recorder chart (Fig. 4.2) gives a good indication of the factors affecting the variation in traffic over a 24 h period. In recent years, however, the tendency has been for the busy hour to extend over a period of 2–2·5 h, rather than be confined to a period of somewhat less than 1 h.

On page 141, in lines 12–14, it is said that, if a telephony hypergroup and television channel on a radio system both fail, then the television channel is lost. This is not necessarily so. The administration would, in difficult cases, decide whether telephony or television should be given priority for restoration, depending on the time of day and other circumstances.

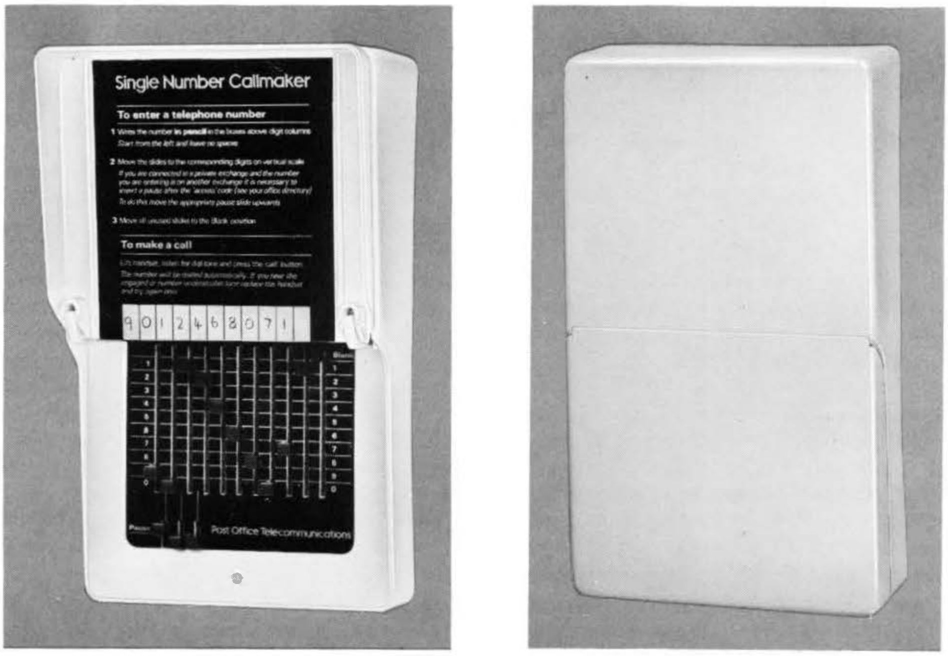
J. F. B.

Mono Callmaker

P. A. BURTON†

UDC 621.395.636:616-7

This article describes the latest addition to the British Post Office range of repertory diallers: the Mono Callmaker. This has a particular application for customers with physical disabilities as well as appealing to a commercial market.



Note: For the field trial, the Mono Callmaker will be known as the *Single Number Callmaker*

FIG. 1—Mono Callmaker (Autodial No. 401A), shown with lid open and closed

INTRODUCTION

The British Post Office has for many years provided the Sender No. 1 to assist handicapped telephone subscribers call a public-exchange operator simply by lifting the handset and pressing a button. The sender consists of a notched disc that is rotated by a 9 V battery-operated motor. Pulsing contacts are positioned such that they give one *break* pulse to line per notch, and off-normal springs duplicate the function of those of the conventional dial. The pulsing and off-normal spring-sets are based on those designed for the now obsolete Dial, Automatic No. 10, supplies of which are rapidly diminishing.

The Mono Callmaker has been developed as a line-powered electronic replacement for the Sender No. 1, and as an addition to the range of repertory diallers currently available.[1] It provides more facilities than its predecessor in that, although it can send still only one number, that number can be chosen and programmed by the customer; the device is not limited to sending the operators' code. The callmaker is thus capable of satisfying more commercial applications. The title of the device is the *Autodial No. 401A* but, for marketing purposes, it is known as the *Mono Callmaker*. (Field-trial items will bear the title *Single Number Callmaker*.)

FACILITIES

One telephone number of up to 11 digits can be selected using a matrix of slide switches (see Fig. 1) to set the required digits. Three additional switches beneath the number-setting matrix enable a long inter-digital pause (IDP) to be inserted, if required, after each of the first 3 digits. A long IDP is needed when the callmaker is fitted to a PABX extension and access is required to exchange lines or inter-PBX circuits. The length of the IDP can be set to either approximately 2 s or 5 s by shifting a strap.

Originally, the device was intended to be wall-mounted only. This was because of the problem of re-orienting a mercury-wetted pulsing reed-relay if the callmaker were, as an alternative, to be used horizontally on a table. However,

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in the final design, a solid-state pulsing element is used, and it is therefore possible to operate the callmaker in any plane.

The callmaker is operated by a single remote change-over switch. This is normally fitted in the associated telephone but, for the more severely handicapped subscribers, an actuating switch appropriate to the particular user's needs can be installed.

PHYSICAL DESIGN

The case has been designed to accord with the modular dimensions recommended for new customer apparatus, and is 250 × 150 × 50 mm in size. The external appearance has been deliberately kept plain and simple to allow the unit to merge into the normal living-room background. The design incorporates 2 novel double-acting hinges that allow the lid to rotate through 180°, hold it open for the number to be set, and give a completely plain surface when the lid is closed (see Fig. 1).

All the electrical components, and the number-setting matrix, are mounted on a single printed-circuit board which extends the complete length of the unit and is supported on a pressed-metal base using snap-in plastics pegs. The sliding contacts of the number-setting matrix are mounted in a plastics moulding having a specially designed profile that provides guides for the setting switches and a means of ensuring their precise location when set. The fixed contacts consist of gold-plated wires soldered to the printed-circuit board. An anodized-aluminium label, bearing the markings for the number-setting matrix and the "Post Office Telecommunications" motif, is used as a face plate for the matrix. A second anodized-aluminium label inside the lid presents the complete operating instructions, and also includes an area on which to write the selected telephone number.

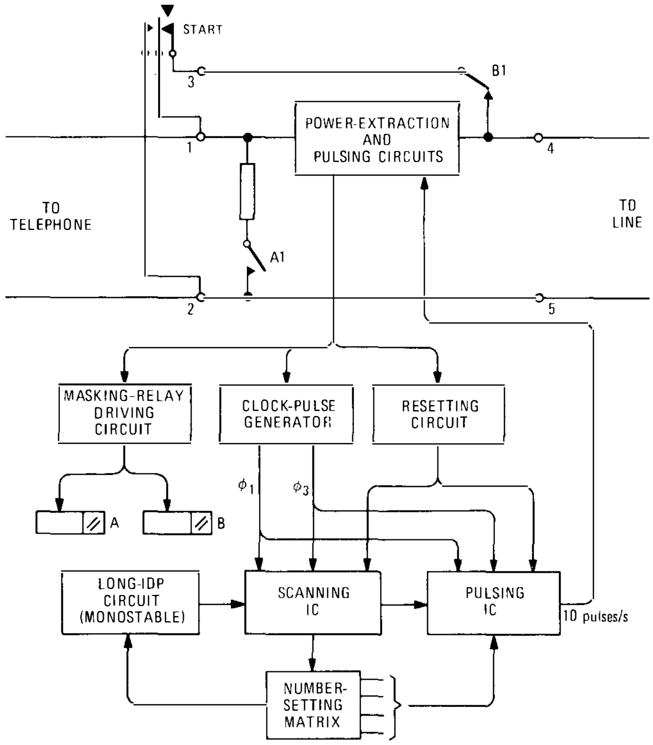
The complete case and lid, which are fastened to the base by a single screw, are removable, giving access to the connexion terminals and the long-IDP strap. Press-out sections in the case cater for connexion by cable or standard telephone cord. The base has rubber feet for table-top use, and keyhole slots for wall-mounting. The components on the part of the printed-circuit board that is exposed when the cover is removed are protected by a shroud which prevents damage during installation.

The metal base has holes that coincide with the press-out sections in the case, and a clamp to retain a connexion cord. The rubber feet are recessed to give a low profile, and do not need to be removed when the callmaker is wall-mounted. The case fits over 2 tongues at the top edge of the base, and is secured by a single screw in a tapped extension to the cord clamp.

CIRCUIT OPERATION

Fig. 2 shows a block diagram of the callmaker connected to a telephone circuit. When the callmaker is not in use, the line is connected through to the instrument via masking-relay contact B1 and the *break* contact of the START button. To activate the callmaker, the START button is pressed to remove the short-circuit from the power-extraction circuit. Power is drawn from the line to start the clock-pulse generator, operate the 2 masking reed-relays, and apply a *reset* condition to the scanning and pulsing integrated circuits (ICs). Contact B1 maintains the power supply to the callmaker when the START button is released, until pulsing is completed. Contact A1 provides a low-resistance pulsing loop, guarding the telephone against acoustic shock.

The clock-pulse generator supplies 2 clock-pulse streams, ϕ_1 and ϕ_3, to the 2 p-channel metal-oxide-silicon ICs: the scanning IC and the pulsing IC. Two further streams, ϕ_2 and ϕ_4, are derived and used internally by the ICs from ϕ_1 and ϕ_3. Streams ϕ_1 and ϕ_3 supply power to the ICs; ϕ_2 and ϕ_4 are used only to control gates. The scanning IC interrogates the matrix of programming switches sequentially and converts each digit of the telephone number into a 4 bit binary code. The code for each digit is passed to the pulsing IC, where it is stored and processed in a way similar to that previously described for loop-disconnect-signalling push-button telephones.[2] The 10 pulses/s output is used to drive a pair of high-voltage transistors that constitute the solid-state loop-disconnect pulsing element. At the end of pulsing, the *reset* condition is again applied to the ICs to prevent misoperation when the masking relays are released and the power supply removed.



Note: Terminals 1–5 are on the callmaker

FIG. 2—Block diagram of callmaker

When a long IDP has been programmed, the scanning IC interrogates the matrix and forwards the information as described above until it reaches the programmed pause. It is then inhibited from further interrogation by the long-IDP monostable circuit. When the monostable circuit resets, interrogation continues.

CONCLUSION

Prototypes of the Mono Callmaker have undergone extensive laboratory testing, and the next stage is to obtain small-scale production and field-trial experience. Although primarily intended as a dialling aid for handicapped customers, the callmaker could well find applications in other fields.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the help given by his colleagues in the Telecommunications Development Department, and by GEC Telecommunications Ltd., who carried out the development work.

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TXE4 Electronic Exchange System

Part 3—System Security and Maintenance Features

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UDC 621.395.345:621.316.54:621.395.65

This concluding part of a 3-part article describes the security features of the TXE4 electronic exchange system, together with the diagnostic and maintenance aids provided.

INTRODUCTION

Previous parts of this article[1,2] have described the overall structure and operation of the TXE4 system and the detailed design of the major building blocks of the control and switching network. This final part of the article deals with the security features of these individual blocks, and the way in which they are dimensioned and interconnected to provide the requisite standard of performance. The methods of fault detection and identification, together with maintenance features and aids to fault diagnosis, are also described.

SYSTEM SECURITY

Security is the ability of a switching system to maintain an acceptable grade of service in the face of equipment malfunction, and is a major factor dictating the design configuration of a system. Flexibility, ratio of initial to incremental growth costs, and facilities offered, are other determining factors to which a potential user will attach varying degrees of importance. Therefore, the need to provide systems with a wide range of fundamental requirements at minimum cost has led to a large variety of design configurations for electronic common-control systems that vary greatly in detail.

The detailed design of any common-control equipment is defined by 2 factors: the control function that the overall system configuration requires it to perform, and the speed at which it is required to perform this function. At one extreme, a single control equipment could perform all common-control functions for a complete system, while at the other extreme, a control unit could be associated with each switching point. Between these extremes lies an infinite number of configurations, each of which offers a particular balance of fundamental requirements.

Use of a single control equipment generally offers great flexibility to incorporate change, but involves high initial cost as the cost of the control cannot be spread over the life of the system. Usually, this approach is not highly tolerant of simultaneous faults, and the equipment has to be designed with a high degree of inherent reliability. Use of distributed control, where the processing requirement of the system is spread over a number of units, allows the size and cost of the common control to grow in parallel with the capacity of the exchange. Failure of a single unit does not generally have a catastrophic effect, instead it reduces only the grade of service offered by the system. A distributed-control system is tolerant of many forms of simultaneous failure.

TXE4 System Design

The TXE4 system uses a distributed-control configuration, and the major call-control functions are handled by a number of identical control units. Supervision and cleardown functions of established calls are completed by a further set of special-purpose processors. The rate of provision of both of these items is related to the equipped capacity and traffic loading of the exchange. Failure of a single item reduces the traffic carrying capacity of the exchange, but the resultant deterioration in the grade of service can be held to any selected figure by appropriate dimensioning rules. For TXE4, extensive computer simulations were made to determine rules which maintain acceptable service under a wide variety of failure conditions.

In certain areas of TXE4, it is not practical to spread the total control load over a number of identical equipments. Firstly, where identical and normally independent items of control equipment need to be given access to the remainder of the system, control of such access needs to be performed centrally and in a highly secure manner. Secondly, where control equipment is specifically associated with service to groups of customers, failure would prevent service being given to those customers. In these cases, the requisite degree of security is achieved by using duplicated, triplicated or quadruplicated equipment, and a controlling output is derived by comparison processes.

TXE4 System Operation

Although a high degree of system security is achieved in TXE4 by the use of distributed control, the performance of the system as it affects the customer is further enhanced by a number of operational features. Not all faults necessarily lead to the immediate removal of equipment from service. Some faults are of a transient nature, and can be safely ignored until their frequency reaches a predetermined level; others have little effect on the system, and immediate maintenance attention is not economically justified. To limit the effects of such faults, an automatic repeat-attempt facility is built into TXE4. To ensure that a subsequent attempt to complete a connexion does not encounter the same fault that caused the initial failure, a different path is chosen through the switching network. For example, when a connexion is to be made to one of a group of junction relay-sets on a single route, a different circuit is selected for the second attempt, and to improve path diversity still further, circuits in a group are spread evenly over the available terminations of the switching network.

Switching Network

In the event of a marker or interrogator fault, an acceptable exchange performance is achieved by limiting the size of the

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switching network section controlled by a single marker; in practice, this varies between one sub-unit on small exchanges and 5 sub-units on the largest. If a critical failure in a marker or its associated interrogator occurs, such that service is seriously affected, the plane combinations affected are busied to further traffic. A similar procedure takes place in the event of an isolated non-critical fault, but should a second marker then become faulty, the first is automatically restored to service by a special-purpose control known as a *one-out-of-n busy circuit*. This ensures that successive minor failures do not lead to an unacceptable reduction in the grade of service.

Main Control Units and Registers

Main control units (MCUs) and their associated registers are responsible for all control functions involved in setting-up calls. The number of MCUs provided at a particular installation is dependent on the traffic load of the exchange, and each MCU is able to process all types of call. Regardless of exchange size, a minimum of 3 MCUs is always provided and this, together with system dimensioning rules, ensures that failure of a single MCU can be tolerated. A one-out-of-*n* busy-circuit is used to control simultaneously the service status of all MCUs, in a manner similar to that used for the markers.

To ensure that an MCU fault is detected as quickly as possible, self-checking is carried out within each MCU. Internal transmission of all data is over highways in a 2-out-of-5 code format and is checked at the MCU transfer store to detect any corruption. Additional hardware and program checks are provided to detect other types of fault. Internally-detected faults are applied to the fault action unit (FAU) associated with the MCU concerned. The FAU is responsible for discriminating between critical and non-critical faults, initiating maintenance print-outs, and providing a filtering function to prevent premature alarms and busying of the MCU as a result of transient faults. To perform these functions, the FAU contains 2 counters, one associated with critical faults only, and the second with all faults. Fault threshold limits can be set on each counter and the MCU is not removed from service, or an alarm raised, until either fault-count threshold is exceeded. Both counters are automatically reset after a predetermined number of calls have been processed by the MCU.

When an internal fault is detected by an MCU, the action taken depends on whether the *main* or *register* program is in use. In each case, a fault print-out is initiated by the FAU, and the fault counter(s) are incremented as appropriate. If the register program is in use, all calls being processed by the MCU are cleared; if the main program is in use, the particular call being dealt with at the time is abandoned. Although each MCU operates independently for call processing, all MCUs become interdependent when access to the rest of the exchange is required. Such access control is required to be secure, therefore, the *pre-alloter*, which controls allocation of the MCUs to new calls, and the *marker-highway control*, which permits the MCUs to have sequential access to the common marker highways, are triplicated. The controlling output from each of the triplicated circuits is derived by majority decision.

Supervisory Processing Units

Supervisory processing units (SPUs) are responsible for performing local-call timing, called-subscriber-held timing, and manual-hold timing. The SPUs also control the application of periodic meter pulses to subscribers' meters and the cleardown of connexions at the completion of calls. To perform these functions, the SPUs have access to bridge-link circuits and outgoing-junction relay-sets for supervision of local and outgoing-junction calls respectively. An SPU is associated with each odd-plane marker and it processes the bridge-link circuits connected to the associated odd sub-unit(s). Therefore, each bridge-link circuit is controlled from one SPU. Each outgoing-junction relay-set connected to the switching unit(s) served by a set of 3 SPUs (6-plane exchanges) or 4 SPUs (8-plane exchanges), is directly controlled by a pair of SPUs operating in synchronism. Failure of an SPU results in loss of all calls being carried by the associated bridge-link circuits, but the associated marker is instructed not to set further calls using these circuits. Processing of junction relay-sets served by the failed SPU continues under the control of the partner SPU of the pair.

For a 6-plane exchange, between 1 and 5 link rack terminals (one per sub-unit served) and between 1 and 5 junction rack terminals (one per switching unit served) are associated with each SPU. Instruction signals are sent to each bridge-link circuit via the appropriate link rack terminal. A link rack terminal receives signals only from its controlling SPU.

For junction relay-set processing, each of the 3 SPUs in a set receives status signals from all junction circuits served by the associated switching unit(s) and sends instruction signals for each circuit, not only to all its own junction rack terminals but also to all others associated with the remaining SPUs in the set. Each rack terminal compares each instruction signal received from its parent SPU with those received from the other SPUs. The signal from the parent SPU is allowed to go forward only if it agrees with one or more of the equivalent signals from the other SPUs. The instruction signals are sent directly from the rack terminals to the logic buffers associated with each relay-set. For a given relay-set, however, signals from only 2 of the 3 junction rack terminals are used and the existence of either or both will operate the circuit correctly, thus providing continuity of service in the event of rack terminal failure. The association of an SPU pair with a relay-set is arranged so that each SPU directly controls two-thirds of the processed junction circuits on the associated switching unit(s).

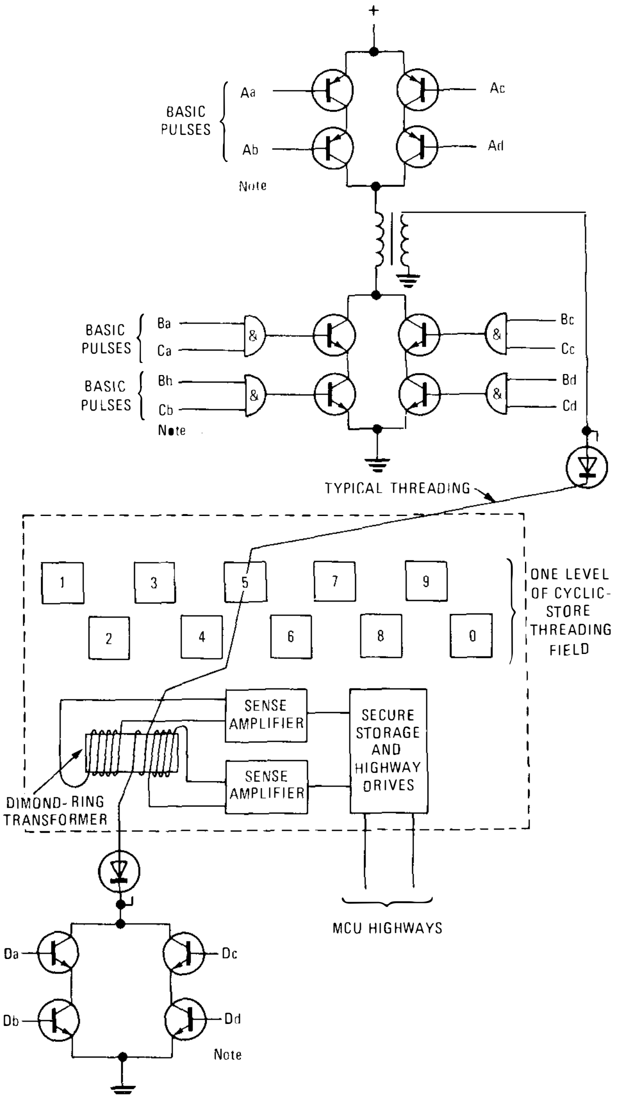
In an 8-plane exchange, a similar arrangement is used, except that the fourth SPU of a set does not directly control any junction relay-sets and therefore has no junction rack terminals associated with it. The SPU is used solely for processing bridge-link circuits connected to the fourth odd sub-unit(s) and, for this purpose, is associated with between 1 and 5 link rack terminals (1 per sub-unit served). To check correct operation of this fourth SPU, status signals are received from all the junction relay-sets served by the other 3 SPUs, and the fourth SPU generates instruction signals for these circuits. Special circuitry compares these signals with similar signals derived by majority decision of the instruction signals from the other 3 SPUs.

The checking and inhibit circuitry in each junction rack terminal prevents false operation of the junction relay-sets in the event of an SPU failure, but does not identify the faulty SPU. It detects instances where an instruction signal from the parent SPU is not identical with at least one of the equivalent signals from the other SPUs. When such a disagreement is detected by a junction rack terminal, a signal is passed to a *supervisory processing fault unit* (SPFU) associated with the SPU concerned. If more than a preselected number of disagreement signals are received within a given period, the SPU is removed from service and an alarm indicated. The fault-filtering function provided by the SPFU protects against premature removal from service of the SPU as a result of transitory disagreement signals.

Cyclic Stores

The cyclic stores form the semi-permanent library of information for each exchange termination, and certain sections of the stores are associated specifically with an individual group of customers' lines or junctions. Failure, therefore, involves loss of service to the affected circuits rather than an overall reduction in traffic-carrying capacity of the exchange. The structure of the cyclic-store area is based on a modular approach dictated by economic growth steps, and security is achieved by replication of common circuitry. The security feature can be considered in 2 parts: the pulse-gate, drive and read-out circuits, and the *state-of-line* (SOL) logic.

The generation of drive signals, used to pulse the cyclic-store threading wires, is quadruplicated. For this purpose, the first 2 racks of each cyclic store set receive 2 identical supplies of each basic pulse from the pulse generator. On each of the 2 racks independently, these pulses are used to generate 2 independent but identical sets of pulse combinations that form the basic drive signals for the complete cyclic-store set. The 4 drive signals so formed are fed to drive amplifiers which pulse the threading wires. Each drive amplifier uses 4 transistors in its circuit arrangement with a single transistor gate being used for each of the 4 drive signals. These gates are interconnected such that failure of any one gate or any one input signal cannot affect the correct operation of the drive. For each Dimond-ring transformer in the store, the secondary winding and associated sense amplifier are duplicated, and form 2 independent inputs to the duplicated MCU highway. The security arrangements of the pulse-gate, drive and read-out circuitry are shown in Fig. 1. The 2 pulse-plus-bias gates, known as the *calling gate* and the *free gate*, (from which are derived the CG and FG signals) used to establish the condition of each peripheral relay-set or customer's line, are interrogated simultaneously with the associated cyclic-store threading. The output from each gate is divided to provide 4 separate outputs. Each output is combined with its equivalents from all other line circuits and peripherals on the set, in a series of gating and buffering stages, to form 4 secure paths for the CG condition and 4 for the FG condition. Each path consists of 2 wires; one wire conveys the actual gate condition (CG or FG) and the other the inverse signal ($\overline{\mathrm{CG}}$ or $\overline{\mathrm{FG}}$). The CG paths form the inputs to duplicated majority-decision circuits, and the FG paths form the inputs to a second pair of majority-decision circuits. The output from each majority-decision circuit consists of 2 wires, one wire conveys the gate condition (CG or FG), and the other the inverse signal ($\overline{\mathrm{CG}}$ or $\overline{\mathrm{FG}}$) and feeds one of the duplicated pair of SOL logic sets. The SOL logic sets provide 2 independent inputs to all MCUs. There is a degree of cross-connexion between the 2 sets of logic to allow mutual update of SOL store information following, for example, maintenance action on one SOL path. The security arrangements of the cyclic-store read-out and SOL circuitry are shown in Fig. 2 for a typical junction relay-set calling gate.



Note: Upper-case characters represent different pulse identities; lower-case characters represent different pulse supplies

FIG. 1—Security arrangements of the cyclic-store pulse-gate, drive and read-out circuits

Pulse Generator

Pulse trains are used throughout the TXE4 system to operate and synchronize sections of the equipment that periodically have to interwork to exchange information. The pulse trains required are generated on a pulse generator rack, and pulse generation is made secure by triplication with 2-out-of-3 majority decision. Error-checking equipment monitors the operation of the pulse generation and distribution system.

The pulse generator is divided into 4 identical sections: 3 masters and a slave. Each of the 4 sections contains an oscillator that is synchronized by a majority-decision signal derived from the 3 outputs of the master sections. Each oscillator drives a separate series of ring counters that divide the basic generated frequency to produce the various pulses required. Each ring counter is synchronized to its equivalents in the other 3 sections by majority-decision circuits in a similar manner to the oscillator sections. If a single fault occurs, 3 of the 4 generator sections still operate in synchronism and the remainder of the exchange is not affected. In practice, it is possible for several faults to exist simultaneously without immediate effect. Four outputs of each non-secure pulse are taken from the 4 pulse-generator sections directly to the cyclic store, where a check circuit identifies pulse errors or highway faults. Periodic inhibiting of different combinations of outputs allows the cyclic-store error-check circuitry to identify both highway faults and internal cyclic-store faults. All other exchange equipment uses secure pulse trains, for which 2 separate supplies are provided. These are derived by comparing the outputs of the 4 pulse-generator sections in 2 pairs. The 2 independent supplies serve each rack in turn and, following the last rack, return to the pulse-generator rack for comparison with each other to identify highway faults. Checks on secure pulses are not generally performed, but the equipment will continue to operate correctly in the face of failure of either input.

The pulse generator error-check circuit is responsible for checking pulses at source by comparing each signal with a corresponding signal in one of the other sections. Monitoring is performed on a time-sharing basis; a detected fault is signalled to the alarm unit and a lamp indication is provided to identify the faulty pulse. The alarm unit can be arranged to give a PROMPT alarm, or the alarm indication can be delayed until either 2 or 3 faults (depending on a manual setting by maintenance staff) have occurred within a 3 min period.

Security Features in System Operation

To ensure successful connexion of calls in the presence of minor or transient faults, a number of repeat attempts to

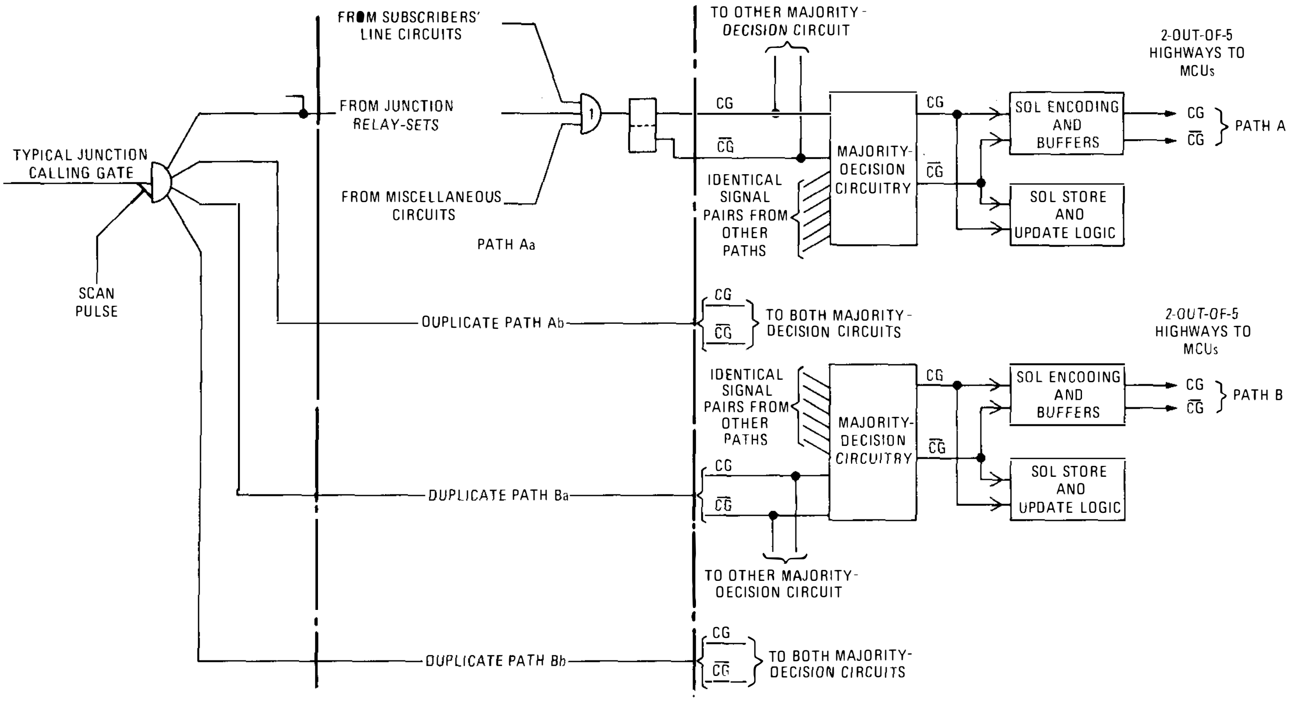


FIG. 2—Security arrangements for state-of-line logic

connect a call through the switching network is made if necessary. Four interrogation repeat attempts can be made in succession. Once a successful interrogation has been achieved, a marking attempt is made. If in turn this fails, a further series of up to 4 interrogation and one marking attempt is made before an appropriate service tone is returned to the caller and a print-out given. If 4 interrogation attempts fail in succession, it is assumed that congestion is the cause; subsequent action taken by the MCU depends on the type of terminations involved. If the path is from a specific termination to one of a group of circuits, such as a subscriber to an outgoing junction on a particular route, the MCU re-examines the cyclic-store highways to determine if a second circuit in the required group is free. If a free circuit is found, the interrogation and marking sequence is repeated to find one or more paths through the switching network.

Failure to complete a selected path is detected by the marker which, for this purpose, is provided with access to both sides of the link circuit involved in each path connexion. The positive, negative and P-wires are examined for correct potentials from either the line circuit or relay-set and, in the event of failure of any path check, the marker fails to indicate to the MCU that a successful path connexion has occurred. The MCU generates a path failure print-out and initiates either a repeat interrogate/mark sequence or connexion to a tone circuit to indicate call failure to the customer.

MAINTENANCE FEATURES

When a fault has occurred, it is necessary to identify to maintenance personnel the existence of that fault and the equipment area in which subsequent repair action is required. This is achieved by the exchange alarm system and the fault print-out facility. Further analysis of a particular fault is performed by using special testers and other maintenance aids. Routiners are also provided for items where fault detection by self-checking circuits during normal system operation is impractical.

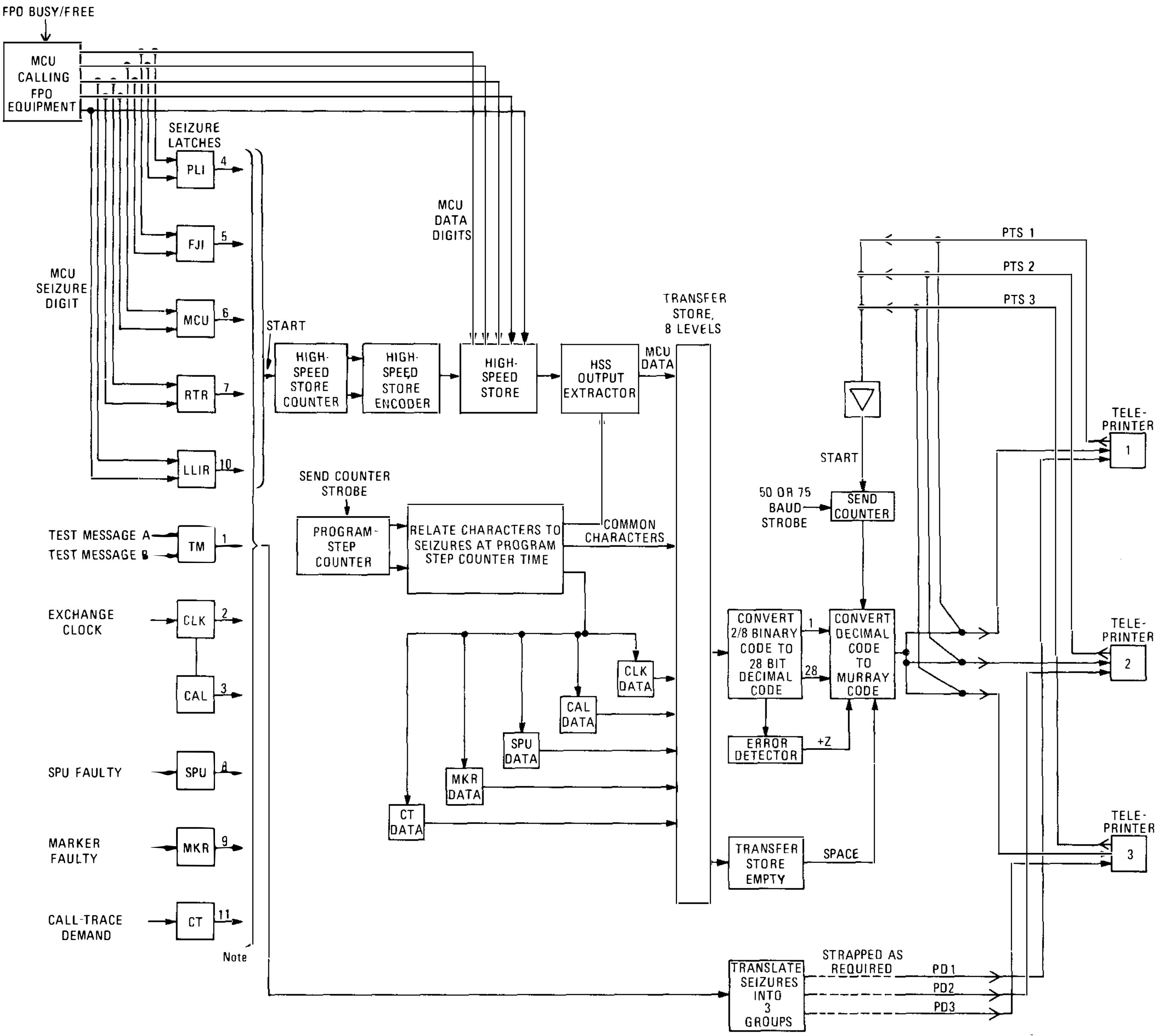
Fault Print-Out

The print-out equipment receives fault information for all major items of common-control equipment and displays this information in a standard format message on the exchange teleprinter. The information to the fault print-out (FPO) equipment is signalled on separate highways from each equipment, the sources of fault messages being the call-trace equipment, marker, SPU and the MCU. Messages arising from routiners, path failure information, program faults and parked lines, are assembled and sent to the FPO via the MCU. Clock and calendar messages are generated internally by the FPO to assist in the interpretation of exchange performance. Only one source is able to seize the FPO at any one time, and in the event of simultaneous seizures of the FPO equipment, an order of priority is allocated to each message type and the one with the highest priority is accepted first. The priority for individual messages is indicated beside each message type in Fig. 3, which shows a block diagram of the FPO equipment.

Information from the SPU, marker and call-trace equipment is passed to the FPO on a one-character-at-a-time basis. This requires the reporting equipment to remain associated with the FPO until the entire message has been printed. In the case of the MCU, a high-speed store (HSS) is provided within the FPO to allow a complete message to be retained in advance of print-out, and the MCU is released. This reduces connexion time, and allows more efficient use of the MCU. The HSS is controlled by a counter that is stepped at 24 μs intervals from the exchange pulse generator. The store has 30 levels, each of which can store one digit in 2-out-of-5 form. The information is extracted from the HSS in a particular order related to the type of message, under the control of the program step counter (Fig. 3).

On seizure, the FPO generates standard format messages by interleaving data from the reporting sources with internally generated alpha-numeric and other teleprinter characters. This is achieved by advance of the program-step counter which, in turn, is stepped by each cycle of the send counter. The send counter is stepped at a rate equivalent to either 75 baud or 50 baud, dependent on the teleprinter signalling speed required.

Each step of the program-step counter represents either a character position on the message line or a basic teleprinter control instruction. The pulse combinations representing each step are fed to a wired-logic array where, together with message-type indications, they are used to generate characters, or read specific data from reporting highways or from the MCU HSS. Each item of data or character is passed to the



Note: priority is indicated alongside each message

PLI—parked-line indentification
FJI—faulty-junction identification
HSS—high-speed store
RTR—routiner
PD—print demand
PTS—proceed to send
LLIR—local-line insulation routiner
TM—test message
CLK—clock
CAL—calendar
MKR—marker
CT—call trace

FIG. 3—Fault print-out equipment

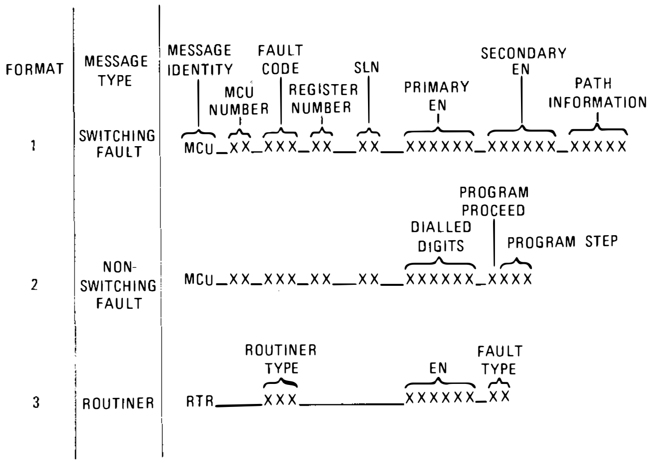
FPO transfer store in 2-out-of-8 parallel form. From this store, each character is read out serially at a speed of 75 bauds or 50 bauds, coded into International Alphabet No. 2, and passed to the exchange teleprinters. Up to 3 teleprinters can be provided for each FPO, depending on the size of the exchange.

Format of Fault Print-Out Messages

All print-out messages are prefixed by a 7-digit exchange identity code, followed by a 3-letter code to identify the message type. The exchange identity code defines the exchange type (TXE4), the Telecommunications Region and the exchange; this permits the exchange to be identified on a national basis when the print-out is processed centrally. Examples of the format of messages are shown in Fig. 4. Test messages can be printed out when required and are designed to assist in the interpretation of the more complex fault reports. Certain messages (for example, those relating to switching path failure) will be printed out repeatedly whenever a particular path fails to set correctly. The connexion desired may, however, be successfully set up on a repeat attempt. Such switching faults can be tolerated by the system and do not require immediate maintenance action. In such cases, to avoid repeated fault messages, a print-out restriction facility is provided, whereby certain message categories, defined by the hundreds digit of the fault code, can be restricted. The number of messages in a particular fault category is counted, and further print-out inhibited when the number exceeds a pre-selected limit. The restriction can be reset automatically on the hour or every 24 h and can be completely inhibited during any maintenance activity. A similar option is available to restrict seizures from any particular MCU.

Computer Analysis of Fault Print-Out

From a print-out that identifies a switching fault (Fig. 4, format 1) it is possible to ascertain the primary and secondary



Note: The MCU fault-code messages are categorized and identified by the fault code hundreds digit. The sequence location number identifies the stage reached in call setting-up process by the MCU program

SLN—sequence location number
EN—equipment number

FIG. 4—Format of fault print-out messages

equipment numbers (ENs) and the plane connexions used in any instance of path failure. Such messages, relating to crosspoint failures in the system switching network, do not require immediate action, but are analysed collectively by comparison of different paths and ENs printed out on a number of similar messages. This method of analysis establishes a common recurring failure pattern that may lead to the identification of a particular cross-point fault within the switching network. In TXE4, this analysis is performed by batch-process computing, using a paper-tape produced by the exchange teleprinter. Before analysis, the computer program separates the print-out associated with switching network faults from the other messages which are not subject to computer analysis. All the switching-network fault print-outs are collated and the individual crosspoints used in each faulty path identified. An appearance count is maintained against each crosspoint, and since only the potentially faulty crosspoints will continually appear in the print-out, the count against these will increase at a faster rate than those against non-faulty crosspoints used in the failed paths. Each count is compared with a predetermined failure threshold level and, when this is exceeded, the counts of all crosspoints of that particular switch are printed. The print-out is a representation of the suspected faulty switch-matrix, and a typical example of a print-out is shown in Fig. 5 which shows a switching-fault print-out count for B-switch 5 on plane 4. Inlets are shown horizontally and outlets vertically, with the number of print-out messages at each crosspoint. In the example shown in Fig. 5, a high count is recorded against inlet 4 that suggests a need for maintenance action. Due to the finite turnround time of the data, faulty crosspoints that have been the subject of one week's fault messages will continue to generate messages for the next week. To prevent failures producing a duplicate print-out at the end of the subsequent processing run, any crosspoint that exceeded the threshold is barred from analysis in the following week. In addition, the analysis provides weekly counts of messages in each category, together with a quantitative breakdown of these on an individual equipment item basis where appropriate. For each exchange, data are also given relating to the exchange identity, dimensions such as number of switching units and planes, and parameters for the fault threshold selected.

```
      048
      UNIT 2.3  PLANE 4  B SWITCH  5
      SEE O/P 064
      FC 11.13
      TIMES 1

      01      02      03      04      05      06      07      08      INLETS

01     1                     151               1               2
02             1              91
03                            98               1               1
04                           150
05                           112
06                           116
07             1             152     1
08                           161
09                           132
10                           121

OUTLETS
```

FIG. 5—TXE4 switching print-out analysis showing example of computer output (B-switch)

Routiners

Routiners are provided for periodic testing of large quantities of similar units, for example, outgoing-junction relay-sets and link circuits. In these cases, continuous checking of an individual circuit would result in an uneconomic ratio of fault detection circuits to functional circuits. Four types of routiner are provided to perform programmed series of tests on TXE4 exchange equipment.

Register Routiner

This routiner performs a sequence of tests on each register in the exchange, and checks that a register will accept dialled pulses within a specified range of parameters and X and Y party discrimination signals. The routiner also checks that a register transmits pulses correctly for calls terminating at a distant exchange.

Link Routiner

The link routiner tests bridge-link and through-link circuits. In the case of bridge-link circuits, the routiner checks that the link circuit can apply a holding earth to the P-wire at both terminals of the link circuit, that ringing current and ring tone can be correctly applied, and that ring trip occurs on receipt of a called-subscriber-answer condition. The ability of a link circuit to apply meter pulses in a specified phase, and to disconnect both positive and negative wires on cleardown, is also checked. For through-link circuits, the ringing current and ring-tone tests are omitted, and a check is made to establish that the link can be split and restored (referred to as *unsplit*) correctly.

Outgoing-Junction Relay-Set Routiner

This routiner tests each outgoing-junction relay-set. Tests are performed on relay-sets providing local-call timing or metering-over-junction facilities, and those using either loop-disconnect or DC2 signalling. The selection of individual tests applicable to a particular relay-set is performed by the MCU routiner program from the cyclic-store information relating to that relay-set. The routiner first checks for the correct operation of a relay-set under primary seizure (when the transmission bridge in the relay-set is bypassed) and secondary seizure (with the transmission bridge in the circuit); these tests check continunity of transmission, line balance, metering and coin-and-fee-check-pulse repetition. In the second part of the routiner tests, the relay-set under test is connected to a distant exchange test number, and the receipt of correct supervisory signals and tones is checked.

Marker Routiner

Markers are routined by setting up a series of test calls between the 2 terminals of the routiner, using first a bridge link circuit and then a through link circuit associated with the markers being checked. The tests check for correct transmission of class-of-service information, seizure of the correct link circuits and detection of busy terminations.

Routine testing is normally performed at night or during periods of light traffic density, and can be started and stopped automatically by a time-switch or under manual control. The automatic facility is generally used at night and the manual facility is useful during the day to retest individual items of equipment found busy during the night routine or after clearance of a fault. Routiners can also be used as a general maintenance aid by arranging for continual routining of a single selected item.

Each routiner is associated with a particular MCU and replaces a single register. When only one set of 4 routiners is provided (which is normally the case), these routiners are associated with the first 3 MCUs. Each routiner is connected to an A-switch outlet, and uses the general purpose switching network to provide connexion between the routiner and the item of equipment to be tested. No special access is provided and the connexions are serially trunked under MCU program control. The MCU associated with each routiner holds a special routiner program that controls the routining process and responds to the routiner START and STOP instructions from the routiner control panel. In addition, each MCU in the exchange is equipped with a register routiner sub-program for routining its own registers. Operation of each routiner is controlled by a set of switches and an APPLY key mounted on the routiner control panel. The switches are used to identify the item or group of items to be routined, the particular mode of the routine and the choice of tests to be performed during any test cycle. The routine test program is initiated either by operating the APPLY key or by a signal at a preset time from the time-switch, causing each routiner to apply to its respective MCU via the calling gate in the cyclic store. After the acceptance of the routiner calling condition, the MCU routes to the routining program for that particular routiner. All the switch settings on the control panel are then interrogated to establish the required mode of routiner operation selected by maintenance staff. The operating modes available for each routiner are shown in Table 1; it is possible to routine test a single item continuously or a group of items with or without print-out.

The item to be routined is chosen by the MCU program which, in association with the markers, sets up the necessary serially-trunked connexion. Thereafter, the routiner performs a sequential series of tests within a predetermined time. If a routine is not successfully completed within the predetermined time set in the routiner program, the routiner is interrogated by the MCU program, and any test failure is printed-out on the exchange teleprinter. While the routiner is testing an item, the MCU is free to process other exchange traffic and checks the progress of the routine cycle via the normal register-processing program.

An example of the interconnexion of a routiner is given in Fig. 6 which shows control signalling arrangements for the link routiner. The routiner START and STOP signals are detected by the MCU call detector via the cyclic-store SOL logic. The MCU program responds to the calling condition from the routiner and interrogates the routiner panel switches to determine the mode of operation, and link circuit identity if appropriate. The MCU program subsequently initiates that part of its routiner program provided for link routining. The link circuit routine cycle is performed by passing instructions to the routiner test control logic via the register instructor. Appropriate link circuits are chosen and serially trunked to the routiner terminal hardware that performs the detailed tests.

Routiner Fault Print-Out

In general, at the start of any particular routine cycle, a print-out is initiated by the MCU showing the type of routine and the identity of the first item of equipment chosen for the routine. Thereafter, a print-out is given for all items found faulty or busy; for a faulty item, 2 additional digits are printed that indicate the type of fault. At the end of the routine cycle, a number is printed which indicates the completion of the routining cycle and the equipment identity of the last item routined. Each routiner also has a PRINT AND PROCEED facility which can be selected on the control panel. This enables maintenance staff to request print-out of the identity of the current item being routined. Hence, at any time during a particular routining cycle, it is possible to assess the progress of the routiner without the need to stop and restart the routiner.

In addition to the TXE4 equipment routiners so far described, a local line insulation routiner (LLIR) is provided to test the insulation resistance of subscribers' lines. The LLIR is controlled by one of the first 3 MCUs in the exchange and replaces a single register. Again, the MCU program controls the sequence of tests to be applied, and a control panel enables manual setting for either automatic or manual operation of the LLIR. The standard of insulation resistance against which the lines are tested can be selected from resistances of 50 kΩ, 250 kΩ, 500 kΩ, 1 MΩ or 2 MΩ; the presence of extraneous voltages can also be detected. The EN of a line that fails to pass the insulation resistance test is printed. The LLIR also has a self-test facility for checking the operation of the unit that applies the various test conditions.

TABLE 1

Operational Facility of each Routiner

Switch Position	Marker	Link	Outgoing Junction	Register
1	STOP	STOP	STOP	STOP
2	All from specified Mkr	All from specified link	All from specified RN	All from specified MCU
3	All from last Mkr routined	All from last link routined	All from last RN routined	All from last MCU routined
4	One U value once	All links of one unit once	One RN once	All registers of one MCU once
5	One Mkr once	One link once	One EN once	One register once
6	One Mkr 10 times †	One link 10 times†	One EN 10 times†	One register 10 times†
7	One Mkr continuously†	One link continuously†	One EN continuously†	One register continuously†
8	One Mkr continuously‡	One link continuously‡	One EN continuously‡	One register continuously‡
9	One Mkr†	One link†	One EN†	One register†
0	Print and proceed	Print and proceed	Print and proceed	Print and proceed

†—with camp-on-busy
‡—without print-out
RN—route number
Mkr—Marker

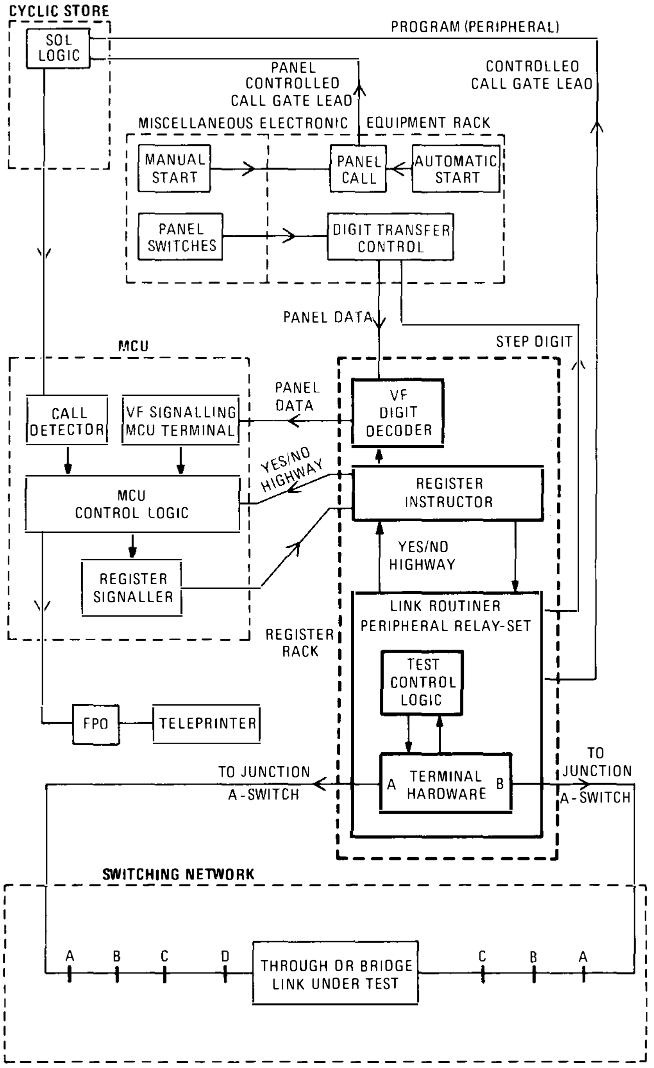


FIG. 6—Link routiner (control signalling arrangement)

Call-Trace Facility

A call-trace facility is provided to identify both terminations of a connexion and the path through the switching network when only one termination identity is known. Call trace is initiated by operating the CALL TRACE key and dialling the 6-digit EN of the known termination. To an MCU, the call-trace equipment appears as an incoming junction with a call-trace class-of-service. This enables the MCU to establish an overlay connexion between the call-trace panel and the known termination. The call-trace circuitry, in conjunction with the odd-plane marker used to set up this call-trace overlay connexion, identifies the odd marker involved in the original connexion to the link circuit by applying +12 V to the P-wire and an earth signal to all odd markers in the exchange via the call-trace access wires. Coincidence of these signals occurs only at the odd marker required, which then sends an identifying signal to the call-trace unit. The particular link circuit used in the connexion is also identified in a similar manner. An earth signal is applied to all the link circuits served by the odd marker concerned, but only the link circuit concerned responds to the +12 V signal on the P-wire. The link circuit and odd marker are accessed by the call-trace equipment, and the odd-plane marker of the overlay connexion is released. The sequence is repeated to identify the required even-plane marker by applying +12 V from the odd-plane marker via the link circuit already identified. An earth signal is applied simultaneously to all even-plane markers and coincidence occurs at the required even-plane marker. The odd-plane marker then applies suitable potentials to the hold-wires to enable the interrogators to identify the path used. The path information is decoded by the call-trace circuit to derive the EN of the unknown termination, which appears as a lamp display; the 2 ENs are also printed on the exchange teleprinter. A similar process occurs when path trace is requested; the path information is displayed on a lamp display and is also printed, but the EN is omitted. The complete call-trace sequence prior to print-out takes approximately 600 ms.

TXE4 Testers

The information provided by alarms, print-out and computer analyses enables a particular item of the common control to be identified when faulty, and also gives an indication of the particular failure involved. To assist further diagnosis, testers are provided as maintenance aids. The MCU tester enables the maintenance personnel to cycle through, stop at, or start from, various program steps in the MCU program, and indicates the contents of selected MCU stores on a lamp display. Testers are also provided for the detailed fault analysis of the SPU and marker. Except for the MCU tester, which is provided as an integral part of the MCU, all the other testers are either trolley or bench mounted.

Miscellaneous Maintenance Facilities

Parked Lines and Faulty-Junction Identification

Facilities are incorporated in the TXE4 design to allow maintenance personnel to request a print-out of parked lines or faulty junctions. Each facility is provided by instructing the MCUs to examine the information in the cyclic store, and scan and identify those terminations having the appropriate SOL.

Outgoing-Junction Fault Alarm

This equipment is provided on a route basis to monitor the continuity of outgoing junctions. The alarm circuit is arranged so that a PROMPT alarm is raised if a pre-set number of junctions in that route/group become faulty. The number of junctions allowed to become faulty before a PROMPT alarm is raised can be adjusted between 2–11.

Test Access

Test access is used to provide a test connexion from the test desk to a subscriber or an outgoing-junction circuit. The test desk may be situated locally or in a remote exchange, and connexion to a subscriber can be made by dialling either the subscriber's directory number or the EN. For outgoing junction relay-sets, test access is possible only by dialling the EN. When test access is requested, the calling condition from the test desk appears as an incoming junction with a test-access class-of-service to an MCU. The MCU then connects the test desk to the required equipment, regardless of whether it is free, busy or parked.

Diagnostic Manual

The TXE4 system handbook and maintenance instructions have been supplemented by a diagnostic manual. This was prepared following a study into the failure modes and predicted fault rates of each component within each functional area. The following are examples of some of the information contained in the diagnostic manual:

(*a*) the fault rates of individual circuit elements, the relative probabilities of causing a failure condition, and how the failure can be recognized,

(*b*) procedures for locating system failures to plug-in-unit level where possible,

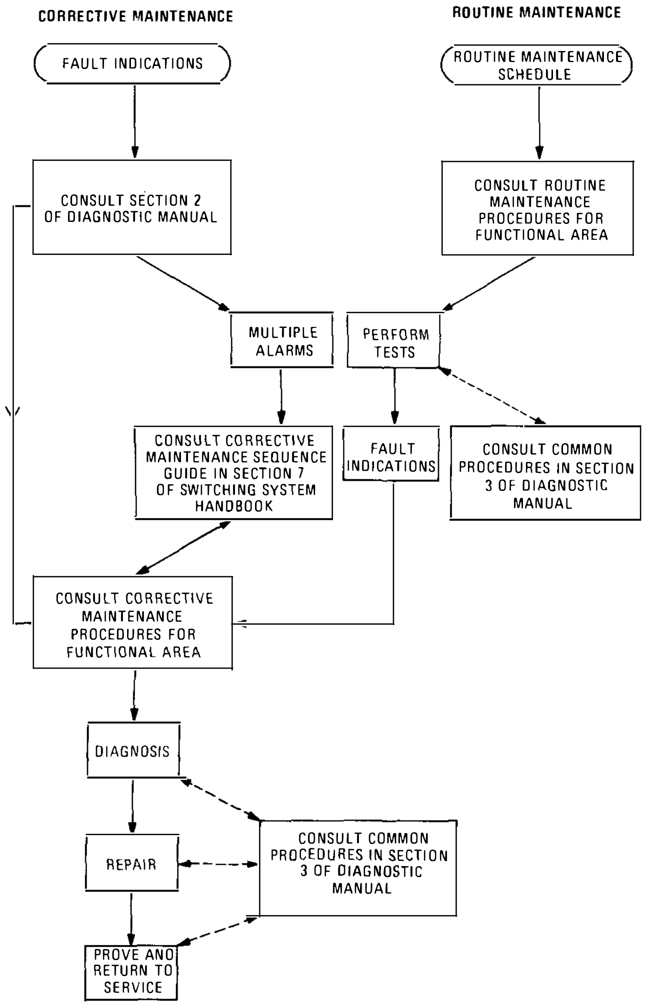


FIG. 7—Flow chart illustrating the use of the diagnostic manual

(*c*) a recommended procedure for dealing with a multiple alarm situation, and

(*d*) routine maintenance procedures to prevent the build-up of undetected faults.

The diagnostic manual is divided into sections, each covering a different aspect of maintenance. During the study, failures of each circuit element were traced through the system to establish the effect on the monitoring and alarm equipment. Where more than one logic-gate or unit failure could produce the same symptom, the relative failure probabilities were examined to identify a preferred sequence of fault localization.

Use of the diagnostic manual enables maintenance personnel to work systematically from the alarm and fault print-out information to identify the actual location of a fault; in most cases, to a plug-in-unit card. A flow chart illustrating the use of the manual is shown in Fig. 7. The fault diagnostic manual also lists routine tests to be performed on all check circuits to detect any dormant faults.

CONCLUSIONS

The use of a modular approach to equipment provisioning allows growth of both the switching network and common control to be achieved in economic steps, and has the additional advantage that many types of equipment failure can be tolerated without loss of service to any subscriber. Comprehensive fault-monitoring and reporting equipment forms an essential part of the fundamental TXE4 design and this, together with a full range of maintenance aids, ensures that any failure can be quickly detected and diagnosed.

References

[1] GOODMAN, J. V., and PHILLIPS, J. L. TXE4 Electronic Exchange System, Part 1—Overall Description and General Operation. *POEEJ*, Vol. 68, p. 196, Jan.1976.

[2] PHILLIPS, J. L., and ROWE, M. T. TXE4 Electronic Exchange System, Part 2—Design of Switching and Control Equipment. *POEEJ*, Vol. 69, p. 68, July 1976.

Book Review

Sir William Preece: Victorian Engineer Extraordinary. E. C. Baker, M.B.E. Hutchinson Publishing Group. xiv + 377 pp. 33 ills. £6·50.

Edward Baker's biography of Sir William Preece, third Engineer-in-Chief of the British Post Office (BPO), provides BPO people with an important part of their family history. Preece was, by contemporary consent, Victorian Britain's outstanding engineer.

He enjoyed the optimistic promise, the glow of intellectual well-being, and the warmth of inventive achievement that was the lot of engineers of his time. Not for him the cynicism and the destruction-without-betterment of Christian and humanist values, and the dismal ambience of much of present-day Britain.

In 1854, within weeks of joining the Electric Telegraph Company (ETC) at the age of 20, Preece worked with the ETC's Assistant Engineer and Sir George Airy, the Astronomer Royal, in experiments using the telegraph link between London and Paris via the 1851 submarine cable, with the object of more accurately determining terrestrial longitude. Effects of induction bedevilled the work and brought in Michael Faraday; later, Preece became his assistant.

Sir William Thomson (later, Lord Kelvin) also strongly influenced Preece with his view that the life and soul of science was its practical application, the desire to solve practical problems having led to great advances in mathematics—"the only proper language of engineering". With physical science, mankind's greatest advances had resulted from the desire to turn knowledge of the properties of matter to useful purpose.

Faced in 1882 with breakdowns of submarine cables across the Solent, Preece became the first to put the phenomenon of leakage (as demonstrated by Samual Morse and James Bowman Lindsay of Dundee) to commercial use. He immersed copper plates at each end of gaps caused by cable failure off Ryde Pier and Sconce Point, so restoring the circuit and enabling transmission of Morse-code telegrams between Newport (Isle of Wight), Southampton and Portsmouth.

Preece studied electromagnetic induction between parallel wires. Later, in February 1892, a report that Edison had sent telegraph messages without wires enabled Preece to winkle £100 out of the Treasury. He built a pole line carrying two 400 lb/mile copper wires (earthed at each end) along the cliffs at Lavernock, Penarth. In November, messages in that "wireless" circuit were reproduced in parallel insulated copper wires erected 5 km and 8·6 km distant on Flat Holm and Steep Holm islands, confirming that wireless telegraphy was feasible.

In July 1896, 22-year-old Guglielmo Marconi visited Preece, who had Marconi's equipment improved and demonstrated at BPO headquarters. Preece's headquarters staff numbered less than 30, but included engineers whose qualities embraced the ability to analyse and improve apparatus new to them. Preece sent one such engineer, H. R. Kempe, with Marconi to Salisbury Plain for tests that resulted in major improvements to both apparatus and aerial.

Others, including Oliver Lodge, disparaged Marconi and his 1896 patent, but Preece testified, "Marconi has produced from known means a new electric eye more delicate than any known electrical instrument, and a new system of telegraphy that will reach places hitherto inaccessible".

Published by Hutchinson at £6·50, this encyclopaedic book is compulsory reading. Read it; it is part of your heritage.

A. H. WILLITT

Network Synchronization

R. A. BOULTER, B.SC., C.ENG., M.I.E.E., and W. BUNN, B.SC.†

UDC 621.395.74:621.395.345

In an integrated digital transmission and switching network, it will be essential that the timing of the switching and multiplexing functions at the switching centres are controlled to closely defined limits. An article,[1] *published in this Journal in 1971, reported on work done by the British Post Office (BPO) Research Department towards establishing the feasibility of using a synchronized method of operation to control the frequency of telephone exchange timing units. The BPO has since decided to adopt a synchronized method of control. This present article reviews the argument leading to that decision, and includes description of proposals relating to network topology, the synchronization equipment and its operation.*

INTRODUCTION

The British Post Office (BPO) has used pulse-code modulation (PCM) since 1968, when 24-channel systems, operating at a bit rate of 1·536 Mbit/s, were first used to provide junction circuits, and subsequently main-network circuits. Soon, 30-channel PCM line systems operating at 2·048 Mbit/s will be introduced, and will eventually form the basic multiplexing unit of the main-network digital transmission hierarchy,[2] and will supersede the 1·536 Mbit/s system. Further higher-order multiplexed digital systems are being considered, operating up to a maximum transmission rate of around 500 Mbit/s, including 120 Mbit/s line systems that are at present undergoing trials.[3,4]

When digital transmission links are used to provide circuits between space-switched telephone exchanges, then analogue-to-digital converters and digital-to-analogue converters are required at the interface of each exchange. A family of digital main-network switching centres is proposed for the future and these, together with the transmission proposals will result in an integrated main network of digital switching centres and transmission links, in which the analogue-to-digital and digital-to-analogue, conversions will be performed at local-exchange level or possibly, in the distant future, at the telephone instrument.

At the present time, the transmission rate of a digital line system is governed by a crystal oscillator in the multiplexer; the demultiplexer uses clock-extraction principles to derive an identical clock, thus ensuring that no problems arise due to clocking differences at each end of the line system (each direction of transmission is independent). In an integrated digital network, the transmission rate of the line systems radiating from an exchange will be governed by an exchange timing unit (TU); this is a reliable frequency source, operating with a tolerance of ± 3 parts in 10^7 on the uncontrolled frequency. If clocking difficulties due to this frequency inaccuracy are to be avoided, the mean frequency difference between any 2 TUs must be controlled such that it is zero, in which case the network is said to be synchronous.

To demonstrate the technical feasibility of providing a synchronous network, 5 TUs with their associated synchronization equipment were built in the BPO Research Department and a field trial carried out in the London area in 1971.[1,5] Since that time, an extensive test-bed facility, composed of 10 TUs and their associated synchronization equipment, has been established at the BPO Research Centre at Martlesham Heath, where the problems of satisfactory operation under various fault conditions have been closely studied. This article describes the arguments that have led to the decision to implement a synchronous digital network and the envisaged structure of that network, together with a brief description of the synchronization equipment required in each exchange. Since it is essential that the network should remain controlled and predictable in the presence of faults and local disturbances, the article finally describes the operation of the synchronization system under various fault conditions.

THE NEED FOR SYNCHRONIZATION

If the TUs are not synchronized, the information rate of a signal coming into an exchange will be different to the rate at which the exchange can process this information and retransmit it. Inevitably, information must be either lost (if the input rate is faster) or repeated (if it is slower), resulting in a distortion of the original analogue signal or errors in a data call. This process is known as *slip*, and if the unit of information that is deleted or repeated is a complete PCM frame, this is known as *frame slip*. Slips will occur at each switching point in the integrated network at a rate proportional to the frequency difference between the incoming and outgoing PCM streams, and the resulting performance degradation of the circuits could be unacceptable. The purpose of synchronization in the digital exchange is, therefore, to prevent this regular occurrence of frame slip on digital circuits.

In deciding whether to provide a synchronous network rather than an asynchronous network, 4 main factors have to be considered. These are the effect on

(*a*) the quality of service to be offered to the customer,
(*b*) the technical feasibility of the alternatives,
(*c*) comparative costs, and
(*d*) international implications.

Quality of Service

The effect of slips upon the quality of service experienced by a customer depends on the type of service the customer is using; for example, telephony or data. Considering the telephony customer, every time a frame slip occurs a complete speech sample of 8 bit is lost (or repeated) simultaneously on 30 channels. Whether the customer hears this as an audible click will obviously depend upon the signal and when the frame slip occurs, and it has been suggested that only 1 in 25 slips results in an audible click.[6] The possible number of frame slips depends upon the number of digital exchanges in a connexion path. In the UK, a 3-level routing hierarchy is to be adopted for the integrated digital network. Thus, a maximum of 5 links could be encountered between main-network switching centres, giving a total of 7 points at which

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† Research Department, Telecommunications Headquarters

slip can occur if digital local exchanges are included. No subjective measurements have been made in the BPO to suggest what may be an acceptable degradation due to slips but a slip rate of 300 slips/h has been suggested[6] as tolerable. It can be shown that, if there is an equal probability that the frequency of a TU can lie anywhere between the maximum permitted frequency difference of ±3 parts in 10^7, then the average frequency difference between any 2 TUs will be equal to two-thirds of this maximum. If there is a total of 8 digital exchanges in the connexion path, then the frame-slip rate would be

$$7 \times \frac{2}{3} \times \frac{3 \times 10^{-7} \times 2{\cdot}048 \times 10^{6} \times 3600}{256} \approx 40 \text{ slips/h}.$$

If only 4% of these were ever noticed by the customer, then the number of noticeable slips is between 1–2 slips/h.

Should a frame slip occur during the setting-up of a call its effect will depend on the type of signalling used. In-band voice-frequency or multiple-frequency signals conveyed in digital time-slots would suffer only slight distortion to one cycle of a tone burst, which in isolation would not prevent their correct interpretation. The effect on signals in time-slot 16 could be more pronounced depending upon the signalling format used. If a multiframe structure is used, as in the present 30-channel PCM format, then multiframe alignment will be lost, causing a burst of errors in time-slot 16 lasting up to 5 ms, which in turn could cause failure of calls that are in the process of being established. In a common-channel signalling system, messages are conveyed in signal units, and error control is provided by incorporating redundant coding in the signal unit for error detection, while correction is provided by retransmission. A frame slip will cause the loss of several signal units as well as loss of alignment in the receiver, which would then result in the detection of errors in the following signal units. These will then be retransmitted, together with any signal units lost during the slip, and so it is unlikely that call failures will occur.

The acceptable degradation due to slips has not been specified for the data customer; several criteria have been suggested for specifying the performance of a data link. One method has been to specify the mean error-rate performance, but since a large proportion of errors occur in bursts (of which slip is one particular type of error-burst), and as data customers often send blocks of information with error-detecting codes which facilitate block retransmission, this method does not seem appropriate. A more appropriate criterion of performance appears to be the concept of the *percentage of error-free 1 s intervals* (EFS), since this will be a direct indication of circuit efficiency. A figure of 99·5% EFS has been suggested as a desirable operational objective with 99·9% EFS being the objective when all errors other than those due to slip are ignored.[6]

Assuming the same parameters previously considered for the telephony circuit that gave 40 slips/h, then there are forty 1 s intervals containing errors in an hour. Therefore,

$$\text{EFS} = \frac{3560}{3600} \times 100\% = 98{\cdot}88\%, \text{and}$$

the desired objective of 99·9% EFS is not achieved. To achieve this figure with the same TU, the oscillators would require retuning every 40 d. This presupposes that it is possible to retune the oscillators to the required accuracy.

Technical Feasibility of Retuning

Periodically, the oscillators in the TU would need to be retuned to counteract the effect of ageing. For this purpose a more accurate frequency source must be available for reference purposes. In a synchronous network, the oscillators can be manually retuned to the network since there is an absolute reference at the highest level in the routing hierarchy, however, in an asynchronous network, retuning would not be so easy. The asynchronous network could still be used, provided that there was a reference exchange somewhere in the highest level of the routing hierarchy, and there were only a few exchanges between the oscillators and that reference. Retuning would then involve the tuning of the oscillators in an exchange to those in the level above via the digital PCM paths between them. Exchange oscillators would then need to be adjusted in a planned order with the oscillators at the highest level being retuned to the reference first. If it were assumed that the accuracy of the retuning required was at worst 10% of the total drift allowed in the time between retuning, then a setting accuracy of 3 parts in 10^8 would be required to the absolute reference. This means that a setting accuracy better than 1 part in 10^8 would be required at a digital local exchange due to the tuning inaccuracy accumulated in the 3 other exchanges between it and the absolute reference. This figure is not unreasonable, and is the accuracy to which it is expected the oscillators in the TU can be adjusted. However, as soon as the time between retunes is reduced, a comparable improvement in the setting accuracy is required; a 40 d period between retunes would require a setting accuracy of better than 1 part in 10^9. Also, as the setting accuracy is improved, problems may arise due to the imperfections caused by the digital paths.

A second method of retuning would be to use portable oscillators of good frequency stability to act as references. These could then be taken from exchange to exchange as retuning was required, but unless the oscillators were caesium standards, they themselves would need retuning to maintain their accuracy. Alternatively, a reference signal could be distributed throughout the country in a manner similar to that used on the frequency-division-multiplex (FDM) network.

A third method would be to provide a frequency source of caesium standards, they would need retuning to maintain their accuracy. Alternatively, a reference signal could be distributed tyroughout the country in a manner similar to that used on the frequency-division-multiplex (FDM) network.

Comparative Costs

The quality of service offered to a customer by an asynchronous network that used TUs would be susceptible to the impairments described; that is, 40 slips/h for telephony and an EFS of 98·88% for data. If these impairments were acceptable, as well as the method of retuning, then obviously an asynchronous network would be cheaper than a synchronized network by the cost of the synchronization equipment. However, any improvement in the quality of service offered by an asynchronous network would carry a cost penalty that could be offset against the cost of the synchronization equipment. Such additional cost could include the cost of manually retuning the oscillators more often (mainly labour costs), or the cost of an improved TU in each exchange, or perhaps both. With present cost trends, it should be remembered that future capital costs of digital equipment are likely to decline significantly in real terms. Therefore, the comparative costs depend almost solely on the quality of service that is to be offered to the customer.

A further cost saving could be made in the transmission area as a result of having a synchronous network. At present, higher-order digital systems are required to provide extra capacity for justification in order that no information is lost due to the variations in transmission rate of 50 parts per million in the lower-order multiplexers. For èxample, an 8·448 Mbit/s digital link is required to accommodate four 2·048 Mbit/s digital streams; an extra 256 kbit/s is thus required. If the 2·048 Mbit/s digital streams were synchronous, they could be carried on an 8·192 Mbit/s digital link, or alternatively an 8·448 Mbit/s digital link could carry extra channels. In both cases, the design complexity of the multiplexer could be reduced.

International Implications

It has been proposed, internationally, that all digital international links should operate plesiochronously to an accuracy of 1 part in 10^{11} to maintain the slip rate below one slip every 70 d.[7] This proposal has assumed that slips in a national network will be as good, or better than this, thereby implying a national synchronous network or a plesiochronous network to an accuracy of 1 part in 10^{11}. (Consideration is also being given to an international synchronous network.) Similarly, a digital hypothetical international connexion has been recommended[8] with a design objective for a mean long-term error rate of better than 1 in 10^5 due to random distributed errors, and proposals have been made for a design objective error rate on a European data hypothetical reference connexion of 2·5 in 10^6. Each of these recommendations assumes a minimal error contribution due to slips in the international and national networks.

NETWORK TOPOLOGY

Present indications are that the BPO integrated digital national network will consist of *digital main-network switching centres* (DMNSCs) and *digital international switching centres* (DISCs). In the foreseeable future, it is expected that digital switching will become a possibility at local-exchange level. In addition to these telephony switching centres, *data switching exchanges* (DSEs) are also envisaged. All these switching centres will be connected by numerous 2·048 Mbit/s digital paths, and it is via a limited number of these paths, designated *synchronization links*, that synchronization will be achieved.

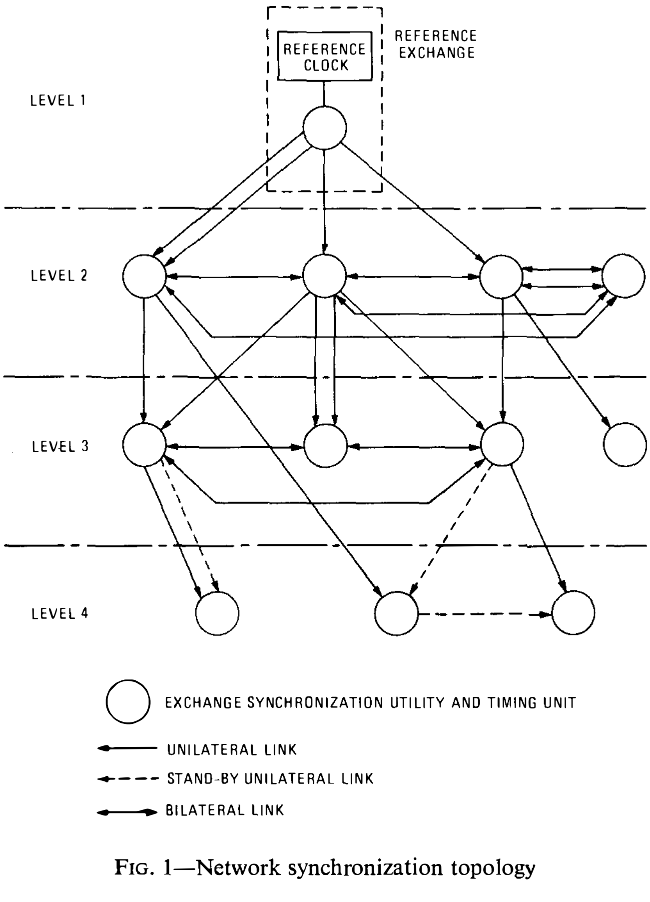

FIG. 1—Network synchronization topology

For the purposes of synchronization, digital switching centres will be divided into 4 hierarchical levels as shown in Fig. 1, level 1 being the highest in the routing hierarchy. A synchronization link will not necessarily influence the frequency of both TUs to which it is connected. Those synchronization links that have one effective and one non-effective end are called *unilateral links* (with control being applied only to the TU at the effective end), and links that have both ends effective are called *bilateral links*. Synchronization links between switching centres in different levels will be unilateral (with the effective end in the lower level), while links between switching centres in the same level will be bilateral. It is necessary to incorporate unilateral links into the system to avoid long chains of bilateral links that, under fault conditions, can be overburdened with control information and cause further failure in the system. The effect of using unilateral links between levels, with control acting only on the lower level, is to make each level self-sufficient and able to act as a unified whole that could take control of all the lower levels should the level above be destroyed in its entirety.

There will be a single level 1 exchange with a TU locked to a secured local caesium frequency standard (called a *reference clock*). This exchange will be the *national reference exchange* and will be capable of participating in international synchronization, and will probably be an international gateway exchange; all national synchronization links radiating from it would be unilateral. The remaining international exchanges, and the most significant DMNSCs and DSEs will be level 2 exchanges, most of which will have direct links to the level 1 reference exchange. Level 3 will contain the remaining DMNSCs and DSEs, while level 4 will contain all local exchanges that have at least one stage of digital switching.

The following topology rules are considered desirable to ensure a coherent synchronization network, even in the presence of link or exchange failure:

(*a*) an exchange can have effective synchronization links only from other exchanges in the same level or higher levels,

(*b*) control between levels will be unilateral from the higher to the lower level,

(*c*) control between exchanges in the same level will be bilateral,

(*d*) most level 2 exchanges will have unilateral synchronization links from the level 1 reference exchange,

(*e*) every level 2 exchange should be connected to the level 1 reference exchange via no more than 2 synchronization links in tandem,

(*f*) level 2 exchanges must have a minimum of 4 effective synchronization links, arranged such that a coherent level would exist to take over control of the synchronization network in the event of a level 1 failure,

(*g*) level 3 exchanges must have at least 3 effective synchronization links of which at least one must be from a higher level,

(*h*) level 4 exchanges should have at least 2 effective synchronization links from higher levels, but when there is only one link available, it would be permissible to have a second link to another level 4 exchange,

(*i*) where suitable 2·048 Mbit/s digital paths are not available, an exchange may have *spur* status by having only one effective link. This link may be from a level 1, 2 or 3 exchange that satisfies the above rules, and

(*j*) extensions off a spur will only be allowed in the case of digital local exchanges (level 4).

The above topology rules may not all be met during the early stages of network growth and, in such cases, prime consideration should be given to the security of the synchronization network, particularly under link-failure conditions. Where effective synchronization links cannot be independently routed, additional links may have to be provided to ensure that the synchronization reliability at that node achieves the desired figure of 0·01 failures per annum.

The reference clock should be provided during the initial stage of implementing the synchronization network; this will probably mean siting it at a level 2 DMNSC. The reference clock interface is nearly compatible with that of a synchronization utility; thus few special provisions will need to be made at the DMNSC initially chosen to be the reference exchange. When the reference clock is moved to its final location, in a main international gateway exchange, the topology at the top of the network will need to be rearranged, and this can be done within the synchronization equipment without affecting traffic.

Synchronization links will be designated in accordance with a *synchronization network master plan*, which has been based on the size and location of digital exchanges and on the network topology requirements described above. The number of links coming into an exchange and affecting the control of its TU (effective links) will not exceed 15, depending upon the exchange's position in the synchronization hierarchy and its physical location. The maximum number of non-effective synchronization links at an exchange (that is, those links having an effect at the remote end, but not controlling the local clock) is 33. The total number of synchronization links at one exchange will not exceed 40.

THE SYNCHRONIZATION UTILITY

Each DMNSC, DISC and DSE will be equipped with a *synchronization utility* (SU) connected to the designated synchronization links terminating at the exchange and to the exchange TU. The SU will derive information from the synchronization links to control the frequency of the TU, and thus maintains it in synchronism with the rest of the network.

The SU compares the phase of the local TU with that of the incoming digital streams on the synchronization links. If the phase is changing, the SU sends a control signal to the TU causing a temporary frequency change by a predetermined amount. The frequency change involved is large enough to ensure that the direction of phase change of the TU, relative to the network, is reversed. The SU can cause such a correction every 16 ms, thus ensuring that the mean phase of the TU remains constant relative to the network.

To avoid false operation, when the phase of the incoming PCM streams change due to seasonal effects, the double-ended method of synchronization is used. This means that phase comparisons are carried out at both ends of the link and control is sought only when the comparison indicates that the TUs at each end of a link have moved apart in phase. This implies a signalling capability between both ends of the synchronization link, and this is provided by using digit 5 of time-slot zero in the odd frames of the 2·048 Mbit/s digital path.

Synchronization Equipment Units

The SU consists of 3 types of unit; *link control units* (LCUs), one of which is associated with each end of a synchronization link; a *common control unit* (CCU), which combines the information coming from the effective LCUs and passes the appropriate control to the TU, and a *flexibility unit* which enables the appropriate LCUs to be connected through to the CCU. Fig. 2 shows how these units and a TU are connected to the digital exchange and to the digital paths used for synchronization, and how they are replicated for security.

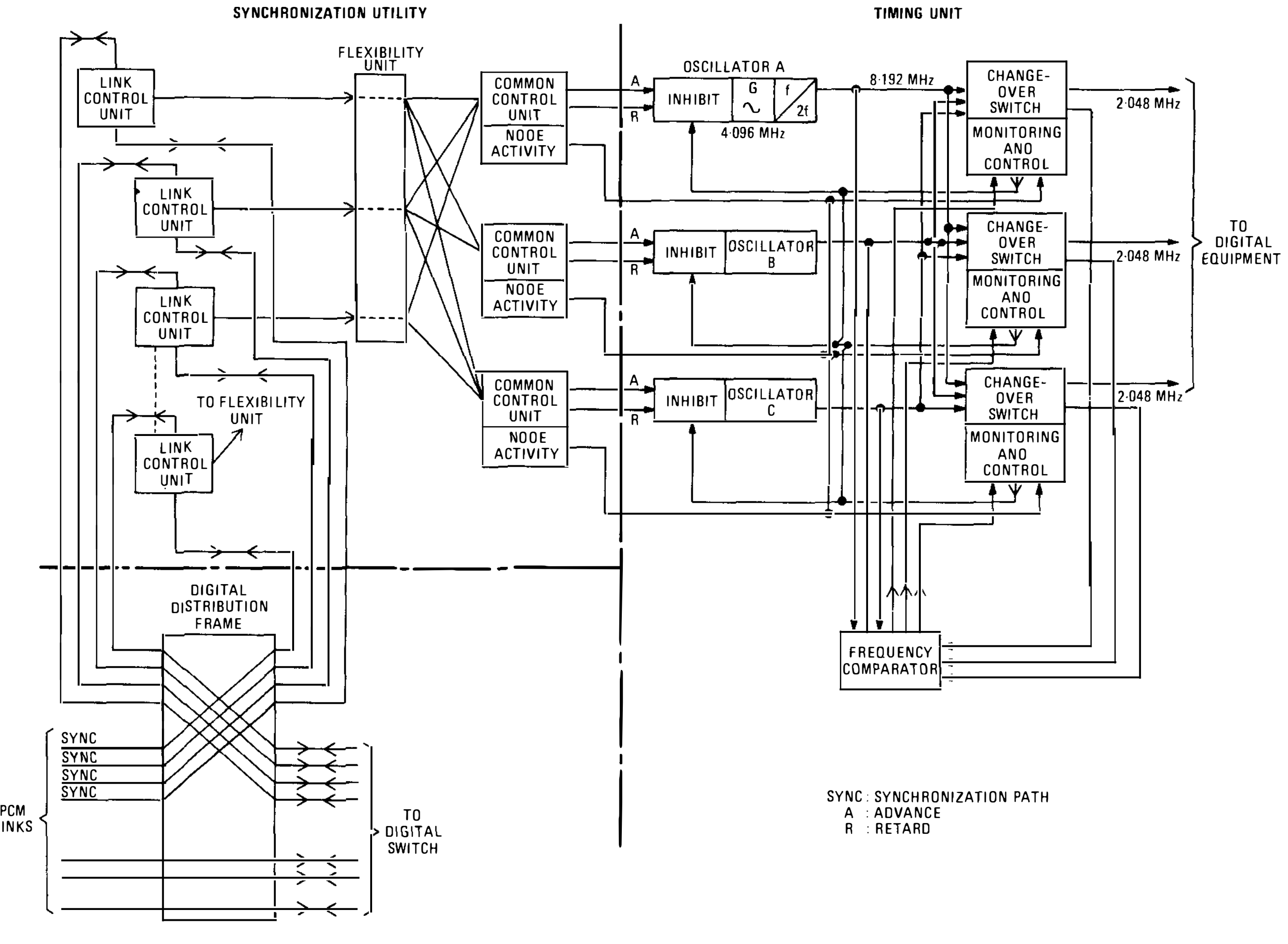

FIG. 2—Synchronization utility and timing-unit security

Although a TU is not part of an SU, the 2 are intimately related for reliability and fault detection purposes. Hence, a brief description of the general structure of a TU is included here with those of the LCU and CCU.

The Link Control Unit

The incoming 2·048 Mbit/s digital path used for synchronization is passed via the digital distribution frame into an LCU in the SU, and is divided to give 2 identical signals. One signal goes to the digital switch via the digital distribution frame; the second is decoded from HDB3,[9]† to binary in the LCU, and monitored for the *frame-alignment pattern* which appears in time-slot zero of the even frames. A remote *frame-alignment signal* (FAS) is generated each time the pattern is recognized, and a flywheel circuit is incorporated to generate this signal during the alternate frames which do not have a frame-alignment pattern. This circuit is also used to generate a remote FAS when the frame-alignment pattern from line is not recognizable due to line errors. If the frame-alignment pattern is not recognized on 3 consecutive occasions, a *loss of frame alignment* signal is generated to indicate failure. This signal will then persist until the normal sequence of a correct frame-alignment pattern, an absent frame-alignment pattern and a correct frame-alignment pattern, is detected in 3 consecutive frames.

Every 125 μs the phase of the remote FAS is compared with the phase of a local FAS which has been derived in the LCU from the outgoing 2·048 Mbit/s path in a similar manner. The absolute value of the phase difference is of little importance since the SU is looking for changes in phase. Consequently, it is possible to introduce a reset operation which, when invoked, sets the phase-difference measurement to the centre of its range. In this way, only a small range of apparent phase differences need be catered for, and only 8 bit are needed to specify the phase difference to within 0·35°. The reset operation is used when a link is brought into service or when there has been a significant change in the phase of the remote FAS; for example, when a synchronization link is re-routed. The number that must be added to the measured phase difference to set it in the centre of its range, is called the *modifier* and each LCU has facilities for calculating a new modifier when requested, and for storing its value. All further reference to phase difference in this article will imply the modified value unless otherwise indicated.

The digitally encoded phase-difference measurement is then processed in a digital filter that reduces the high-frequency variations in the measurement caused by jitter on the remote FAS arising out of the characteristics of the digital line system. The filter has an attenuation characteristic of $20 \log [\sin (\pi f/62\cdot5)/(\pi f/62\cdot5)]$ dB in the range 0–4 kHz. The local phase-difference measurement is then subtracted from the remote phase-difference measurement which has been transmitted over the signalling channel from the remote end. Local control signals and an *out-of-limits* signal are then generated as indicated in Table 1. This operation is performed every 16 ms.

The local control signal is reversed, that is, the *advance* control signal becomes the *retard* and vice versa, and is passed over the signalling channel to the remote LCU; simultaneously the local control signal is compared locally with the remote control signal and, if they are in agreement, and if the link is effective at that exchange, the control is forwarded via the flexibility unit to the CCU. The local *out-of-limits* signal is monitored and, if it persists for 0·5 s, the LCU initiates the reset operation and signals the remote LCU to do the same. After the reset operation, the resulting subtraction of the phase-difference measurements should be zero, and the *out-of-limits* signals should disappear.

TABLE 1
Derivation of Local Control and Out-of-Limits Signals

Result of Subtraction (digits)	Local Control Signal		Out-of-Limits Signal
	Advance	Retard	
> -2 and $< +2$	0	0	0
$\geqslant +2$ and $< +4$	0	1	0
$\geqslant +4$	0	0	1
$\leqslant -2$ and > -4	1	0	0
$\leqslant -4$	0	0	1

To enable the various signals to be transmitted via digit 5 of time-slot zero of the PCM channel, they are formed into a 32 bit signalling word that is sent twice during the 16 ms interval between LCU calculations. A suggested format for this word is:

bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13
	O	P	M	M	M	R	A	N	N	N	O	P	2^7	2^6

bit	14	15	16	17	18	19	20	21	22	23	24
	2^5	2^4	2^3	2^2	2^1	2^0	0	1	1	1	1

bit	25	26	27	28	29	30	31
	1	1	1	1	1	1	1

bits 0, 10 and 20–31, form the signalling word-framing pattern,

bit 1 checks bits 2–9 for even parity,
bit 11 checks bits 12–19 for even parity,
bits 5–6 are oscillator control information,
bits 7–9 indicate a *negative acknowledgement* (NACK),
bits 12–19 are the encoded phase-difference measurement, and
bits 2–4 are the reset command signal.

Since the 4 kbit/s signalling channel provided by digit 5 is more than adequate for the information rate required, several checks are incorporated in the signalling word. In the LCU, certain conditions may arise that could cause it to pass false control information to the CCU. To prevent such an occurrence the LCU is declared to be non-operative, and control is prevented from passing to the CCU if any of the following conditions are detected within the LCU:

(*a*) loss of frame-alignment pattern in either direction of the 2·048 Mbit/s digital path,
(*b*) non-recognition of the signalling word-framing pattern,
(*c*) incorrect parity in the received signalling word,
(*d*) conflict of local and remote control signals,
(*e*) local reset error (phase difference between local and received frame-alignment signals not being 180° immediately after the reset operation has been completed),
(*f*) reset operation in progress,
(*g*) control present after reset (control not removed from LCU output after the reset operation has been completed),
(*h*) link out of limit (difference between local and remote counts of 4 or more 2·048 Mbit/s digits), and
(*i*) negative acknowledgement (if faults (*a*), (*e*) or (*f*) above are detected at remote end of link).

The Common Control Unit

The CCU performs 2 main control functions; it combines all the information coming to it from the LCUs, and it monitors various input and output control activities. Control signals (advance or retard) generated by each effective LCU

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† HDB*n* is one class of highly-redundant ternary codes, known as *high-density bipolar*, of the order *n*, where *n* is the maximum number of consecutive zeros in the HDB*n* signal. In this case, $n = 3$

are updated every 16 ms. The CCU examines all these signals and performs a majority-decision function on them. The result (an advance signal, a retard signal or no signal), is forwarded to the exchange TU. This signal causes a frequency change in the TU of ± 1 part in 10^6 (2 Hz) that persists for 16 ms and which is equivalent to an advance or retard in the phase of the clock of 1/30 of a digit.

Several activity counters are incorporated in the CCU to indicate various conditions. A *net activity counter* monitors the rate at which control signals are forwarded to the TU, and every 10 s indicates the net amount of control applied to the TU during the previous 10 s period, expressed as a percentage of the maximum possible number of control signals. Thus,

$$\text{net activity} = \frac{\text{number of advance signals} - \text{number of retard signals}}{\text{maximum possible number of advance (or retard) signals}} \times 100\%$$

This net activity is proportional to the frequency difference between the TU and the network, and when the counter indicates an activity of 33% the natural frequency of the oscillator in the TU is 0·66 Hz off the network frequency. At this frequency variation, the oscillator needs retuning, and so the counter immediately signals the TU to change-over to a stand-by oscillator and indicates that the original oscillator needs retuning. Under normal working conditions the net control activity will increase at approximately 2% per month; thus, intervals between retuning should be in excess of one year. A *consecutive activity counter* checks for consecutive control to the TU over 1·5 s intervals, and passes an oscillator change-over request to the TU if this condition arises. This alarm will be raised if, due to a fault condition, the working oscillator is ignoring the control signals.

Link activity counters monitor control activity on all links coming into the CCU. If the net activity over a 1 s interval reaches at least 95% (nominally 100%), this information is stored locally, together with the sense of the control (advance or retard). If there are 2 links with nominally 100% activity, but in opposing directions, a *reset command* signal is generated by the CCU and passed to both LCUs. This situation can arise when links are switched on (either initially, after a fault, or due to re-routing), when the phase difference between local and remote frame-alignment signals is between 1–2 digits. The *100% link activity* signal is updated at the end of each 1 s interval.

The Timing Unit

The basic unit of the TU is a 4·096 MHz high-quality quartz-crystal oscillator with varactor-diode frequency control, all contained within an oven. It has an electrical tuning range of ± 1 part in 10^6 and an ageing rate of less than 2 parts in 10^8 per month. However, since the failure of the TU causes the loss of all calls through an exchange, an unsecured crystal oscillator of this kind, which has a failure rate of the order of 0·33 failure/year, will not be sufficient. Exact requirements for the reliability of the TU have not yet been defined, but a failure rate of 0·0016 failures/year has been discussed for a DMNSC. The basic oscillator contained within the TU will thus require either duplicating, with provision of change-over facilities, or triplicating with majority decisions or change-over. The solution proposed in Fig. 2 is for triplicated oscillators, with one acting as the worker and the other 2 acting as stand-bys. The reasons for this choice are, briefly,

(*a*) it is the most secure of the 3 main alternatives,

(*b*) triplication with majority decision requires that the 3 oscillators be phase-locked; this introduces problems of interaction when one fails, and presents difficulties in retuning and maintenance—the links between the oscillators also reduce reliability,

(*c*) if the digital exchange is required to work in isolation from a synchronized digital network, 3 oscillators are required to determine when an oscillator goes outside the frequency specification, and

(*d*) oscillators, unlike other spare equipment, cannot be replaced by one from a shelf of spares since they require an initial "burning-in" period of up to 100 d before they settle at the required ageing rate. This means that one of the oscillators in the TU could be out of commission for a long period if a new oscillator was required. The TU meanwhile must still be secured.

The change-over switch in the TU must introduce a no-break change-over from the working oscillator to a standby when initiated by its own loss-of-signal detection mechanism, or on instruction from the SU or a frequency comparator contained within the TU. To facilitate the no-break requirement, the fundamental frequency of the TU (4·096 MHz) is doubled to 8·192 MHz before being applied to the input of the change-over switch. Since triplicated waveforms are required to secure the distribution to the shelves and racks where a majority decision can be made, the change-over switches are also triplicated.

The purpose of the frequency comparator is to monitor the natural frequencies of the stand-by oscillators (to ensure that they are within the control range of the SU) and also to detect when a fault causes the worker to drift significantly off frequency.

Reliability of the SU

The complexity and cost of measures taken to avoid mis-operation of any exchange equipment must be related to the importance of that equipment in the functioning of the exchanges as a whole. Failure of a TU will cause the whole of a digital exchange to stop working, therefore, a very high mean-time between failure is required. However, it is not necessary for a SU to be so reliable since its failure will cause the exchange only to lose synchronism with the network; this will introduce frame slips and so degrade the quality of service to the customer. There are 3 main areas which could cause loss of synchronism; loss of the synchronization links between exchanges, failure of the LCUs, and failure of the CCU. The synchronization links and their LCUs are protected by virtue of their number since, with the majority of faults, all must fail before synchronism is lost. The effects of faults in the CCU are reduced by replication, and since 3 oscillators are required in the TU, a simple and convenient solution is to provide 3 CCUs. The secondary power supplies (which convert the exchange -50 V power supply to voltages needed by the SU) are secured by providing 3 supply feeds, one for each CCU and every third LCU. Thus, a single secondary power-supply failure will cause the loss of one CCU and one third of the LCUs.

As a result of replication of equipment in the SU, the loss of synchronism at an exchange is dominated by the failure rates of the actual synchronization links. The overall requirement is that synchronism should not be lost at an exchange more than once in 100 years.

OPERATION OF THE SYNCHRONIZATION UTILITY

A brief description of the operation of the SU is given under the following conditions:

(*a*) normal fault-free conditions,
(*b*) the introduction of a new link,
(*c*) faults in the link or LCU,
(*d*) faults in the CCU or TU, and
(*e*) failure of the reference clock.

Normal Fault-Free Conditions

The LCU at each end of a synchronization link performs certain measurements and calculations as previously described, and arrives at a figure from which it determines the control signal to be forwarded to the CCU. The manner in which these signals from the LCUs affect the TU can be described by reference to a vector diagram in which 360° represents 1 frame (256 bit). Fig. 3 shows a vector diagram in which vectors w, x, y and z represent the apparent remote frame-alignment signals derived from the phase differences calculated in 4 LCUs, and are shown relative to a local reference vector r representing the local frame alignment signal. Two inner thresholds, A and B, one digit away from r, and 2 outer thresholds, C and D, 2 digits away from r, are used by the system, and these are also shown in Fig. 3. In normal operation all the frame vectors from the LCUs will be within, or just outside, the inner thresholds A and B, causing the appropriate control signals to be generated by the LCUs in accordance with Table 1. Thus, although a majority decision is made of all the control information coming from all the LCUs, in practice generally only one or two links are at threshold and actually controlling the TU. In the example given in Fig. 3, it is vector z which is giving sufficient advance signals to the clock to maintain it in synchronism with the network. The other vectors, w, x and y are within the inner threshold and so do not produce any control signals.

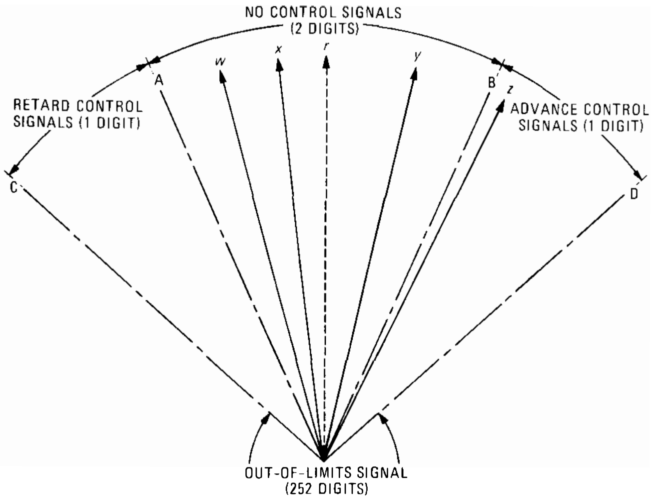

FIG. 3—Vector diagram

The Introduction of a New Synchronization Link

When a new link is introduced, or an existing link is changed, the derived vector can lie in one of 4 different phase sectors, and the action taken by the LCU is different in each case. If the derived vector lies within the inner thresholds, A and and B (Fig. 3), it will either remain stationary, if the TUs at both ends of the link are in synchronism with the network, or it will gradually drift, at a rate depending upon the frequency difference, to threshold A or B where it will cause control to be applied to the TU to correct the frequency difference. If the vector lies outside of the outer thresholds C and D, an *out-of-limits* signal will be produced which, if it persists for 0·5 s, will cause the LCUs at both ends of the link to reset. The resulting derived vector is then coincident with reference r, and lies exactly between the thresholds A and B. The vector will then act as if it had originally been between the thresholds A and B. The third and fourth sectors lie between the inner and outer thresholds. If the vector initially lies between B and D it will generate *100% control* signals in the same direction as the controlling link z. This will cause frequency corrections to be applied to the TU until the new vector reaches the threshold B, the situation will then stabilize with the new link controlling the TU. However, if there is a vector sufficiently near threshold A, such that the phase movement of the TU would cause this vector to go outside this inner threshold, then opposing control signals would be produced by this link. A stable situation would then result with 100% activity on the new link which would be partially opposed by activity on the link at threshold A, the resulting net activity being sufficient to maintain the TU in synchronism.

When the new vector initially lies between thresholds C and A, and is producing 100% activity in opposition to that normally required, it causes the original controlling link (vector z) to increase to 100%. No control is forwarded to the TU, and the TU then drifts until another vector (vector y in Fig. 3) reaches threshold, or until the link activity counter in the CCU detects 2 opposing 100% activities, when it instructs the appropriate LCUs to reset. The 100% activities are removed and both the new and the z vectors then appear coincident with the reference and the TU is controlled by vector y.

Faults in a Synchronization Link or an LCU

Any failure in a synchronization link or the transmit or receive portions of an LCU results in loss of frame alignment or corruption of digit 5 in time-slot zero. This is detected in the form of

(*a*) non-recognition of the signalling framing pattern,

(*b*) incorrect parity check in the received signalling word, and

(*c*) a conflict of the control signals within the LCU.

Any of the above conditions will cause the LCU to be made non-operative, and will prevent control passing forward to the CCU. After a persistence check of 10 s, a deferred LCU fault alarm is raised. The loss of any single LCU in this manner has very little effect on the TU except in certain circumstances when it could cause a phase movement of up to 2 digits in a period of not less than 1·5 s. This can arise if the faulty link happens to be the link that is at the threshold and controlling the TU. The remaining frame vectors are randomly distributed within the threshold, but in the worst case they could all be situated near the opposing inner threshold. When the controlling vector fails, no control is applied to the TU which causes r, and the various thresholds, to drift until one of the other vectors is at the original inner threshold. In this worst case, a relative phase movement of 2 digits results, although in general this phase movement would be less. Only if all links with effective LCUs fail will synchronism be lost at the exchange.

A fault could occur in the LCU such that a permanent control (advance or retard) is sent to the CCU. The effect this has on the TU depends upon whether this 100% control activity is in the same or opposite sense to the net control that would be needed by the TU under fault-free conditions. If the control from the faulty LCU opposes the previous net activity of the SU then the TU will drift until 2 links (that is, a majority over the faulty one) are giving control in the correct direction. A stable situation will then exist, with the original controlling link and the faulty link giving 100% opposing activities, and a third link providing effective control at the threshold. The 100% active links will then be detected and a reset instruction issued by the CCU, whereupon both activities should become zero with their vectors being brought to the centre between the 2 inner thresholds. However, the false 100% activity will not disappear, and this state will be detected and the LCU declared non-operative. If the false 100% activity is applied in the same direction as the net activity required by the TU, the reference vector and its associated thresholds will rotate such that the original controlling vector will come within the inner threshold, and its associated LCU will cease to generate control signals. The rotation of r will continue until one of the vectors reaches the opposing inner threshold and its LCU generates control signals in the opposing direction at a rate such that the net activity, due to the faulty link and the good links, will be as before. The false 100% activity overcorrects the frequency of the TU, requiring opposing activity from the other links. This results in a phase movement of the TU of up to 2 digits, depending upon the relative phase of the other vectors. The situation that then arises is a stable one and the faulty 100% activity will remain undetected until such time as a reset is required on that link.

If a faulty LCU does not give a control signal when required (that is, the control outputs are permanently at zero), the fault will remain undetected unless special routine maintenance to detect dormant faults is performed.

Most calculations made in the LCU are checked with the calculations at the remote LCU, via the signalling channel; any disagreements cause the link to be made non-operative, and if this persists for 10 s, an LCU fault alarm is activated.

Failure in the CCU or TU

A fault in the CCU associated with the working oscillator, giving rise to incorrect activity in excess of 33%, will cause the TU to lose synchronism with the network and the remaining CCUs to have high opposing activity. This condition will then be detected, either by the frequency comparator in the TU if the frequency difference between the working oscillator and the network is in excess of 1·2 Hz, or by the net-activity counters in the CCU if it is less than this, and a change-over is initiated to a second CCU-TU pair.

Incorrect control below 33% of the maximum, including loss of control signals, also causes the TU to lose synchronism with the network. This will be detected in the CCU by a permanent demand for control. If control persists for 1·5 s, change-over to the next CCU-GU pair will be initiated, together with the CCU-TU fault alarm. An LCU produces continuous control signals only during the time its remote frame-alignment signal takes to drift between the inner and outer thresholds, and when the oscillator is 0·6 Hz off frequency, this will persist for at least 1·5 s.

A fault in the TU causing its frequency to increase by greater than 0·6 Hz will be detected, either by the node activity counter in the CCU, or by the frequency comparator. If the increase is in excess of 3·2 Hz, the frequency comparator will detect it by indicating that both stand-by oscillators are off frequency (whereupon it is assumed that the worker is faulty). A frequency change of between 0·6 Hz and 3·2 Hz will be detected by the net activity counters in the CCU and possibly by the frequency comparator. Either or both of these detection mechanisms will initiate a change-over to a stand-by oscillator. The frequency comparator will then indicate that the original oscillator, now on stand-by, requires retuning.

Complete loss of the working oscillator output will be detected by the change-over switch itself and a change-over immediately performed by all the change-over switches.

Failure of the Reference Clock

If the reference clock fails, the network will still remain in synchronism with the TU in the level 1 exchange, but the network frequency will age at the same rate as the level 1 TU (2 parts in 10^8 per month). If the level 1 TU or SU fails, then the network will be mutually synchronized to the level 2 TUs and age in a similar manner. The effect of either of these failures will not initially be felt in the national network but, on international links, the slip rate will probably increase dramatically on failure and continue to increase gradually as the TUs age, until the reference is reinstated. If isolation from the reference clock persists for a long period, the national frequency of some TUs is likely to drift outside the normal control range of ±0·6 Hz from the absolute reference frequency, but may remain within 0·6 Hz of the mean frequency of the level 2 TUs if the natural frequency of the TUs drifts in the same sense. Thus, on reinstatement of the reference clock, a change-over will be initiated, and in an extreme case, all the oscillators in the TU could be outside the maximum control range of 2 Hz and the TU would lose synchronism until the oscillators were manually retuned. If there was a stand-by reference clock located in one of the level 2 exchanges as has been suggested, then this effect can be greatly reduced. If it is known that the original level 1 exchange will be out of commission for synchronization purposes for a long period, the network can then be reconfigured in a relatively short time (less than 1 d) to give the stand-by level 2 exchange temporary level 1 status.

CONCLUSIONS

The BPO is now proposing to implement a synchronous integrated digital network that will ensure that future digital services will not be jeopardized by the regular occurrence of frame slips.

The comparative costs of synchronous and asynchronous networks depend upon the acceptability of slip-induced error performance. There are no internationally agreed requirements at this time, but with the decreasing cost trends of digital logic, synchronization is likely to be a cheaper solution for the performance targets most frequently proposed, particularly those for data.

To achieve high reliability, the synchronization network has to be carefully planned to ensure that the probability of exchanges losing synchronism with the network, or even of forming sub-networks that are not synchronized with the main network, is acceptably low.

The operation of the synchronization equipment under fault conditions has been very carefully studied and several checking procedures have been incorporated. These, together with the replication of equipment in those areas where failure is likely to be most serious, have resulted in a system that will operate satisfactorily, even under severe fault conditions.

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Audio Transmission Equipment

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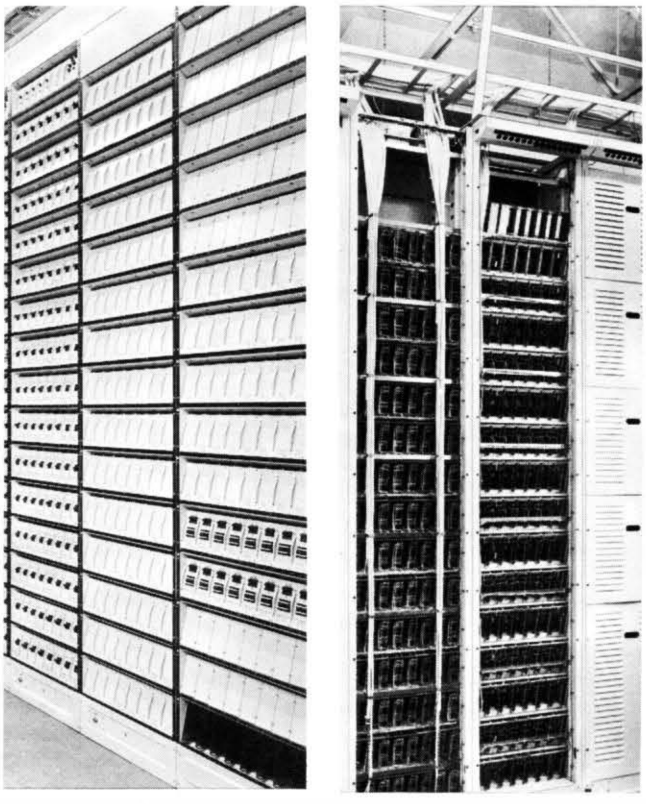
UDC 621.316.1

This article reviews the range of audio transmission equipment currently in use by the British Post Office for public and private circuits provided on pairs in audio junction cables; an outline of the equipment construction and use is included.

INTRODUCTION

Audio transmission equipment is primarily used in association with pairs in audio junction cables to provide junction[1] and main-network[2] circuits and private circuits. This article reviews the equipment used, including 2-wire and 4-wire repeaters, programme (music) amplifiers, private-circuit signalling units, passive equipment (for example, transformers), and a miscellany of specialized items such as data branching units, impedance balance networks, building-out networks and group-delay equalizers. This type of equipment is now usually installed in telephone exchange buildings, often within the same room as the switching equipment, whereas in the past it was mostly installed in buildings or rooms designated as repeater stations. Fig. 1 shows a typical installation of audio transmission equipment.


(*a*) (*b*)

(*a*) Front view
(*b*) Rear view with some covers removed to show cabling arrangements

FIG. 1—Typical installation of transmission equipment

In spite of the use of modern high-circuit-capacity transmission systems, there is still a continuing demand for audio equipment which will reduce only when there is wide-spread provision of digital switching and transmission equipment. At present, the approximate cost to the British Post Office (BPO) of new installations of audio transmission equipment is about £3M/year and the historic cost of existing equipment exceeds £70M.

HISTORICAL BACKGROUND

At the turn of this century, the transmission efficiency of long-distance telephone circuits, which provided trunk services, was dependent on the use of expensive heavy-gauge overhead copper conductors. Inductively-loaded underground cables[3] made some improvement to transmission efficiency, but it was the development of the electronic-tube repeater in the early 1920s that made a significant expansion of trunk services economically possible.

The repeaters allowed a gradual reduction in conductor gauge to take place and, as the cost of the repeaters reduced, standardization to 0·9 mm (20 lb) gauge conducter was achieved by 1930. At that time, most amplified circuits were established on a 4-wire basis.

Over the next 35 years, the advent of carrier and high-frequency coaxial cable systems gradually reduced the use of long audio circuits, particularly on the high-traffic-growth 0·63 mm conductors, and the longer junction circuits used 2-wire repeaters. Many private circuits continued to use 4-wire working.

CONSTRUCTION

The present standard form of construction practice for transmission equipment is designated *62-type* and has been previously described in this *Journal*.[4] The construction is based on a hierarchy of rack, shelf and card-frame units; the racks are 520 mm wide, 450 mm deep, and are available in a range of heights up to 3·23 m.

Shelves

Audio equipment shelves are 152 mm high, and when mounted in a rack, are inclined at 15° to the horizontal. There are 2 basic types of shelf: one accommodates active units that use plug-in connectors, and the other passive units that are permanently wired to the rack cabling. The most frequently used version of shelf accommodates 8 card-frame units, each having a front panel 60 mm wide.

Shelves for active units use high-reliability connectors between the permanent rack wiring and the equipment units. A 40-way plug is mounted on each card-frame unit, and connects with a 40-way socket mounted on the rear of the shelf. The contacts of the plug and socket connectors are

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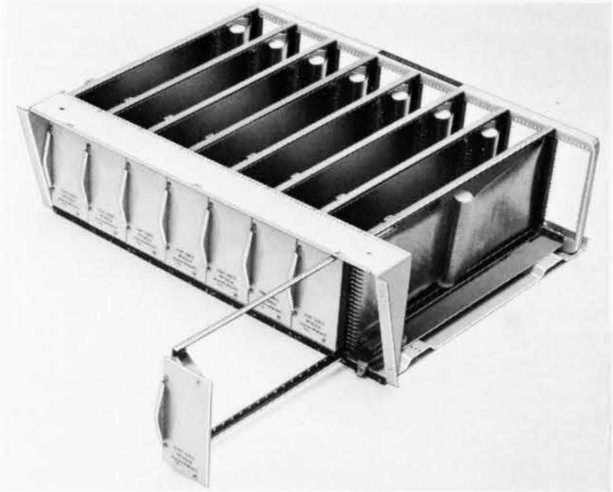
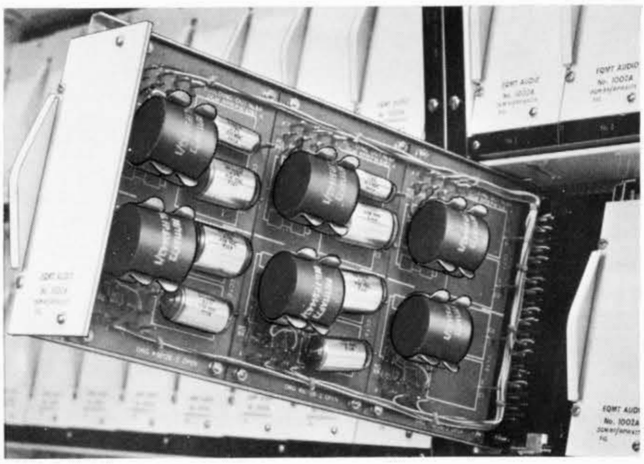
gold plated, therefore, because of the high cost of gold, not all of the 40-way contacts are equipped. Instead, it has proved economic to stock 3 types of shelf with different numbers of contacts fitted to cater for commonly used equipments; for example, 2-wire repeaters, 4-wire repeaters and signalling units. Other types of shelf accepting plug-in units include one that accommodates 4 music amplifiers and one for sterophonic broadcast equipment.

The shelves for passive units are based on the use of rectractile 40-way flexible connectors, each of which is fastened at one end to the shelf and at the other end to a card frame which is supplied as part of the shelf (Fig. 2(*a*)). The connector allows a card frame to be partially withdrawn, but not removed, from the shelf so that the items can be wired in position or subsequently adjusted whilst maintaining circuit continuity. Two versions of this type of shelf are used, one for speech-band equipment (shown in Fig. 2(*b*) fitted with building-out networks), and the other for music-quality equipment; the latter type includes some screened cabling on the card frame.



(*a*) General view



(*b*) Fitted with building-out networks

FIG. 2—Shelves for passive equipment

Installation

The top of a 62-type rack is attached to overhead ironwork which supports the power distribution and cabling. Racks containing active equipment have power feeds taken from the supply busbars, via fuses, to the power shelves at the top of the rack. Cabling is brought from the station distribution frames, fed down the back of the racks (see Fig. 1(*b*)) and the wires terminated on the rear of the shelf-mounted connectors by soldering or wire wrapping. Cables with 0·4 mm gauge conductors are used and the most common size of cable has 200 wires, but occasionally 100-wire and 50-wire sizes are used.

Power Equipment

The top 2 shelf positions on each rack are reserved, although not always equipped, for shelves which contain power, fuse and alarm units. Power units give a stabilized output of 20·5 V and are available to operate from station supplies of 22–28 V, 44–52 V and a.c. mains, although the last version is used only for a few installations in customers' premises. The output current from each power unit is just over 0·5 A, and 5 such power units can be mounted on each shelf. The use of a number of small power units rather than one large unit allows the number of units of equipment fed from each to be kept reasonably low, and this has several advantages. For example, shelves of different types of equipment, and having different power requirements, can be fed from their own power unit, thus minimizing the effects of power-unit failure.

TWO-WIRE REPEATERS

The use of 2-wire repeaters is confined, principally, to the provision of junction network circuits of medium length. The repeaters are used with loaded cable pairs and are of 2 types: the negative-impedance repeater and the hybrid repeater. A negative-impedance repeater, of simple design and low cost, is used for circuits having only one type of cable pair throughout, either 0·63 mm or 0·9 mm conductors, with 88 mH loading at 1·83 km intervals. The hybrid repeater is used when the circuit is made up from a combination of cable types and also for circuits slightly longer than those permitted using the negative-impedance type. Typical maximum circuit lengths for the 2 types of repeater are shown in Table 1. The repeaters are positioned either at the end of a circuit (end-connected) or at an intermediate point (mid-connected). The limitations of circuit length for the negative-impedance repeater are mainly due to the attenuation/frequency response at high frequencies, whereas the gain of hybrid repeaters is limited by the crosstalk characteristics of the external cable pairs.

Negative-Impedance Repeater

The negative-impedance repeater, the Amplifier No. 173 (Fig. 3), is of the series-shunt type, the principles of operation of which have been described elsewhere[5,6]. Eight units are accommodated in one shelf.

The engineering of circuits using negative-impedance repeaters is minimal because of the uniform standards of junction cables; the main requirement is that the repeater is connected to a cable having a half-loading section termination the impedance of which is nominally 1200 Ω, and to achieve this, building-out of the cable pairs is often necessary. Cable pairs may be built-out either with capacitance only or capacitance and a loading coil, depending on the length of cable to be simulated. The building-out components are mounted within the repeater assembly and, when the repeater is end-connected, a 2 : 1 impedance ratio transformer is also included to present a nominal 600 Ω impedance to the exchange.

Hybrid Repeater

A hybrid repeater is formed by the use of 2 Amplifiers No. 202, each of which contains a unidirectional amplifier, a 4-wire-to-2-wire terminating unit, filters, attenuators and a balancing network. The 2 units forming a repeater are mounted in adjacent positions on a shelf, allowing 4 such

TABLE 1

Maximum Circuit Lengths for the use of 2-wire Repeaters

Circuit Loss (dB)	Cable Conductor Diameter (mm)	Negative-Impedance Repeater		Hybrid Repeater	
		End-Connected (km)	Mid-Connected (km) Note 1	End-Connected (km)	Mid-Connected (km) Note 1
3·0 dB	0·63	15·8	Note 2	Note 2	33·2
	0·9	29·5	50	Note 2	66
4·5 dB	0·63	17·6	26·8	19·4	36
	0·9	35·5	51·5	38·0	71
6·0 dB	0·63	19·9	30	21·5	38·1
	0·9	38	58·8	41·4	74·4

Notes: 1: Maximum length with repeater in optimum position
2: Not generally used in this configuration

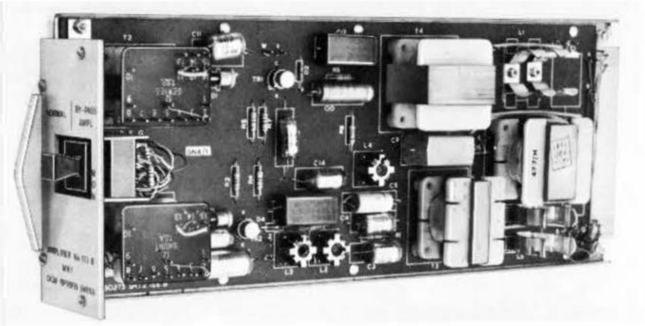


FIG. 3—Negative-impedance repeater

repeaters to be housed on a shelf. The repeater has been described in detail in an earlier issue of this *Journal*.[7]

The use of precision balancing networks enables the repeater to be employed either at the junction of cables that can be of different types or, by the use of a resistive balance on the exchange side, at the end of a cable. The attenuation/frequency response of each direction of transmission can be adjusted individually by the use of equalizers, which can be fitted to a repeater assembly as required.

FOUR-WIRE REPEATERS

Four-wire repeaters are now mainly used for private circuits routed wholly or partly on cable pairs. A repeater is formed by the use of 2 Amplifying Units No. 3, each of which consists of a 30 dB fixed-gain amplifier with attenuators for gain adjustment. These components are mounted on a card-frame with sufficient room to mount a variety of other items such as 4-wire-to-2-wire terminating units, line transformers, precision balancing networks and equalizers. The most commonly used combinations of these items are stocked as pre-assembled units, but other combinations can be made-up on site as required. Eight Amplifying Units can be accommodated in one shelf catering for four 4-wire circuits. This may not appear to be a particularly high packing density until it is realized that no additional equipment is required for a normal intermediate or terminal repeater.

The 4-wire repeater can be used between a variety of input and output impedances by the use of different line-matching transformers. However, for almost all applications, the cable impedance is, nominally, either 600 Ω (unloaded cable) or 1200 Ω (cable loaded with 88 mH coils at 1·83 km intervals). The impedance of terminal repeaters is usually 600 Ω at the 2-wire point. Each amplifier is provided with 600 Ω test points. Access to a 600 Ω point within the repeater also allows for the interconnexion of additional equipment to provide facilities such as signalling or group-delay equalization.

For the purpose of circuit line-up, the normal maximum output to line is +10 dBm but, exceptionally, +13 dBm is permitted; the amplifier is, however, capable of giving up to +17 dBm. The gain of the amplifier at 1 kHz is 30 dB ±0–5 dB, and in the frequency range 200 Hz to 4 kHz must be within ±0–2 dB of the gain at 1 kHz.

PROGRAMME EQUIPMENT

Programme circuits are provided mainly for the broadcasting authorities, and the majority of requirements can be met by a standard range of equipment. However, certain stereophonic programme circuits have special requirements and equipment has been designed solely for their use.

Standard Range

All the equipment required for the equalization and amplification of programme circuits routed over screened or unscreened audio pairs, or the phantoms of carrier pairs, can be accommodated on a plug-in chassis unit (Amplifying Unit No. 2). Four such units can be mounted in a shelf. The unit incorporates 2 printed-circuit boards which include 2 attenuators and various tags for the wiring-in of additional items dictated by the particular circuit requirements. The additional items include

(*a*) an auto-transformer that is connected to the input and/or output for matching the impedance of the amplifier to the cable pair,

(*b*) an amplifier, with input and output impedances of 140 Ω, having a gain of 30 dB; the maximum working output of this amplifier is +10 dBm and it has an attenuation/frequency response, from 50 Hz to 16 kHz, of +0·1 dB to −0–3 dB of that at 800 Hz: one amplifier is sufficient when the loss of the highest frequency to be equalized does not exceed 24 dB and for greater losses, or when temperature equalization is employed, 2 amplifiers are used,

(*c*) an additional gain-adjustment attenuator when a second amplifier is used, (*d*) a main shunt equalizer,

(*e*) a high-frequency residual shunt equalizer, and

(*f*) a temperature equalizer to compensate for variations in cable loss at high frequencies.

A unit with all these items fitted is shown in Fig. 4.

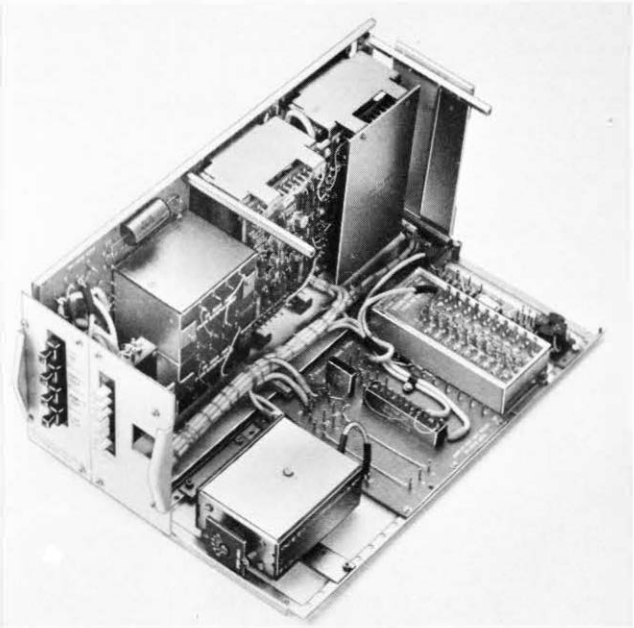


FIG. 4—Programme amplifier

Stereo Programme Equipment

The introduction of high-quality stereophonic broadcasting services, particularly for very-high-frequency (VHF) local radio, has resulted in a need for pairs of circuits of 15 kHz nominal bandwidth and up to 40 km long to link broadcast studios with radio transmitters. Each pair of circuits must be closely matched in their transmission performance characteristics, particularly in respect of attenuation/frequency response and phase distortion; these requirements are achieved by routing the circuits on 2 screened pairs in the same cable and using a range of purpose-designed audio equipment. Apart from the 2 terminal stations, the circuits can be routed via up to 2 intermediate stations. The terminal stations provide defined line-termination conditions, isolation from the customer's equipment and gain requisite to the signal emphasis which the circuits incorporate. The terminal at the radio transmitter end, and any intermediate stations, provide attenuation/frequency and temperature equalization. Phase equalization between the 2 circuits is rendered unnecessary by the careful co-routing of circuits. At the radio transmitter end of the circuit, special lightning protection facilities are provided.

SIGNALLING UNITS

Telephone exchange signalling units used for public circuits, and units forming part of the apparatus in customers' premises are outside the scope of this article. Two types of signalling unit in common use for private circuits are described.

Signalling units are used on private circuits when the apparatus at the customers' premises cannot provide the correct signalling conditions for the type of line employed. Of 2 types available, one converts signalling conditions from the customer into a suitable d.c. condition to send over long electrically-continuous circuits; that is, circuits routed on cable pairs throughout. The other converts signalling conditions from a customer into a 2280 Hz signal suitable for sending over any speech circuit but, in particular, for circuits that are routed for part of their length on high-frequency systems. Each unit is capable of being connected into a 2-wire circuit or a 4-wire circuit. Two units of the same type are required in a circuit, one at each end.

AC-to-DC Signalling Unit

The a.c.-to-d.c. unit, the Signalling Unit No. 27 (Fig. 5), consists of a relay unit, a send oscillator and a tone receive unit (Fig. 6). The relay unit can be adapted to accept, and present, one of a variety of signalling conditions to suit the equipment at customers' premises. On receipt of the appropriate condition from the customer, a 2280 Hz signal from the oscillator is sent to line. Similarly, a 2280 Hz incoming signal from line is detected by the tone receive unit and the appropriate condition sent to the customer.

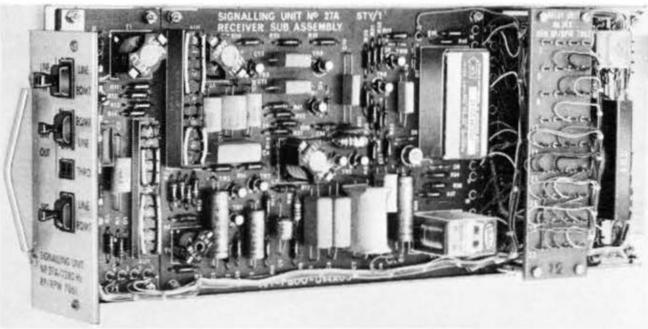
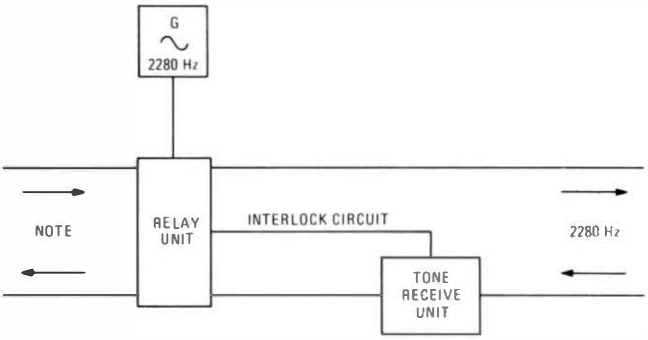


FIG. 5—Signalling Unit No. 27



Note: Signalling state to suit customer's requirements

FIG. 6—Signalling Unit No. 27—block diagram

The tone receive unit comprises a high-input-impedance amplifier that passes the incoming 2280 Hz signal to a peak-clipping limiter, followed by a low-pass filter with a cut-off frequency of 3200 Hz. The signal is then split into 2 paths; path 1 has a frequency response substantially flat but with a small rise in response around 2280 Hz, while path 2 has a sharp dip in frequency response at 2280 Hz. The 2 paths are fed to a comparator that operates a relay. The relay will operate only when a 2280 Hz signal tone is present but will not operate when other signals (for example, speech or data signals) are also present.

The receiver and oscillator are electrically interlocked so that the signalling unit cannot transmit and receive a tone simultaneously. Furthermore, after transmitting a tone, there is a delay during which it is impossible for the receiver to operate. This prevents false operation from reflected signals.

DC-to-DC Signalling Unit

The d.c.-to-d.c. unit, the Signalling Unit No. 28, consists of 2 relay units, each of which is the same as that used in the a.c.-to-d.c. unit. The 2 relay units are interconnected such that a particular signalling condition from the customer is converted to a d.c. condition (usually balanced battery) suitable for passing over pairs in quad-type cables. Similarly, an incoming signal from line is converted to an appropriate condition to send to the customer.

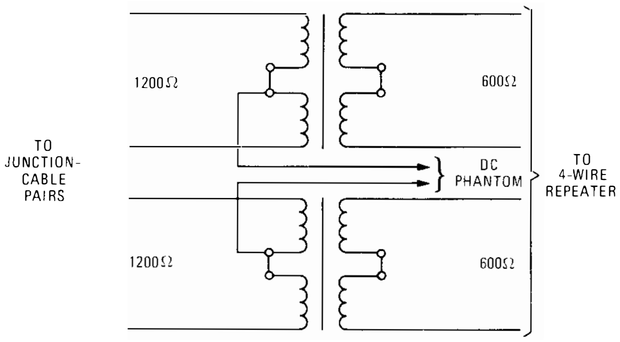
PASSIVE ITEMS

Transformers

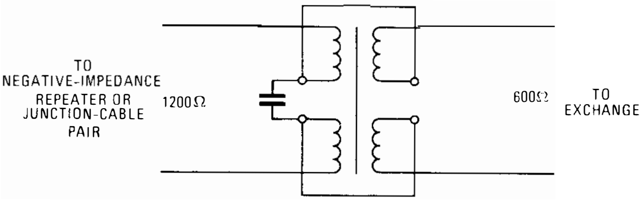
The most commonly used item of audio equipment is the line transformer. Among its functions are impedance matching, protection of equipment from high electrical potentials, suppressing longitudinal currents and phantom derivation.

Transformer units consisting of 2 transformers on a printed circuit board are available, and 3 such units can be mounted on a card frame or added to such items as 4-wire repeaters. Transformers with impedance ratios of 1 : 1 and 2 : 1 cater for the vast majority of requirements. A transformer, of impedance ratio 1·6 : 1 is also available but its application is limited to use with a few older types of cable. Other ratios can be supplied for special requirements. The most typical uses for transformers are given below.

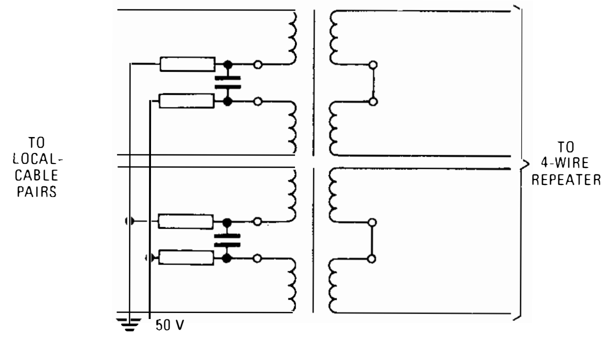
Four-Wire Circuits Transformers are used to match cable pairs of nominal 1200 Ω impedance to 600 Ω equipment and to provide d.c. phantom derivation for signalling (Fig. 7(*a*)).



(*a*) Impedance matching and phantom derivation



(*b*) Impedance matching and maintenance of d.c. path



(*c*) Provision of d.c. wetting current

FIG. 7—Typical applications of transformers

Two-Wire Circuits Transformers are used to match a nominally 1200 Ω impedance negative-impedance repeater to 600 Ω equipment when the repeater is end-connected and also to provide a d.c. path for signalling. The same configuration is used at the end(s) distant from a 2-wire repeater (Fig. 7(*b*)).

Private Circuits Transformers are used to provide a d.c. wetting current over the phantoms derived from a 4-wire circuit to the customer, to break down any high-resistance connexions at unsoldered local-cable joints or where screw connexions are used in customers' premises (Fig. 7(*c*)).

Four-Wire-to-Two-Wire Terminating Units

A 4-wire-to-2-wire terminating unit is constructed using 2 interconnected transformers (see Fig. 8), the transformers being similar in construction to line transformers. There are 3 types of terminating unit available which, by design of transformer turns ratio and balance impedance, cater for a range of impedances at the interface of terminating units and associated line plant. One type of unit presents a 600 Ω impedance at both 2-wire and 4-wire interfaces and is used mainly in association with 4-wire terminal repeaters, or at customers' premises. A second unit presents a 600 Ω impedance at the 2-wire interface and 1200 Ω at the 4-wire interface; this unit is used at terminal exchanges when no other equipment is required and provides impedance matching to cable pairs. The third unit presents 1200 Ω at 2-wire and 4-wire interfaces and is used only for special applications.

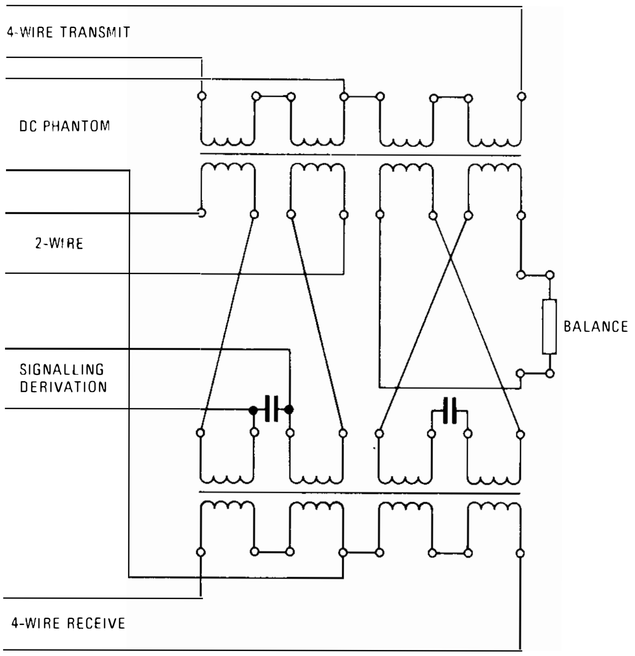


FIG. 8—Circuit of a 4-wire-to-2-wire terminating unit

Balancing Networks

Situations sometimes arise where the 2-wire end of a 4-wire circuit is extended on a cable pair, and a better balance return loss is required than is possible with a resistive balance. In these cases, a complex balancing network can be connected to the terminating unit. There are 2 types available: the Network Balancing No. 8 is used where the 2-wire circuit is extended on cable loaded with 88 mH coils at 1·83 km intervals; the Network Balancing No. 9 is used when the 2-wire extension is on unloaded cable.

Building-Out Networks

The process of "building-out" entails the addition of inductive/capactive components to simulate those primary constants of cable pairs to effect an increase in apparent length of the cable pair. Building-out of cable pairs is mainly necessary on circuits using 2-wire repeaters that need to interface with cable pairs having half-loading section terminations with continuity of loading throughout the circuit. The components for building-out at a repeater location are usually accommodated within the repeater, but there is a need for separate building-out units at ends distant from the repeater and at points where pairs in different cables are interconnected. Building-out of cable pairs is also carried out on some 4-wire private circuits when particularly good transmission performance is necessary; for example, on data circuits.

Two types of building-out network are available. One type contains only a capacitor, which is fitted to build-out an end cable section that is less than half a loading section long. A second type accommodates a capacitor to build-out to a full-section an end-section that is greater than a half-section but less than a full loading section; an 88 mH loading coil and another capacitor are then fitted to simulate a half section. A unit of the first type accommodates capacitors for 18 cable pairs and is mounted on a card frame. A unit of the second type accommodates components for 2 pairs, and 3 such units can be mounted on a card frame (see Fig. 3).

A separate range of units is available for use on programme circuits and these cater for pairs loaded with 16 mH coils at 0·915 km intervals, and 22 mH coils at 0·457 km intervals.

BRANCHING AND COMBINING EQUIPMENT

Branching and combining equipment is used whenever it is necessary to split or combine circuits; for instance, multipoint or omnibus private circuits or where duplication of a circuit section is required without recourse to switching.

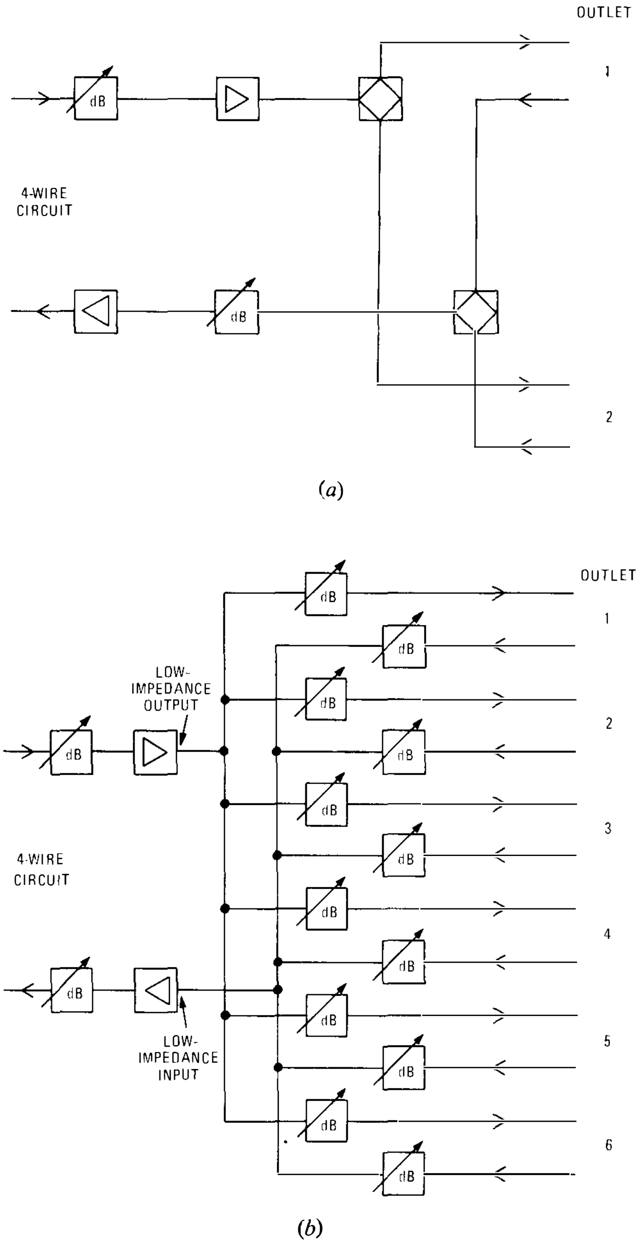
Two-way Branching and Combining Equipment. This equipment comprises a Branching Unit No. 8 and a Combining Unit No. 2, each of which consists of a card frame fitted with a 30 dB amplifier with gain adjustment attenuators and a 4-wire-to-2-wire terminating unit that is used for either splitting or combining (Fig. 9(*a*)).

Six-way Branching and Combining Equipment. This equipment consists of a special shelf which contains 9 card positions, 6 of which accept plug-in amplifiers and the other 3 have wired-in card frames equipped with attenuators. One fully equipped shelf provides 6-way branching facilities for 3 circuits: as shown in Fig. 9(*b*). The combining amplifier is an Amplifying Unit No. 6. The input and output impedances of this amplifier are 5 Ω and 600 Ω respectively and the gain is 30 dB. The branching amplifier is an Amplifying Unit No. 7 and its input and output impedances are 600 Ω and 5 Ω respectively, and the gain is 30 dB. The design specifications for both amplifiers are stringent in respect of frequency response, harmonic distortion, group delay and noise.

Omnibus-circuit Branching Equipment. This equipment is used to provide a means of connecting together three or four 4-wire sections in such a way that signals from any one section are transmitted to the other 2 or 3 sections. It provides very high attenuation between the RECEIVE and TRANSMIT pairs of the same section. Each branching point is made up from 2 Branching Units No. 3, eight of which plug into a shelf. Each unit contains two 30 dB amplifiers and various attenuators and resistive branching networks.

GROUP-DELAY EQUALIZERS

With the increasing use of audio circuits for non-speech purposes, such as private circuits for data transmission, the phase/frequency response characteristic has become important on some circuits. Non-linear phase/frequency characteristics resulting from filters in the transmission path produce group-delay/frequency distortion, which can be overcome by equalization. The nature and sources of group delay, and details of equalizer design and performance, have been dealt with in a previous article.[8]



(*a*) Two-way
(*b*) Six-way

FIG. 9—Branching and combining equipment

TABLE 2

Equalizer	Associated Line Plant
No. 74	19, 40 or 59 km of 88 mH/1·83 km PCQT cable
No. 75	19, 18 or 99 km of 88 mH/1·83 km PCQT cable
No. 76	160 or 180 km of 88 mH/1·83 km PCQT cable
No. 83	30 km of 88 mH/1·83 km PCQT cable
No. 84	4 kHz spaced channel translating equipment (most types)
No. 85	4 kHz spaced channel translating equipment (certain types only)
No. 86	3 kHz spaced channel translating equipment

PCQT: Paper-core quad trunk

Because of the standardization of plant, the amount of group-delay/frequency equalization required for a given circuit configuration can be decided on a prescriptive basis, and is met by a standard range of equalizers which are fitted to those circuits where the group-delay/frequency characteristic is important. The equalizers cater for a variety of circuit lengths and plant types, and are listed in Table 2.

PLANNING

The quantity of racks and equipment installed is dictated by estimated future circuit requirements. In general, racks are installed to meet 6 years' growth, shelves and wired-in equipment to meet 3 years' growth, and plug-in equipment to meet only one years' growth or less. Any number of shelves up to the maximum determined by the rack height may be provided at the outset and there is no restriction on the future provision of remaining shelves as these can be added without disturbing existing shelves.

PROVISION

At large installations, there is usually sufficient demand for common items of equipment to justify one or more racks dedicated to each type of equipment, although each rack is not necessarily fully equipped with shelves or equipment at the outset. At smaller installations, it is usual to provide a rack containing different types of equipment, although each shelf is equipped with items of a common type.

In small rural exchanges, space is at a premium and only a small quantity of any one type of equipment is required. A further complication is often the limited space available for the exchange distribution frames. To meet this situation, a miscellaneous rack can be provided which can accommodate shelves containing mixed equipment types and a rack-mounted cross-connexion shelf (jumper field) to allow interconnexion of the various units. Access to the exchange and external cable distribution frame is achieved by tie-pairs.

Testing

When assembly and cabling is complete, the installation is tested. The tests usually consist of checking wiring continuity and a sample of crosstalk performance. A functional test of each unit is also made, but a detailed check of the technical performance is unnecessary as this is determined by the basic design, prototype approval, manufacturing and quality-control techniques, and factory inspection.

Documentation

A series of diagrams is issued for all items of equipment; these refer to the manufacture, installation and maintenance of the equipment. Also, comprehensive instructions relating to the equipment are issued for the use of field staff.

THE FUTURE

Audio transmission equipment has been in use for many years and its development has been that of evolution rather than revolution, notwithstanding the change from electronic tubes to transistors and linear integrated circuits. This evolution is likely to continue in the future with increased emphasis placed on reducing the cost and the size of the equipment units, and simplifying circuit setting-up and lining-up arrangements. Only when the use of digital signalling and transmission equipment is widespread will the importance of audio equipment diminish from its present level.

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Book Review

Programming Electronic Switching Systems. M. T. Hills, PH.D., C.ENG., M.I.E.E., and S. Kano, M.SC. Peter Peregrinus Ltd. (IEE Telecommunications Series). viii + 207 pp. 64 ills. UK: £11·90; overseas (excluding the Americas): £13·90.

According to the preface, the principal purpose of the authors is to present the basic real-time programming concepts and techniques as applied to computer-controlled switching systems, and to discuss the role of these in the design of high-level languages.

In the final chapter, the authors admit to having only scratched the surface of the total software problem.

It is perhaps the latter statement that is the more true, and herein lies the major criticism of the book. A book that tries to be many things to many men, if it is not to fail, requires a diligent reader with sufficient self-discipline to use the very comprehensive bibliography for background and further information.

The book is intended for those with an understanding of the fundamentals of programming, and certainly will be difficult to read for anyone without these basic skills. In certain chapters, however, the authors go to great lengths to explain aspects of programming that fall within this category.

Chapter 1 contains a brief history of stored-program-control (SPC) telephony and a very sketchy outline of the telephone system—barely sufficient for a newcomer to the field—and goes on to introduce the reader to the basic structure of an SPC system.

Chapters 2 and 3 are the best of the book. Chapter 2 introduces some programming principles associated with call processing, and Chapter 3 goes on to show how these principles have, and could be, developed into practical SPC systems.

The remainder of the book is more or less devoted to high-level languages, Chapter 4 being an introduction to the software engineering principles involved, Chapter 5 a comprehensive discourse on data structures and methods of accessing them, and Chapter 6 a survey of high-level language features considered, by the authors, to be important in SPC call-processing programs.

Very little of high-level language formalism is widely accepted and much remains as a matter of taste. Although I believe the authors have been careful to keep their personal bias in check, the reader will need to negotiate Chapter 6 with some care.

In essence, the book is about the design and management of call-processing programs, and it fulfils this function well. Other aspects of SPC software, some very important, are given very perfunctory treatment. The book should be considered as an aperitif, with the menu for the meal contained in the very excellent bibliography and suggestions for further reading.

K. F. C.

Charges for Inland Telecommunication Services

P. J. WILKIN†

UDC 621.39.003.13

This article gives an insight into some of the considerations that influence the fixing of charges for telecommunication services provided within the UK by the British Post Office.

INTRODUCTION

It is easy to fix the price of something. All that is necessary is to find out how much it costs, add on whatever percentage is required for profit, put the result on the customer's bill and send it off in the cheery expectation of it being paid by return of post. So why does it need a whole Division in Telecommunications Headquarters to ponder on what charge customers should pay for the privilege of being able to communicate with each another? One obvious problem is that, using a cost-plus-profit system in its simplest form, the chances are high that a different price will result for each of the 14-million exchange connexions and their multitude of associated apparatus. This would be patently unmanageable and would require legions of staff to calculate each separate price which, in itself, would add to the costs. The capital cost to the British Post Office (BPO) of an item of equipment or the provision of a service must be taken into account, but the procedure for calculating this is not really relevant to this article, which is concerned more with the philosophy of the charging structure. However, it can be said that costing relies heavily on regular sampling of the cost of various items of equipment and services, from which average costs can be assessed so that charges based on those averages can be set to give, overall, the required financial return.

This article considers the main factors, in addition to the cost of provision of an item or service, that must be taken into account before the charge can be fixed.

BASIC PRICING POLICY

Since the BPO has, with the exception of Hull, the monopoly of providing telecommunication services within the UK, there is not the direct comparison with competitors' charges that exists in a normal business concern. This, in itself, presents a problem. The BPO has to make a largely subjective assessment of whether its charges are at the correct level relative to the worth of the service to the consumer; that is to say, are they reasonable? Against this must be balanced the ability of the charges to earn sufficient revenue to meet the financial return target, both for the Business as a whole and for the individual items or services to which they relate. Finally, the charges need to take account of sundry other factors, such as control of supply and demand; too low a price could inflate demand whereas too high a price could result in shelves full of unused stock. It is conceivable that these factors could be in balance, so that, at a price that seems fair to the customer, the service makes its required profit and there is neither a waiting list nor a glut of equipment. More often, the factors are not in balance.

The various factors may be internally (within the Business) or externally motivated. Usually, the Government lays down general guidelines for nationalized industries on the annual level of financial return to be aimed for. Between 1964 and the early 1970s, the target fixed for the BPO varied between 8% and 10% return on capital. Return on capital, in this instance, is defined as the profit made by the Business before allowing for interest and supplementary-depreciation charges, expressed as a percentage of the value of net assets. More recently, the target has been expressed in terms of profit on turnover. The level of profit on turnover was originally set at 2% although, by agreement with the Government, this was altered to a "break-even" percentage (0%). This was to restrict the size of tariff increases that would otherwise have been required.

Within this general framework, it is the responsibility of the BPO Board to decide what pricing policy should be adopted in respect of the different services although, as will be shown later, other influences may still be brought to bear in respect of certain of the more important services. The policy that has been in force since 1971 is that, as far as possible, the prices for each main service (for example, exchange-line rentals or subscribers' calls) should be sufficient to give a profit from that service equivalent to the overall Business target. Within each main service, the charges for individual services or items of apparatus are also generally intended to achieve the overall Business target, but there are exceptions. Items of an optional or luxury nature (for example, loudspeaking telephones and Trimphones) are expected to yield a return above the average.

At the other end of the scale, some apparatus provided for the handicapped person is charged with no profit element. Also, certain services have, through historical accident or natural decline in their popularity, fallen far into a loss-making situation. The prime example of this is the public telegram service, where the decline in usage, and therefore income, has not been matched by a reduction in the cost of the service. The result is that cost outweighs income, and to return the service to profitability would require such massive price increases (in percentage terms) that the traffic would probably disappear altogether. The BPO could then face public accusations of killing off a service that provides the only really rapid means of communication with people who, for one reason or another, cannot be reached by telephone. This suggests that the time is approaching when a fresh look must be taken at the basic pricing philosophy to decide whether the aim of each sector contributing equally to the overall target is still valid and, if not, how changes should be made. For the time being, to get the primary split of income and expenditure, the inland services are broken down into *sectors*; these are listed in the *Post Office Annual Report and Accounts*, and are as follows:

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† Inland Tariffs Division, Marketing Department, Telecommunications Headquarters

Inland Service Sectors

Rentals: business
residence
apparatus
} including income from and expenditure allocated to connexion charges

Subscribers' calls (including calls from renters' coin-collecting boxes).

Call-office receipts

Private circuits

Telegrams

Telex

Agency and miscellaneous items

An idea of the allocation of costs between various services can be gained by looking at the broad split of the public switched telephone network (PSTN) costs between the RENTALS sector, which includes connexion charges, and the CALLS sector. In essence, the costs regarded as appropriate to rentals are those for a customer's telephone, the circuit to the exchange, and any equipment in the exchange provided for the customer's individual use. The costs of common equipment in the exchange, which is used by all customers, and the trunk and junction circuits linking exchanges together, are allocated to the CALLS sector. The allocation of plant to the sectors is shown in Fig. 1.

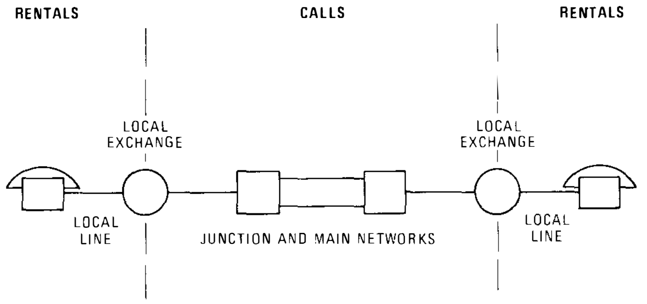

FIG. 1—Allocation of plant between RENTALS sector and CALLS sector

If this general pricing policy worked completely satisfactorily, and the charges fixed to cover these costs with the appropriate margin for profit met all the other constraints, the work of the Tariffs Division of Telecommunications Headquarters would be greatly simplified. The problem is that prices fixed in this way are, generally, not practicable because a number of other constraints exist.

PRICING CONSTRAINTS

Pricing contraints fall into 3 main groups: those relating to customers, those relating to use of BPO resources and those imposed by Government. Their relative importance depends on whether one is buying, selling or governing.

Customer Considerations

Customer considerations can be placed under the following 4 sub-groups:

(*a*) price sensitivity,
(*b*) acceptability of prices to customers,
(*c*) relativity of prices, and
(*d*) social obligations.

The first of these, price sensitivity, is the extent to which the demand for a service or facility is affected by its price. This is generally a question of whether the service is a worthwhile proposition from the customer's point of view at the price being charged. This does not necessarily always depend on economic viability. For example, a business customer may elect to replace a PMBX with a PABX because it will save the cost of one or more operators, and lead to a quantifiable saving in the time spent by his employees in waiting for calls to be set up. At the other end of the scale, the value comparison may be against something as intangible as relative peace of mind, as in the case of an elderly or lonely person weighing the price of a telephone against the disadvantages of not having one. In either case, the decision is equally important to the person making it. The limit of price sensitivity is the highest price that the market will bear and, clearly, for the BPO in its position as a monopoly supplier, a pricing policy that relies on this philosophy is a dangerous proposition. The variations in the point at which a customer decides not to have a service at the asking price are as many as there are customers themselves. All that can be done is to make a subjective assessment based on experience gained in the past, the trends established over the years and knowledge of how telephone service compares with the desirability of other commodities that may be competing for the customers' available money.

The second factor, acceptability of prices to customers, generally reflects the degree of satisfaction, in terms of value for money, which a customer derives from the service given. This is often not an easy thing to justify to a customer. He may fail to see why the only visible part of the service, the telephone instrument in the home, should cost as much as it does. A customer may not comprehend that most of the equipment lies hidden beneath roads and in anonymous buildings. This is an understandable point of view, which arises from a lack of realization of what the telephone service entails. Another aspect of acceptability is that a customer generally expects to pay a lower price for older types of apparatus. On cost grounds, the reverse can often be justified. New equipment may use cheaper technology for which the maintenance costs are lower.

Relativity of prices, the third constraint, refers to the relation between prices for different BPO services. It is partly an extension of acceptability. Logic indicates that the longer a private circuit is, or the greater its capabilities in terms of transmission quality, the higher should be the charge. Similarly, a large PBX should cost more than a small one, a PABX more than a PMBX, an exclusive exchange line more than a shared line and so on. Because of the vast number of different services offered by the BPO, it can be quite a problem to maintain a logical pattern of price relativities. What is more, the relativities must be kept more or less constant; otherwise, customers might be tempted to hop from one type of service to another every time the charges change. Furthermore, the BPO would be vulnerable to complaints that changing relativities were invalidating customers' long-term planning of their telecommunications requirements.

The last constraint, social obligations, is the most nebulous. In its widest sense, it implies that the BPO must meet the telecommunications needs of society at a reasonable price. More specifically, it is taken to refer to people who are in some way at a disadvantage, most often by virtue of physical handicaps, age or poverty. In general, the BPO holds the view that any assistance in such cases by way of financial aid should be the responsibility of the various social services. There are good reasons for this. The BPO does not have the expertise to adjudicate on claims for assistance, nor the right to enquire into personal circumstances to check their validity. The BPO view on this is supported by the Government. Nevertheless, assistance is given in several ways; notably in providing equipment for the handicapped at subsidized rates and, with somewhat less justification, in tolerating a continuing loss on calls from coin-collecting boxes.

Proper Use of BPO Resources

The second group of constraints, use of BPO resources, can be sub-divided into the following categories:

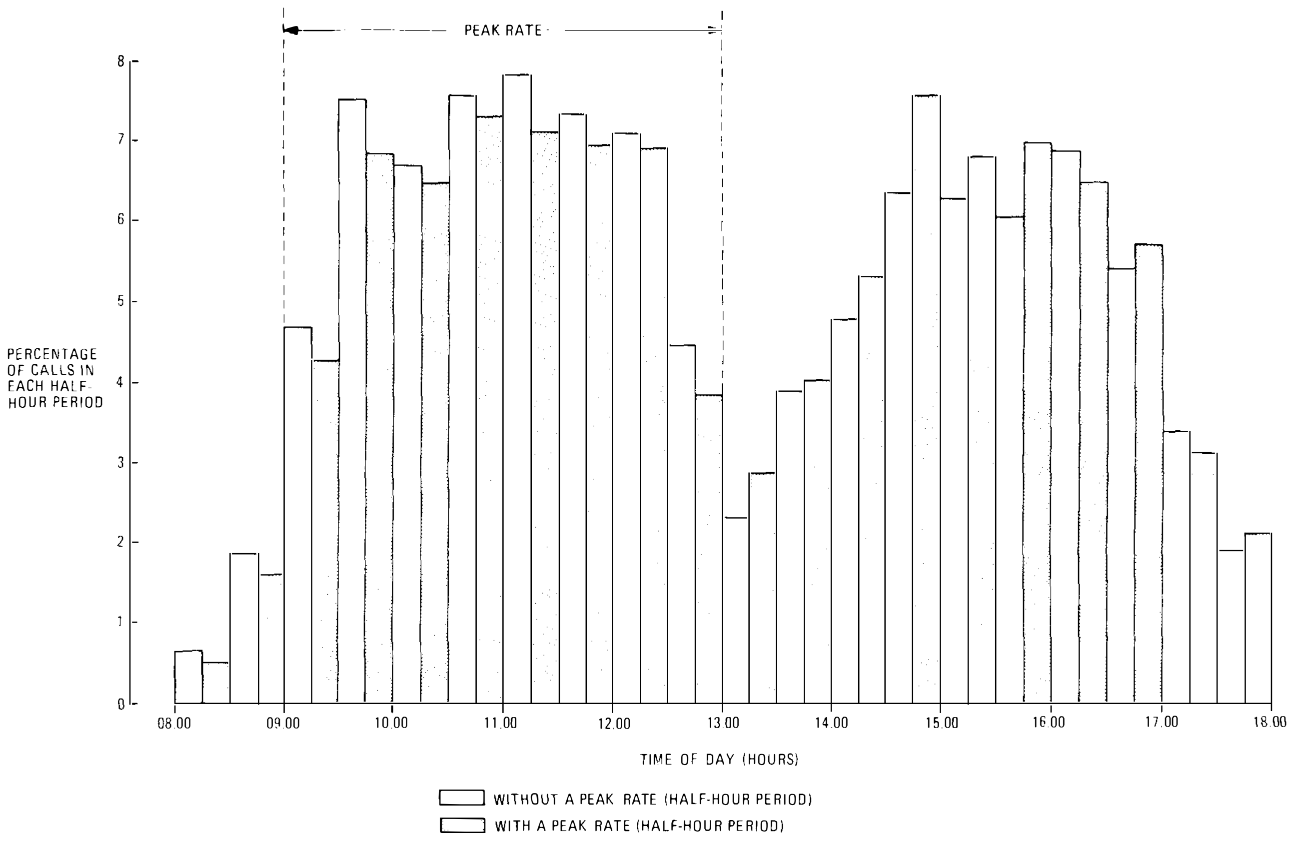

FIG. 2—Incidence of trunk calls

(*a*) optimizing use of plant,
(*b*) optimizing use of staff,
(*c*) coping with operational problems, and
(*d*) cost to the BPO.

Efficient utilization of assets is a vital prerequisite of any business. Where the amount of plant involved is as great as in the BPO, this applies even more, and pricing strategies can play a very effective role in achieving the objective. Probably the best example of this lies in the differential tariffs for calls made at various times of the day. The natural pattern of call traffic builds to a peak during the morning, falls off at lunch time, builds again to another, but smaller, peak in the afternoon, and falls off again in the evening with minimal use throughout the evening and night hours. To provide sufficient plant to cater for the busiest time, the morning peak, would lead to gross under-utilization of plant throughout the remainder of the day. The differential call charges, *peak*, *standard* and *cheap* rates, help to counteract this.

The peak rate, currently from 09.00 to 13.00 on weekdays, tends both to encourage business subscribers to delay their calls until the less-busy afternoon period, and ensures that those who make their calls in the morning make a positive contribution to the cost of providing the extra trunk and junction plant that is required solely for their benefit. The standard rate, from 08.00 to 09.00 and from 13.00 to 18.00 weekdays, should be low enough to provide an incentive to shift business traffic to the afternoon period. The cheap rate, covering all other times, is intended to encourage the use of the service during the hours when the network is least used. The introduction of a peak rate has had some success as can be seen from the "before and after" pillargraph given in Fig. 2. However, the situation is now beginning to arise where the afternoon traffic is coming up to the level of the morning peak. Clearly, if this trend continues, there may have to be a review of peak and standard rates.

Optimizing use of staff has a similar rationale because staff are just as much an asset as exchange equipment and line plant. If charges were increased to such a degree that demand for service fell away sharply then there could be no work for large numbers of installation engineers. The supply of trained engineers cannot be turned off and on like a tap. A major consideration in setting charges, particularly rentals and connexion charges, is to try to regulate the flow of installation work to the level for which an engineering workforce has been planned. This can be complicated by the fact that external factors, such as the state of the economy, can influence the amount of money which people are prepared to spend on commodities such as the telephone. Unforeseen changes in the state of the economy, coupled with a misjudgement of the price sensitivity of the telephone service, could upset the balance between demand for telephone service and the BPO's capability to meet that demand. The best possible forecast has to be made of what demand will arise naturally, assuming that prices stay as they are. Again, the purpose of this article is not to examine forecasting methods but, those used by the BPO rely on the evidence of past trends and take account of all known factors which could affect demand. In general, they are recognized to be as accurate as any comparable forecast. Against this forecast must be weighed the effect of possible tariff changes. If the natural demand is too high for the available labour and equipment capacity provided for under a planned expansion programme, then it is a fair indication that charges are too low. Charges can be increased to a point where demand and supply coincide, or nearly so. This, however, is a very delicate area. For price adjustments of this nature to be acceptable, there must be assurance that there is no basic miscalculation of the rate of expansion of the service. If the rate of growth has been underestimated, then it would be wrong, particularly as a monopoly supplier, to cut back demand purely by pricing the service out of the reach of some applicants. If the natural demand is too low, then various options are available; for example, charges could be reduced. However, this might bring income down to the point where the service became unprofitable. Alternatively, charges could be left at their existing level and the demand shortfall could be made up through increased selling effort. Whichever option is adopted depends on the circumstances prevailing at a given time. The art lies in getting the equation to balance, and this is very largely a matter of experience based on past trends. Similar considerations apply in the setting of charges for calls connected by a telephone operator.

The availability of telephone-exchange operators depends, to some extent, on influences outside the control of the BPO. The attractiveness of the job will increase or decrease according to the ease of getting a more desirable, or better paid, job elsewhere. As in the case of the engineering workforce, the operating force is not capable of rapid adjustment of its numbers. Charges for operator-connected calls have, therefore, to be regulated with due regard to the effect on staffing. This can be a very critical balance to achieve because operator-connected calls are far more expensive to handle than calls which the customer dials for himself. Charges that are too high depress the traffic and result in the planned workforce of operators being under-employed. Charges that are too low have the opposite effect and, if the cost of handling these calls should outstrip the charges, this unwanted stimulation of traffic aggravates the financial loss.

The third item in this group of constraints is coping with operational problems. These can be either technical or staffing problems. An example of the former lies in the limitations imposed by the capabilities of call-timing and metering equipment. Because of the extremely large numbers of calls made, a comparatively small increase in the charge per call realizes a considerable amount of money. In the situation where it is required that income be raised by a certain amount, the smallest reduction possible in the time allowed for a call unit fee on one class of call may result in an income far beyond that required. If this happens, the excess of income has to be balanced by giving some money away elsewhere, perhaps by allowing more time per unit fee on another class of call. Often a number of changes have to be made to arrive at the situation where overall income will go up or down by the required amount. Similar technical limitations are imposed by the restricted number of different denominations of coin accepted by coin-collecting boxes. There is a point, fast approaching, where it will no longer be feasible to have a box which takes 2p and 10p coins, and the BPO will have to move to a box that will take coins no smaller than 5p pieces.

Staffing problems, in the main, lie in the physical effort required to introduce a major tariff revision. At one time, because of the enormous number of different charges contained on customers' rental-record cards, each of which had to be amended manually when charges were changed, an extra workforce of some 400 staff had to be specially recruited throughout the country and employed for about 3 months. Such a time lapse between an agreed tariff change and the date of introduction leads, of course, to a cost penalty equivalent to 3 months at the rate by which the prices have been increased. A computerized customer rental records system should ease this particular problem.

Whatever other constraints are operating, the fourth item under this heading, the cost to the BPO of providing a service, must remain a fundamental consideration in setting charges. If charges are set too low for a particular service in relation to its cost, this tends to encourage customers to use the service more than they would if it were correctly priced; in this way losses increase. Ensuring that charges cover costs, or do so as nearly as possible having regard to all the other factors that need to be taken into account, is a valuable aid to making the most efficient use of resources. This is a principle endorsed by the Government, witnessed by their encouraging nationalized industries to raise their charges to break-even point, or above, and thus avoid the need for subsidy by the tax payer.

The BPO has elected to work on a basis of national standard charges related to the average cost of providing a service. In this way, the expense of cost identification is minimized. There are other advantages in setting standard charges; the number of different charges is kept to a minimum and they are more comprehensible to customers. The possibility is avoided of complaints arising through, for example, a call from A to B costing more than the same call in reverse, from B to A. Admittedly, this principle of standard charges appears contrary to the idea of charging services as closely as possible to their cost. The cost of an exchange line in the Highlands of Scotland may be many times that of a line in a more densely-populated area, yet the customer pays the same rental. However, the alternative of charging each line at cost would be so cumbersome as to be unworkable.

Constraints Imposed by Government

The last group of pricing constraints considered in this article is that imposed by Government, consisting of:

(*a*) the statutory duty of the BPO to provide telecommunications services,
(*b*) the statutory duty of the BPO not to discriminate between customers,
(*c*) Government control of finance, and
(*d*) political constraints.

Section 9 of the Post Office Act 1969 lays on the BPO the obligation to "so exercise its powers as to meet the social, industrial and commercial needs of the British Islands . . . and, in particular, to provide throughout those Islands . . . such telephone services as satisfy all reasonable demands for them (having regard) to efficiency and economy". The Post Office Act does not impose any direct restrictions on what, or how, the BPO charges for the services it provides, but its implications carry through into the field of pricing. For example, the BPO is obliged to provide telephone service anywhere in the country, both in urban areas where customers live close to the exchange and lines are comparatively short and inexpensive to provide, and in remote rural areas where a single exchange line may cost several thousands of pounds to install. Activities cannot be restricted to the less costly, more profitable urban areas and, unless the BPO were to adopt a radically different approach from the existing policy of standard charges based on average costs, there will always be some element of subsidy between urban and rural areas. This can lead to invidious comparisons with, for example, telephone charges in Hull, where all exchange lines are comparatively short. However, it is considered that, on balance the "national standard charges" concept is still the fairest to customers, as well as being operationally the most satisfactory.

This leads into the second of this group of constraints: the duty of the BPO not to discriminate between customers or groups of customers. This is contained in Section 11(4) of the Post Office Act. Precisely what would fall under the definition of discrimination is not clear because, as yet, the Minister has not given a directive to stop discriminating in any particular instance. Clearly, in any business with as many customers as are served by the BPO, it is difficult to ensure that all are treated equally. It could be argued, for example, that subsidy of rural lines by urban lines is discriminatory to some degree. Conversely, it could also be argued that the alternative system of charges related to individual costs would discriminate against those customers who choose to, or have to, live in the more remote parts of the country. The question is really one of common sense, and it is considered that the underlying principle of treating all customers alike, which has been a tenet of BPO staff for many years, applies with equal force to the charging policy.

There is some direct Government control of finance, through the need for Treasury approval of BPO capital investment. The effects of this can carry through into the field of price setting. For example, a directive that a greater proportion of investment must be met from BPO resources, as opposed to capital borrowing, would require tariff increases to raise the extra money required. Similarly, but perhaps even more noticeably, Government limitation on the degree to which charges may be changed has a serious and immediate effect. The most recent example was, of course, the counter-inflation legislation. This prevented the BPO from increasing prices to keep pace with the rising cost of materials and labour, and it is only since early 1975 that some relaxation of the stringent controls has enabled the position to be recovered.

Finally, political constraints are, quite simply, controls placed by any Government on the size or timing of tariff increases. They may exist for a number of reasons, some patently in the national interest, others less obviously so. An example, which the reader may classify for himself, is the difficulty of getting approval for a major tariff revision just before a General Election.

CONCLUSION

As was stated at the beginning of this article "It's easy to fix the price of something". Or is it?

New Surveillance System for Pressure Contactors on Main-Cable Routes

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UDC 621.395.741:621.315.211.4

A surveillance system for monitoring the state of up to 215 air-pressure contactors on cable routes up to 330 km long is described. Cable damage, causing air leaks, can be detected and accurately located long before service is affected. Comprehensive location information is presented to both route terminals in audible and visual form, together with a permanent printed record.

INTRODUCTION

Most of the British Post Office (BPO) long-distance main-network cables are pressurized to prevent ingress of moisture through small leaks. The new 18-pair coaxial cables, being installed on certain routes, are no exception. These routes, when fully equipped with 60 MHz frequency-division-multiplex (FDM) line systems, will carry as many as 97 200 circuits.[1] It is thus more important than ever to have accurate information regarding the location of cable-sheath faults, to reduce out-of-service time.

The distance between surface terminal and main stations, and the high pneumatic resistance of the cable, precludes the making-up of lost air pressure quickly on a dynamic basis. Air lost through a leak is not quickly replaced by flow along the cable, which means that accurate information concerning the pressure state at any point is required to give an early indication of the presence of a fault.

The pressure in the cable is monitored by means of pressure contactors (pressure-sensitive switches) set to operate when the pressure drops below 150 kPa (1·5 bar), the cable being initially pressurized to approximately 162 kPa (1·62 bar). These contactors are located in the repeater cases at the intermediate repeater points which, on 60 MHz systems, are situated at 1·5 km intervals.

If a cable sheath becomes punctured, the pressure gradually drops, producing a pressure gradient along the cable. The nearest contactor to the puncture operates when the pressure in its repeater case drops below 150 kPa (1·5 bar). Likewise, the second and third nearest operate when the pressure in their repeater cases drops below 150 kPa (1·5 bar). The time intervals between the operation of the first and second contactors, and between the first and third, can be used to give a first-order location of the leak by graphical means.[2] Typical accuracy quoted for this type of location is ±50 m, after which other more direct methods have to be used.

A surveillance system is therefore needed to monitor the state of the contactors along the route and present the information, required for leak location, at a convenient point.

EXISTING METHODS OF SURVEILLANCE

The existing method of locating an operated contactor by looking for a short circuit across an audio pair in the cable, or a short circuit to earth from one leg of a pair, is inadequate because

(*a*) a location bridge cannot measure beyond the nearest short circuit,

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(*b*) on long routes, accurate measurement of loop resistance at the far end is difficult because of the variation of the cable parameters with temperature, and

(c) the Murray bridge normally provided is not practical with a large number of contactors.

To enable the timing information mentioned above to be recorded, the existing methods could be developed. The loop current could either be continuously monitored by a chart recorder, a permanent deflexion of the needle indicating the operation of a contactor, or the value converted into a digital form suitable for the operation of a printer. Both systems would introduce a certain amount of automation, but they still suffer from the disadvantages previously mentioned. A continuous chart is also unsuitable for long-term monitoring.

For these reasons, the whole approach to the method of surveillance was re-examined, and a new system was designed to give the required information.

SPECIFICATION FOR THE NEW SYSTEM

The surveillance system must present at both terminal stations all the information regarding the state of pressure contactors along the whole route. The information required consists of the date and time that a contactor has operated, as well as its location. To simplify the location of the leak from the timing of the first 3 contactors to operate, an interval clock is needed to start from the time when the first contactor switches, and to indicate the time of each successive contactor operation. This information must be in hours and decimals of hours, as it used in the location calculations.

Operation of a pressure contactor must also operate a d.c. alarm on a second audio interstitial pair for stand-by purposes. This alarm works on the *loop-across-the-pair* principle, and enables approximate manual location of the pressure contactor by a bridge technique in the event of a failure of the automatic system.

Audible and visual alarms must be given at the terminal station each time a pressure contactor indicates that the pressure in its repeater case has dropped below 150 kPa (1·5 bar).

SYSTEM CONSTRAINTS

No power is available at any repeater case. A digital system of monitoring the state of the pressure contactors is therefore impossible, because the line voltage and current would have to be much higher than safety permits. Reflection techniques are unsuitable because of the route length. In addition, little space is available at the repeater points to house the equipment needed.

OUTLINE OF THE NEW SYSTEM

In the system chosen, an oscillator, operating at a unique frequency, is associated with each contactor in each repeater case. The oscillators receive power and transmit their tones along an audio pair, which terminates in each surface main station where the tones are monitored by tuned receivers. Low-pressure operation of a pressure contactor switches off the associated oscillator, and the absence of a tone at the receiver indicates a fault; the system thus works in a fail-safe mode.

At the surface main-station where the fault is detected, a carrier is pulse-width modulated by an *absence-of-tone* pulse. This carrier is transmitted to both terminal stations on a second audio interstitial pair, via pulse regenerators situated at each intermediate surface main station.

At both terminal stations, each carrier is demodulated. Every extracted pulse causes a printer to record in black the date, time and the contactor location code. A differential clock also indicates the time of the operation of the contactor relative to the first one in the fault sequence, and this is also part of the printed record. This latter information is required for the location of the leak. Alarms are operated by both the cessation of oscillator tone, causing a pulse to be received at the terminal stations, and by the short circuit across the second pair produced by the contactor itself. System failures also operate the alarms, but cause print-outs to be in red. The short-circuit is actually a low resistance high-impedance path so that the carrier is not affected.

Fig. 1 shows a block diagram of the monitoring system. Having been based on the route layout of the 60 MHz transmission system, up to 330 km of cable with 215 pressure contactors can be monitored.

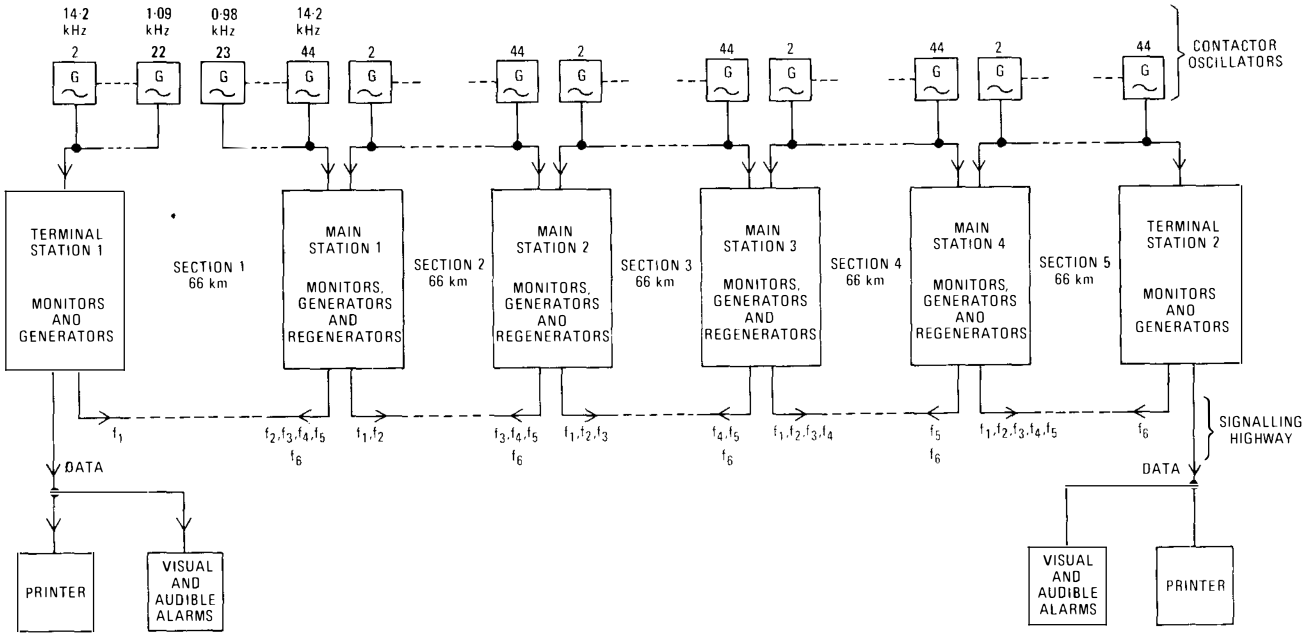

FIG. 1—Block diagram of the cable-pressure-contactor monitoring system

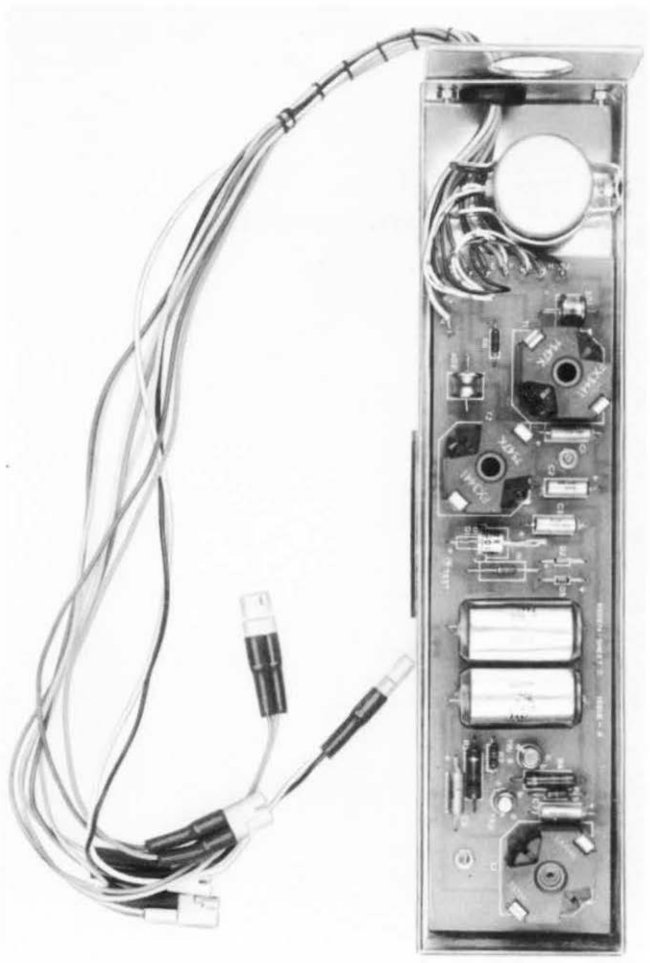

FIG. 2—Contactor oscillator

OSCILLATOR

The oscillator associated with the repeater cases is of the Colpitts type working from a 20 V supply, and is shown in Fig. 2. The design is such that the maximum current drawn from the line by any oscillator is less than 1 mA.

To allow for frequency drift, the oscillator frequencies are chosen such that the separation between each adjacent pair of frequencies is about 10% of the lower one. Certain frequencies, namely 5 kHz, 6 kHz and 8 kHz, are avoided as they are signalling frequencies already used on the 60 MHz transmission system. Space considerations limit the lowest frequency possible to about 1 kHz and, as far as possible, frequencies that are harmonically related are avoided.

The set of frequencies can be repeated from section to section; 43 are therefore needed. However, with a 10% spacing starting at 1 kHz, the highest frequency is about 55 kHz, which is impractical because of the high attenuation at these frequencies. As no power or space is available between surface main stations for amplifiers for the surveillance system, each section is divided in half, and each half feeds tones to its respective surface main station. This way, only 22 frequencies are required, the highest being 14·2 kHz. Even so, attenuation problems exist; to overcome these, the frequencies are allocated in descending order, as the distance from the surface main station increases. To standardize on component values and to cause all tones to be received at approximately the same level, the first oscillator away from the station has a frequency of 14·2 kHz, the second 12·5 kHz, and so on. If fewer than 43 are required for a section, then the lower frequencies are omitted first.

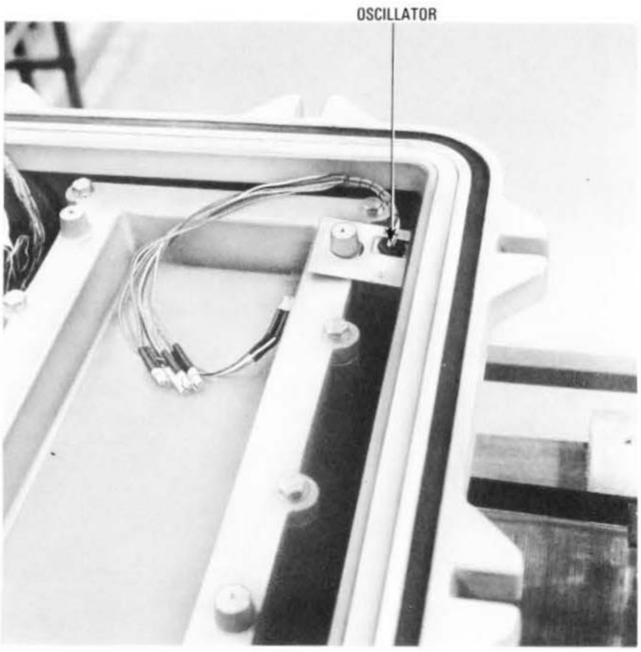

FIG. 3—Contactor oscillator *in situ* in the 60 MHz repeater case

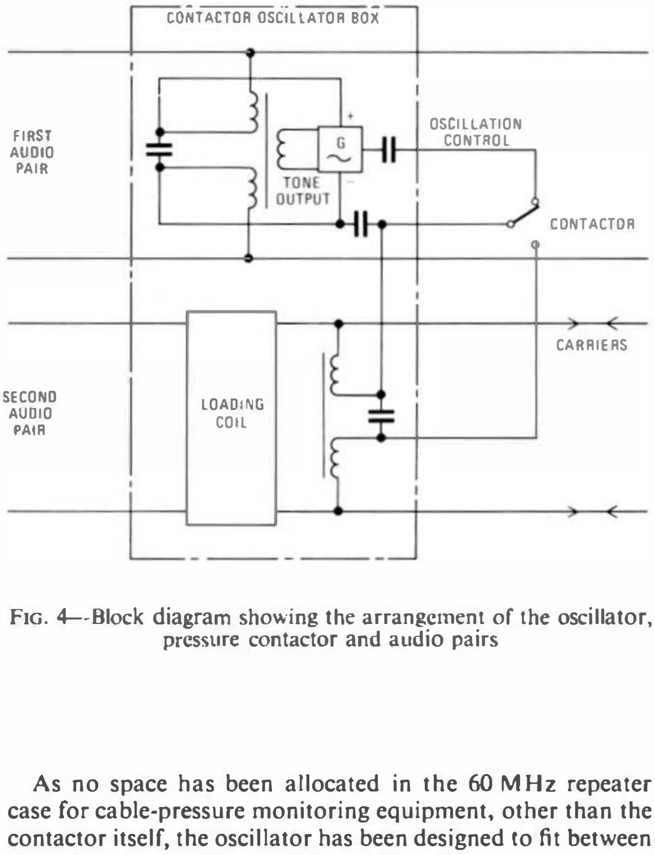

FIG. 4—Block diagram showing the arrangement of the oscillator, pressure contactor and audio pairs

As no space has been allocated in the 60 MHz repeater case for cable-pressure monitoring equipment, other than the contactor itself, the oscillator has been designed to fit between the outer case and the cable box within the repeater case, as shown in Fig. 3. This limits the oscillator external depth dimension to about 29 mm, which thus restricts the tuning capacitor size.

To minimize frequency drift with temperature, the tuning capacitors in the oscillators are of the polystyrene type, and have a negative temperature coefficient. The inductor core has been chosen to have a complementary positive temperature coefficient. Polystyrene capacitors are, however, fairly large and this, together with the limited space available, prevents the use of frequencies lower than about 980 Hz.

Power is fed to the oscillators on the same pair as is used to feed the tones back to the surface main station. The output transformer has its secondary winding bridging the pair, with a capacitor completing the a.c. connexion between the 2 halves of the winding. Power is taken from across this capacitor, whereas the oscillator output is induced into the secondary winding and so fed to line. The output impedance is necessarily high to prevent excessive loading of the line by this shunt arrangement. The circuit is shown in Fig. 4.

When the cable pressure drops below the preset limit, the pressure contactor operates and increases the negative feedback, causing oscillation to cease. The contactor also puts a low-resistance shunt to d.c. across the second pair, and this enables a bridge location technique to be used if the primary system fails. The method of controlling the oscillator thus allows d.c. isolation to be maintained between the 2 pairs, even though the contactor has only 1 change-over contact.

The total current consumption of the 22 oscillators when installed in the route is approximately 5 mA at 20 V. In the event of a failure, the current is limited to about 7 mA; the supply thus falls well within normal safety limits.

Lightning protection is provided in the form of 90 V surge-voltage protectors, one across each pair, and a 30 V Zener diode across the oscillator power supply.

OSCILLATOR MONITORING EQUIPMENT

Fig. 1 shows how each section is split up, and the contactor and oscillator numbers arranged for a complete 60 MHz route. Each section is divided into 2 parts, the first 21 oscillators receiving their power from, and feeding their tones to, the left-hand station, and the other 22, the right-hand station. Fig. 5 shows a complete terminal-station equipment and Fig. 6 a complete main-station equipment.

The oscillator pair is terminated in the current-limited power-feeding unit at its respective station. This unit provides initial wideband amplification for all the oscillator tones, which reach the station at a level of about −70 dBm. The amplifier output is connected to a possible 22 tuned receivers, or contactor oscillator monitors, one for each oscillator on the half section. When a pressure contactor operates due to a drop in cable pressure, the associated monitor ceases to receive its tone and so changes the state of its output. This change in logic level triggers a pulse generator, which produces a pulse whose length is a function of the pressure contactor number. Contactor number 2[†] causes a 60 ms pulse to be generated, number 3 an 80 ms pulse, and so on in increments of 20 ms. The longest pulse generated is for contactor number 44 and is 900 ms. Contactor numbers 23-44 have their pulse generator in the station at the section end.

RETRANSMISSION EQUIPMENT

Information on the state of all the contactors in the 2 halves of any one section must be combined before being sent to the terminal stations. In a particular section, the pulses generated by contactors 23–44 at the end of the section are used to modulate a carrier. This carrier is demodulated at the station at the start of the section, and the pulses gated with the information generated by any change of state of contactors 2–22. In Fig. 1, carrier f_6 on the second pair is used for this purpose. Carrier f_6 is a steady 3·5 kHz signal which is modulated to 100% modulation depth by blanking out the tone for the length of the modulating pulse. The system thus works in a fail-safe mode.

Once all the information for a section has been gated together, the pulses are used to modulate another carrier in the same way. However, at this stage, each section is represented by a different carrier to enable the terminal-station equipment to identify the information appropriate to each section. Fig. 1 shows that carrier f_1 is used for section 1, carrier f_2 for section 2 and so on. All 5 section carriers are in the range 0·57–2·43 kHz, carrier f_1 being the lowest. Carriers f_2–f_5 are transmitted in both directions so that both terminal stations receive all the information; carrier f_1, modulated by the section 1 information, is transmitted in one direction only.

The carriers are fed to line and received via a hybrid transformer. As the line used for retransmission is long and

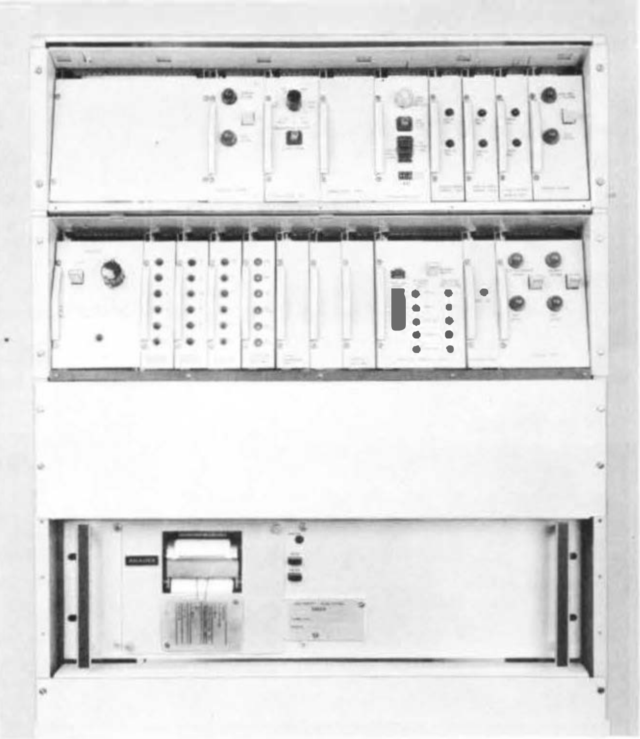

FIG. 5—Terminal-station equipment

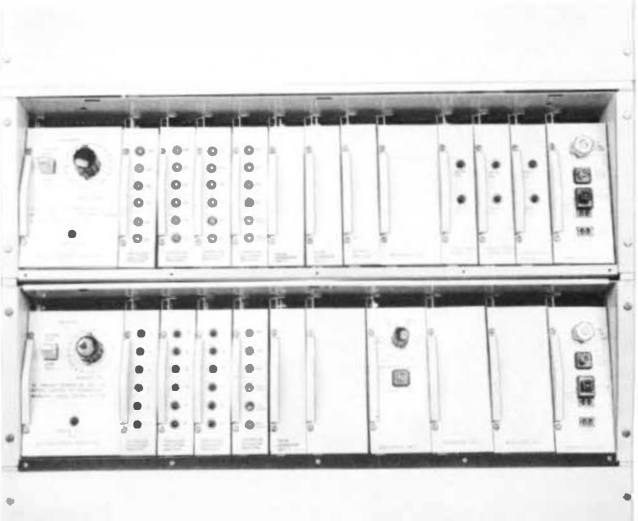

FIG. 6—Main-station equipment

[†] The 43 contactors in a section are numbered 2–44 to correspond with the numbering of amplifying points on the 60 MHz system

has no repeaters, the receive and transmit levels are very different. Thus, to prevent the problem of breakthrough across the hybrid transformer, any one frequency is used in only one direction on the pair between adjacent stations. For the same reason, the second pair is loaded, which reduces the loss, but limits the highest frequency to about 3·5 kHz. A full section, 66 km long, thus has an attenuation of about 34 dB in the passband. The carrier frequencies are as widely separated as possible to reduce the possibility of breakthrough across the hybrid transformer by adjacent frequencies. The cable pair has to be balanced to raise the trans-hybrid loss from about 20 dB to about 35 dB, which also aids separation.

The carriers are demodulated, the pulses regenerated and the carriers remodulated, as they pass through surface main stations. The demodulators are frequency sensitive and have as high a Q-factor as possible to make them selective. However, the value of the Q-factor that can be used is limited; if it is too high, the gap in the carrier due to a modulating pulse will not be detected. This is also the reason for the pulses being so long.

TERMINAL-STATION EQUIPMENT

In addition to the local contactor oscillator monitoring equipment, each terminal station contains equipment for demodulating the carriers, for operating alarms, and for producing permanent fault records. Fig. 5 shows the entire terminal-station equipment.

PERMANENT FAULT RECORD

After the pulses have been extracted from the carriers, they are fed into a control unit. This unit measures the pulse length and produces the code necessary for the printer to operate. The printer has its own crystal-controlled clock for supplying the date and time information.

Every time a contactor operates somewhere on the route, both terminal stations receive a pulse on the relevant carrier. Each pulse causes the printer to print one line of information, normally in black. This line consists of the month, the day, the time, the failed contactor location code, and a 5-column number indicating the time interval, in hours and decimals, since the operation of the first contactor in the fault sequence.

If an oscillator power-feeding unit fails somewhere along the route, the unit generates a pulse, which is retransmitted in the same way as a contactor oscillator failure pulse. The pulse generated is longer than that caused by contactor number 44, and is arranged to produce a red print-out. The contactor code in the print-out has a relevant section number, but the contactor number part of the code is shown as 52; similarly, if a retransmission carrier fails, the printer also prints in red, but indicates that a contactor number 80 has failed. A red print-out thus indicates a system failure and, although the contactor number part of the code does not apply to the state of any contactor, it does indicate the difference between the 2 types of system fault. In both cases, the section number part of the code indicates the approximate location of the fault.

ALARMS AND SUPERVISORY FACILITIES

For each oscillator on the route, there is one monitor, and each monitor has an associated lamp, which is lit only when an oscillator fails, indicating that its respective pressure contactor has operated. These lamps are housed in the surface main station, where the oscillator pair is terminated. They are, therefore, merely a local visual alarm and only those for the half sections at the ends of the route are in the terminal stations. Every demodulator also has a lamp that is lit only when it is not receiving its respective carrier from line.

The control unit for the printer in each terminal station has 5 pairs of lamps associated with it. Each pair of lamps is associated with a section on the route: the first lamp indicates continuously the presence or absence of the respective through transmission carrier; the second lamp provides a memory facility. This second lamp locks on when the first failure pulse is received on its respective carrier. Associated with this control unit is an alarm unit which incorporates 2 alarm lamps. The PROMPT ALARM lamp is operated every time a contactor operates anywhere on the route. The CATASTROPHIC ALARM lamp is operated if the first 3 contactors to operate in a fault sequence do so within 2 h. A power-feeding-unit failure and a carrier failure also operate these alarms. Simultaneously with the first contactor failure print-out, the 150 kPa (1·5 bar) alarm is operated by the loop placed across the second pair by the operated contactor.

To provide an additional indication of the catastrophic nature of a cable-sheath fault, a second contactor is provided in each repeater case. This second device is set to operate at 145 kPa (1·45 bar), and puts a short circuit to earth on one leg of a third audio interstitial pair. It operates an alarm via a unit housed in the terminal station. Both the CATASTROPHIC ALARM and the 145 kPa (1·45 bar) alarm indicate that the cable requires immediate attention.

The PROMPT, CATASTROPHIC, 150 kPa (1·5 bar) and 145 kPa (1·45 bar) alarms all operate the station audible alarm and so have RECEIVING-ATTENTION keys. All the alarm relays are normally operated so that a power failure immediately operates the station alarm. The 150 kPa (1·5 bar) alarm provides a locking facility when operated, to prevent resetting of the memory lamps on the control unit and the interval clock while a fault sequence is in progress.

PRESENT AND FUTURE

The cable-pressure monitoring scheme described in this article has been designed specifically for the 60 MHz routes, but can be applied to any cable route.

ACKNOWLEDGEMENT

The authors wish to acknowledge the help given by colleagues in the Telecommunications Development Department in the preparation of this article.

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A Review of the British Post Office Microwave Radio-Relay Network

Part 3—Equipment

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UDC 621.37 : 001.1

The third and concluding part of this article describes the equipment used in British Post Office microwave radio-relay systems, both in current designs and at various stages in their evolution. The article concentrates on equipment for analogue systems because digital systems are still under development.

INTRODUCTION

Part 1[16] of this article reviewed the history and planning of microwave radio-relay links, and Part 2[33] the performance and reliability. In this concluding part, the evolution of the equipment is reviewed. To discuss in detail all the developments over the past 25 years or so is impracticable. The aim, therefore, is to select the broad areas into which microwave systems are conveniently divided and briefly survey the changes in design philosophy that have taken place. Because digital systems are still under development, Part 3 concentrates on analogue equipment.

DESIGN CONCEPTS AND CIRCUIT TECHNIQUES

It is a tribute to the engineers who pioneered the art[34] that most of the basic design principles set down in the early years of microwave radio communication have remained unaltered. Furthermore, some of the design concepts discarded in the intervening period are being revived in connexion with digital systems that are now undergoing development. For example, direct modulation of the radio frequency (RF) carrier, which was a feature of one of the earliest equipments, may be used in the 11 GHz and 19 GHz equipments.

Although the basic system concepts have changed little during the 25 years of British Post Office (BPO) operations, there have been tremendous advances in radio and electronic technology. As with many other fields of applied electronics, microwave radio has benefited from the invention of the transistor, resulting in a rapid change-over from electronic-tube to solid-state techniques.[35]

The rate of development of semiconductors from the first point-contact transistor in 1948 has been startling and, although the early devices were not readily applicable to microwave systems, the current situation is quite different.[36] For example, varactor diodes and step-recovery diodes are used for frequency multiplication, tunnel diodes provide low-noise front-end circuits of some receivers and Schottky barrier diodes are in use for frequency converters. PIN diodes, which have the ability rapidly to change from high impedance to low impedance with the application of bias, are used for switching at super-high frequencies (SHF), for controlling the gain in intermediate-frequency (IF) amplifiers, and have been tried for modulating digital systems in the phase-shift-keyed (PSK) mode. Linear, transistor-transistor-logic and emitter-coupled-logic integrated circuits have been used for trial digital systems and are currently in use in supervisory systems. Silicon power devices are used in the power units and bipolar transistors abound in the baseband part of the equipment.

Two main types of microwave transistor are currently available: silicon n p n bipolar transistors which have reasonable power handling capacity but are noise and frequency limited, and gallium-arsenide field-effect transistors (FETs) which have better noise performance but are somewhat limited in power handling. The IMPATT* device, which displays a negative resistance at microwave frequencies, is receiving a lot of attention at the moment, as are Gunn diodes.

The use of various types of semiconductor device demanded an appropriate sort of circuitry to be developed. Many methods have been adopted, but it is now normal to use printed-circuit boards in a screened housing to form modules of convenient size for baseband, IF, power and ancillary units. Microwave integrated circuits (MICs) in microstrip form[37] are widely used in the SHF part of modern equipment. Alumina substrates may include ferrite discs

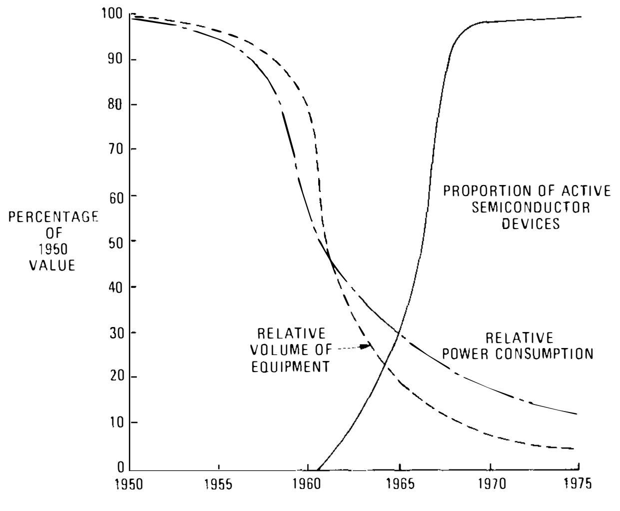

FIG. 19—Effect of advances in solid-state technology on equipment volume and power consumption

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* IMPATT: impact, avalanche and transit time

† Mr. Martin-Royle and Mr. Dudley are in the Network Planning Department of Telecommunications Headquarters, and Mr. Fevin is now in the Service Department, Telecommunications Headquarters

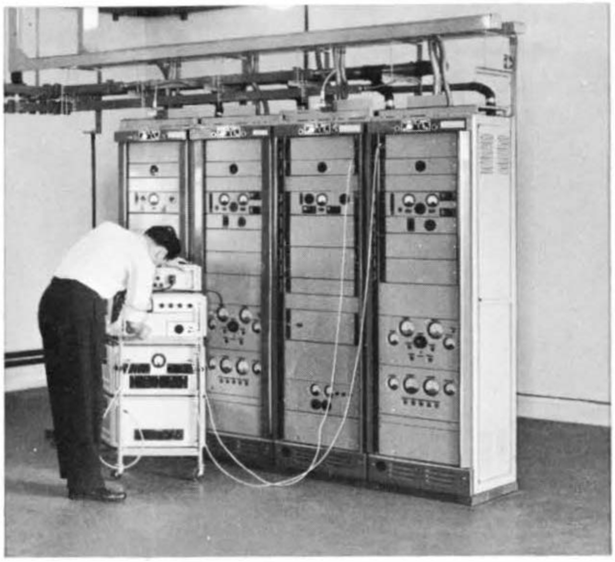


FIG. 20—A 2-channel terminal in typical cubicle construction

inserted where circulators are required. Microwave elements are integrated to form the subsystems. The substrate is mounted in an aluminium housing, connexions being made by coaxial sockets. The use of the MIC technique ensures consistent performance, high reliability and small size.

Because of the change to semiconductored equipment, the radio-station power supplies can now be in d.c., rather than a.c., form. The impact of solid-state technology on the physical size and power consumption of microwave equipments is illustrated in Fig. 19. In the early days, a complex a.c. continuity set was required to provide a no-break station power supply. With d.c. operated semiconductor equipment, battery systems having float charging are sufficient.[38] The reliability of the power supply is significantly improved; the current mean-time-between-failures (MTBF) design objective is 200 years.

The programme of continued innovation has led to better equipment, but this naturally results in a multiplicity of equipment types in service.

EQUIPMENT CONSTRUCTION PRACTICE

The microwave part of radio equipment does not lend itself to the card-and-shelf construction practice that is generally favoured for transmission equipment. Bulky units interconnected at 70 MHz or at microwave frequencies require high-quality coaxial or waveguide connexions, but they must be readily accessible for maintenance purposes. For these reasons, microwave construction practice has tended to follow a unique course.

In the early days, cubicle construction was favoured, similar to the practices for high-frequency radio. A single cubicle, typically 2 m high by 560 mm square, housed either a transmitter or receiver. As designs improved and unit sizes reduced, the basic 51-type rack (2·286 m high, 520 mm wide and 216 mm deep) could accommodate a transmitter and a receiver. Modulators, demodulators and ancillary equipments were mounted in additional 51-type racks. The introduction of 62-type practice coincided with further reduction in unit sizes for modems and ancillary equipments; thus, during the late-1960s and up to the early-1970s, these units were mounted in card-assembled shelf-equipment practice, with the basic microwave transmitter and receiver still located on a 51-type rack.

The dramatic reduction in size now possible due to MICs enables entirely new construction techniques to be introduced. Slim-line equipment practice (SLEP) allows a modern transmitter and receiver to be mounted in a rack only 120 mm or 150 mm wide, 225 mm deep and 2·286 m high. Fig. 20 shows the old cubicle practice, and Fig. 21 shows 4 racks in SLEP, each one containing a transmitter and a receiver constituting, for example, 4 radio repeaters. SLEP is now the BPO standard practice for radio systems, and modem, switching and supervisory equipments are being re-engineered into this form of construction. The 11 GHz digital systems will be developed in this form.

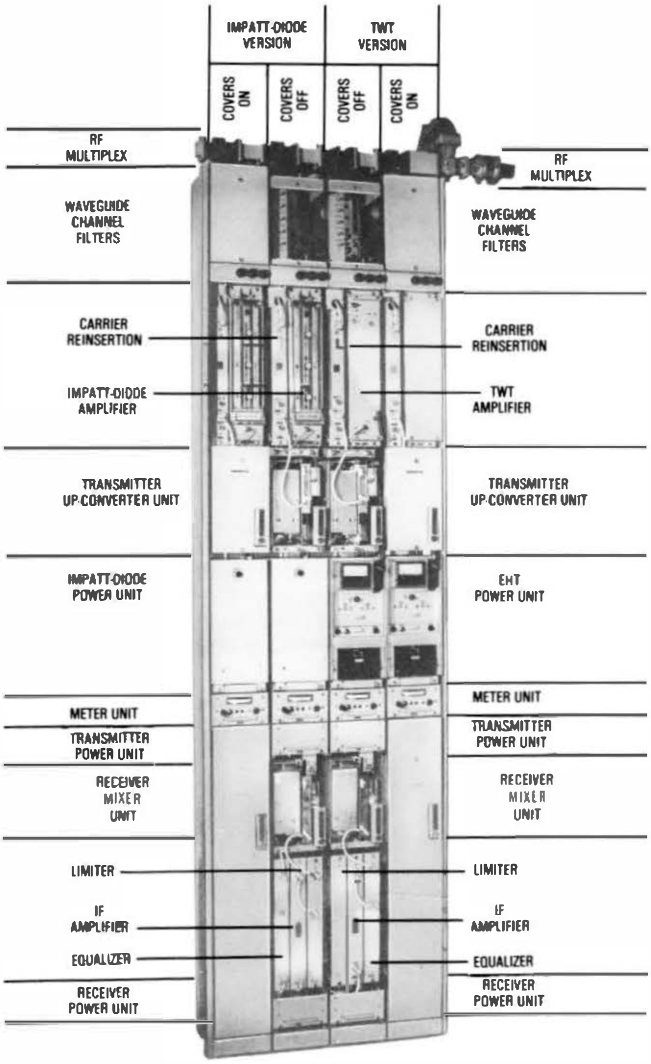


FIG. 21—Four modern repeater racks in slim-line equipment practice

Developments are outlined below in individual areas of equipment that broadly follow the diagram (Fig. 9) in Part 2.

MODEMS

In many of the early radio links using frequency modulation (FM), the modulation process was carried out at RF by causing the baseband signal to vary the reflector potential of the klystron tube that formed the output stage of the transmitter. The resulting variation in electron transit time changed the frequency in sympathy with the baseband signal. This direct RF modulation feature meant that baseband-connected repeaters were necessary. However, the process was not sufficiently linear and distortions arose. Eventually, IF interconnexion of repeaters became the common practice and an International Radio Consultative Committee (CCIR) recommendation was issued to reflect this requirement. A linear IF modulator and demodulator were thus required.

The reactance-tube modulator was used in early very-high-frequency (VHF) work, but the deviation available with adequate linearity was too small. One interim solution for providing an IF output from the modulator was to beat together the outputs from 2 klystrons, each at about 4 GHz, arranging the difference frequency to be the required IF. A coaxial-line oscillator could be used instead of the second klystron.

In 1950–51, the BPO Research Department developed a simple linear modulator based on the resistance-capacitance phase-shift oscillator using earthed-grid triode tubes as the variable-impedance elements.[34] The mean frequency of oscillation was 35 MHz and this was doubled to 70 MHz to give the output IF. The resistance-capacitance phase-shift principle was the basis for all electronic-tube modulators used in the BPO network prior to the introduction of solid-state techniques.

The development of varactor diodes and transistors capable of working at 70 MHz enabled solid-state modulators to be introduced in the mid-1960s. Initially, an oscillator was centred on a frequency of 70 MHz with a varactor diode as the variable-capacitance element in the tuned circuit. The baseband voltage was applied to the varactor diode and, provided that the voltage/capacitance law was correct, linear FM was produced. A junction diode with junction capacitance inversely proportional to the square of the junction voltage was necessary.

A further extension of the frequency range of solid-state circuitry in the late-1960s enabled a return to a twin-oscillator technique similar to the early method. The twin-oscillator or push-pull modulator comprises 2 solid-state oscillators (for example, at frequencies of 448 MHz and 378 MHz), which are modulated in antiphase by the baseband signal. The outputs are then mixed and the difference signal, a modulated 70 MHz, is filtered out to form the output. The advantages of this method are that

(*a*) the sensitivity is twice that of a single oscillator, and so the basic noise of the modulator is reduced,

(*b*) the percentage frequency deviation per oscillator is small, which means that less distortion is introduced and the overload performance is good,

(*c*) the mainly even-order distortion components produced by each oscillator are largely cancelled out, thereby reducing distortion, and

(*d*) abrupt-junction varactor diodes are particularly suitable for operation at these frequencies.

The design of demodulators has, however, remained more or less static. The most common technique is to use 2 tuned circuits, one centred above and one below the 70 MHz IF centre frequency; for example, at 96 MHz and 45 MHz. The outputs from these 2 circuits are detected by series detectors, nowadays using Schottky barrier diodes. The combined output from these detectors, after decoupling the IF signal and its harmonics, is a baseband signal having an amplitude dependent on the instantaneous IF. Such a circuit is highly linear and has a sensitivity of around 60 mV/MHz. The detector circuits are preceded by IF limiters to suppress any residual amplitude modulation (AM), typically by up to 35 dB, but great care is needed to avoid introducing AM–PM conversion in this operation; limiters are notorious in this respect.

OSCILLATORS

The basic objective is to generate the microwave signal with adequate frequency stability, power and freedom from spurious components. When klystron modulators were used, the microwave signal generation was part of this process. Klystrons working in the frequency range 2–35 GHz with output powers of a few watts were obtainable.[34] When IF modulators came into use, the microwave oscillator became a unit in its own right. Klystrons and coaxial-line oscillators were used, but one drawback was the need for a sophisticated automatic-frequency-control circuit. Frequency stability is necessary to maintain the modulated signal within the pass band of the tuned elements throughout the system, which would otherwise result in additional transmission loss, distortion and interference. Crystal control was desirable, but crystal oscillators do not work at microwave frequencies.

The technique developed was to take the output from a crystal-controlled oscillator at about 100 MHz and multiply it up to the desired microwave frequency. At first, electronic-tube multiplier circuits were used, but later, varactor diodes with their very efficient harmonic generating properties offered a better alternative and eased the power requirements of the crystal-controlled oscillator. The introduction of the step-recovery diode, a special form of varactor that is an even more efficient harmonic generator, improved the situation further. However, the basic difficulty with the multiplication process is that the deviation due to the noise components in the basic oscillator output is also multiplied and, hence, the noise output levels are increased. It is desirable therefore to reduce the degree of frequency multiplication, while retaining the crystal-controlled frequency stability. By the early-1970s, transistor oscillators operating at frequencies around 1 GHz were possible and it was convenient to lock them to a 100 MHz crystal oscillator, using a phase-locked loop.[35]

The phase-locked oscillator (Fig. 22) uses a 1 GHz transistorized voltage-controlled oscillator, having its frequency determined by a quarter-wavelength cavity to which a varactor diode is loop coupled. The 1 GHz oscillator output is sampled and its phase is compared with a train of reference pulses derived from a crystal oscillator operating at about 100 MHz; the pulses are generated by a step-recovery diode. The phase comparator output forms a control signal for the varactor diode in the voltage-controlled oscillator. When the voltage-controlled oscillator and reference oscillator are in phase, a constant direct voltage is applied around the loop to the varactor diode to maintain the phase, and hence the frequency, lock. Any variation in the phase relationship causes the direct voltage to vary and adjust the bias on the varactor diode, thereby maintaining the phase lock. This ensures that the 1 GHz oscillator is as stable as the crystal oscillator. To reduce the noise reaching the output from the crystal oscillator, the bandwidth of the loop is limited.

One advantage of this technique is the ability to modulate the oscillator, without losing the phase-locking facility, by placing a second varactor diode in the control cavity. The oscillator is phase modulated by injecting baseband signals into the cavity at a frequency higher than the loop operating frequency. In the BPO, this facility has proved particularly useful for injecting signals for alarms and engineering-speaker circuits at non-demodulating repeaters, below the telephony baseband spectrum, without

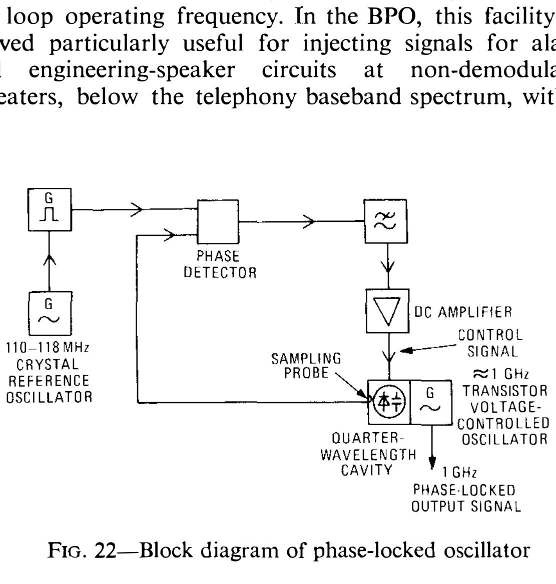


FIG. 22—Block diagram of phase-locked oscillator

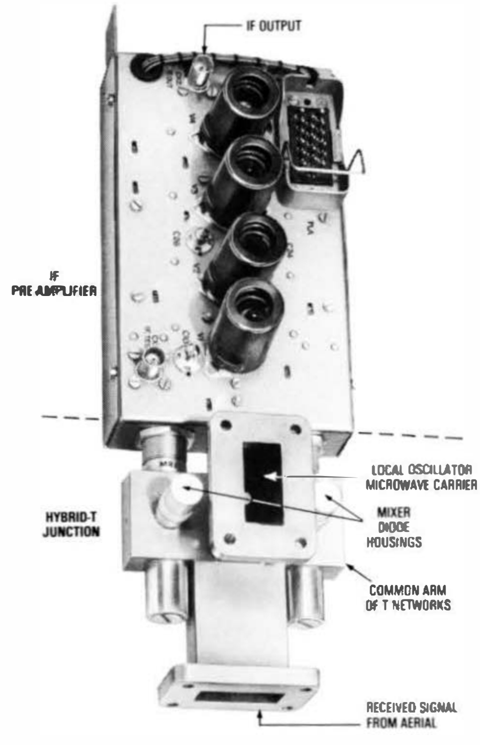


FIG. 23—Hybrid-T receive mixer and electronic-tube IF amplifier (*circa* 1960)

affecting the main signal. Another advantage of the phase-locked oscillator is the ease with which the operating frequency can be changed within the design range, simply by changing the crystal in the reference oscillator and making minor adjustments.

The output level from the 1 GHz phase-locked oscillator is about 350 mW which, if frequency multiplied by 6 using a step-recovery-diode multiplier, yields about 55 mW at 6 GHz.

The development of specialized microwave devices, such as Gunn and IMPATT diodes, makes direct generation of the microwave signal an attractive proposition. This would avoid introducing multiplication noise, but the problem is still to devise a simple technique for obtaining the required frequency stability.

MIXERS

At the transmitter, the FM IF signal and the microwave signal must be mixed to produce the required FM microwave signal. In the receiver, the incoming FM microwave signal is mixed with a locally-generated microwave carrier to produce an FM IF signal. These processes are referred to as *transmitter mixing* or *up-conversion*, and *receiver mixing* or *down-conversion*, respectively. There is some confusion in the use of these terms, but it is proposed to use the terms *up-conversion* or *down-conversion* when the process is achieved by variable capacitance diodes (varactors), and *mixing* when the process is achieved by non-linear resistive diode devices.

Mixers can be either balanced, using 2 diodes, or unbalanced, using a single diode. The circuitry used may be coaxial up to about 4 GHz, and waveguide or microstrip above these frequencies. One popular circuit, in either coaxial or waveguide form, is the hybrid ring.[39] A hybrid ring has a mean circumference of $3\lambda/2$, where λ is the wavelength at the operating frequency; 4 arms are arranged so that the spacing between arms 1–2, 2–3 and 3–4 is $\lambda/4$, and between arms 4–1 it is $3\lambda/4$. Because of this spacing and the fact that energy entering any arm has 2 possible paths to any other arm, a signal entering arm 1 splits equally, but in anti-phase, between arms 2 and 4 with no output from arm 3. A signal entering arm 3 splits equally, and in phase, between arms 2 and 4 with no output from arm 1. Resistive diodes placed in arms 2 and 4 perform a balanced mixing process. Mixers using coaxial hybrid rings have proved particularly useful at 4 GHz where, otherwise, very large hybrid-T junctions would be required.

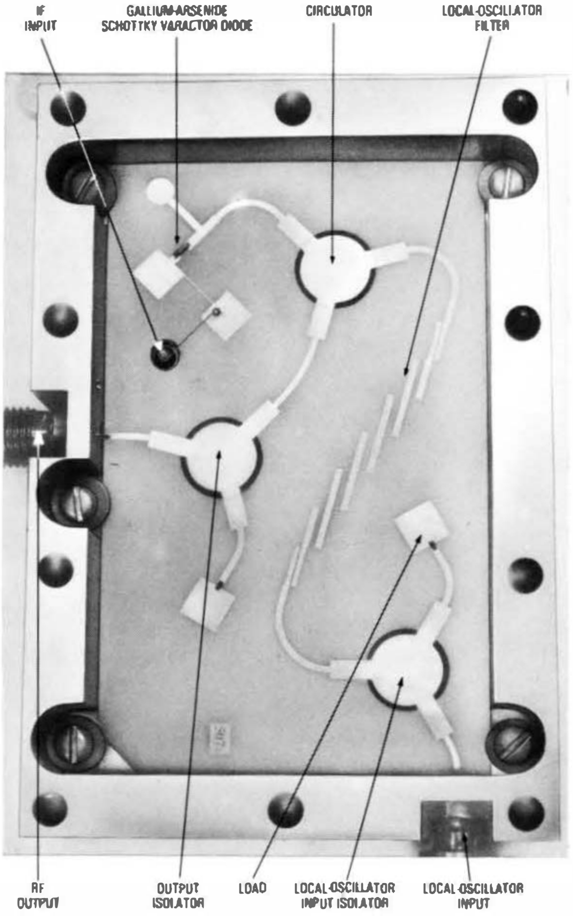


FIG. 24—Modern transmitter up-converter in microwave-integrated-circuit form

Above 4 GHz, the hybrid-T junction has been used extensively. Fig. 23 shows an early type of receiver mixer, using a hybrid-T junction followed by an electronic-tube IF pre-amplifier. The hybrid-T junction is formed by combining 2 symmetrical T arms, as shown. Non-linear resistive elements are placed in the common arms of the Ts. In the early days, point-contact diodes were used, but modern systems use Schottky barrier resistive diodes of much improved performance. The incoming microwave signal from the aerial is fed to one port and the locally-generated microwave carrier from the oscillator to the other. Each of these inputs splits into the common arms where the diodes mix them, giving an output across the diodes at the IF which can then be amplified. One advantage of this balanced technique is that noise components generated in the oscillator tend to cancel out. In the early days, transmit mixers used the hybrid-T junction with non-linear resistive diodes, but the introduction of varactor diodes gave rise to unbalanced up-converters and these became the standard arrangement, either in coaxial, waveguide or microstrip form.

If a varactor diode is mutually coupled to 3 tuned circuits of differing but selected frequencies, either a parametric amplifier or an up- or down-converter is created.[40] If f_1 is the IF signal fed to tuned circuit 1 and f_2 the local-oscillator signal to tuned circuit 2, non-linearity of the voltage/charge relationship of the varactor diode produces the required transmitter output frequency, which can be selected by tuned circuit 3. In theory, there is a power gain offering a very efficient process, but losses in practical circuits prevent this ideal situation being achieved. Fig. 24 shows a practical application using a microstrip technique. The down-conversion process, with the received signal fed to tuned circuit 3 and the IF selected from tuned circuit 1, is less efficient because the local oscillator can absorb power from the signal. For this reason, resistive mixers are still preferred.

MICROWAVE AMPLIFICATION

After the up-conversion process in the transmitter, any required amplification must be carried out at microwave frequencies to increase the power level fed to the aerial so that path and other losses are overcome.

The amplifier that has been used most extensively since its invention 33 years ago is the travelling-wave amplifier (TWA).[41] Despite all the advances in solid-state techniques, only now is the TWA being seriously challenged. The TWA is a wideband electronic tube with a useful life that can exceed 20 kh. Advances over the years have mainly been limited to refinements in the electron-gun assemblies and the change-over from electromagnetic to periodic permanent-magnet focusing.

The TWA requires a direct-voltage supply in the range 2–3 kV, and draws a collector current of about 40 mA. It has a gain in the order of 40 dB. The heat dissipation of a TWA can be relatively high; 70 W for a 10 W signal output is not unusual. This requires very efficient heat-sink arrangements, which become progressively harder to achieve at the higher microwave frequencies; for example, above 11 GHz. Disadvantages of the TWA are its amplitude non-linearity and the relatively high level of AM–PM distortion it produces, typically 3°/dB. AM–PM distortion arises because the tube operates by velocity modulation of the electron beam, which is affected by any amplitude variations of the input signal. The consequent variation in the bunching process leads to phase variations of the output signal. The use of all-solid-state amplifiers offers the attraction of greater reliability, but the TWA is a competitive device in terms of efficiency and output power, and no entirely satisfactory alternative is yet available for all frequency bands. Solid-state techniques also avoid the need for high-voltage power supplies, thereby improving staff safety.

It is possible that the long-term solution will be bipolar transistor amplifiers up to 4 GHz and IMPATT or FET amplifiers at higher frequencies. At present, high-power transistor amplification is readily available at 2 GHz, but, at 4 GHz and above, IMPATT diodes are used. Much development is in hand and the high-power multi-stage transistor amplifier at, say, 6 GHz using FETs may not be far away.

IMPATT devices have produced outputs of 5 W at frequencies up to 11 GHz. The IMPATT diode has been described elsewhere,[36] but briefly it can be considered as a negative-resistance device. If a signal is reflected from an IMPATT diode, it is enhanced in amplitude. A 3-stage IMPATT amplifier operating at 6 GHz is shown in Fig. 25. The overall gain is 24 dB, with a power consumption of about 50 W for a 1 W signal output. This inefficiency of the IMPATT device is its limiting feature and the distortion it introduces is comparable with that of the TWA.

Another novel technique under investigation in the 6 GHz band is the divide-amplify-multiply arrangement. Because transistorized amplification at 6 GHz presents difficulties, the signal is divided down to say 2 GHz, where transistorized power amplification is possible, and then multiplied back up to the 6 GHz band.

Although ultra-low-noise receiver microwave amplifiers are used extensively in satellite-earth-station and radio-astronomy receivers, they have not been economically justified for microwave radio-relay systems where the received signal strengths are of a sufficiently high level to allow mixing without prior amplification. Further, it is questionable whether the use of an expensive receiver front-end amplifier, possibly involving cryogenics, is particularly beneficial in view of the noise that enters the receiver aerial at the low angles of elevation used in line-of-sight links. Available devices include masers, parametric amplifiers and tunnel-diode amplifiers.[42] To gain maximum benefit from ultra-low-noise receivers, they should be located immediately behind the receive aerial, a feature that can lead to maintenance access problems. The advent of the low-noise gallium-arsenide FET without cooling, is causing a reappraisal of the use of receiver RF amplification.

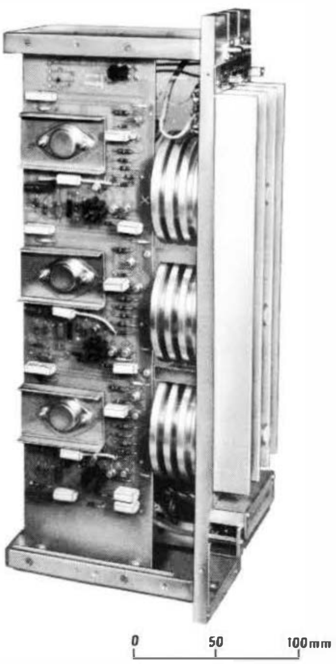


FIG. 25—Three-stage 6 GHz IMPATT amplifier

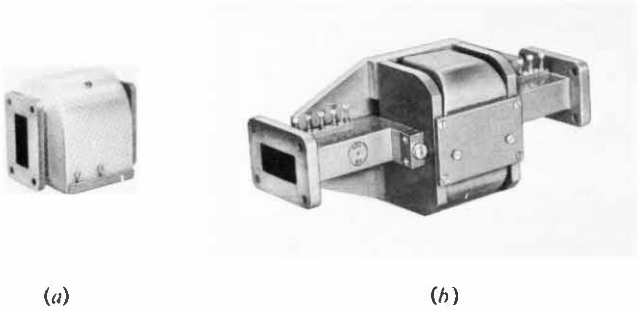
FERRITE DEVICES

The development of microwave ferrite devices[43] from the 1950s onwards has been of major assistance to equipment designers. The most important devices are isolators and 3-port circulators. The 2 main types of isolator in current use are the resonance and field-displacement types, but there is increasing use of 3-port circulators with one port terminated in a matched load to perform the isolator function.

Resonance Isolators

In ferrite materials subjected to a static magnetic field, the orbital electrons of the magnetic ions precess when disturbed because they have angular momentum about their spin axes. The frequency of precession is proportional to the static magnetic field. The resulting resonance effect is analogous to the action of a gyroscope; hence the term *gyromagnetic resonance*.

The resonance effect can be excited by a circularly-polarized RF magnetic field rotating in a plane normal to the direction of the static magnetic field, but in the same sense as the spin precession; it is not excited by a contra-rotating field. Thus, if a ferrite material is placed in a waveguide and a static magnetic field is applied, it absorbs energy from an RF field travelling in one direction, but not in the reverse direction. These unidirectional properties are used in resonance isolators to absorb reflected energy and, hence, improve impedance matching between waveguide components (see Fig. 26(*a*)).



(a) Resonance type
(b) Field-displacement type

FIG. 26—Isolators

Field-Displacement Isolators

Placing a piece of ferrite in a rectangular waveguide disturbs the field configuration inside the guide. If (a) one side of the ferrite is coated with a lossy resistive material, (b) the ferrite is not in its gyromagnetic resonance mode, and (c) the field within the ferrite is at a minimum for one direction of transmission but a maximum for the other, then the resistive coating absorbs energy for one direction of transmission only. An isolation effect is again achieved. The advantage of the field-displacement isolator compared with the resonance isolator is that the former operates over a much larger bandwidth because it is not dependent on a resonance mode. The disadvantage is that field-displacement isolators tend to be larger than the resonance types (see Fig. 26(*b*)).

Circulators

The 3-port circulator consists of a Y-junction of waveguide or microstrip with a magnetized ferrite material at the centre of the junction. The device circulates energy so that signals fed into port 1 appear only at port 2, those fed into port 2 appear only at port 3, and those fed into port 3 appear only at port 1. The precise mechanism of this effect has been the subject of much debate, but the explanation by Bosma[44] is thought to be the most convincing. Three-port circulators are invaluable for combining or branching a number of radio channels into or from one aerial, as shown in Fig. 9. Alternatively with a load connected to one of the ports, the circulator functions as an isolator (termed an *isocirculator*). Circulators can be easily produced in microstrip technology (Fig. 24).

FILTERS

RF and IF filtering is necessary to enable multi-channel systems to operate within the compact CCIR channelling plans, as discussed in Part 1.

The proportion of modulated RF signal containing the wanted information occupies a bandwidth that is only about 2·5% of the carrier frequency. This allows RF filters to be realized in waveguide using resonant elements to achieve high Q-factors and low insertion loss. The resonant element is a cavity, or a number of cavities, formed within the waveguide by inserting obstructions such as metal plates or posts. When 2 obstructions are placed a distance l apart in a waveguide, the section between them behaves as a cavity of wavelength $2l$, or an integral multiple of this; the behaviour is akin to sound resonance in a closed organ pipe. The energy is reflected to and fro, with each reflection at the input end arranged to be in phase with the energy introduced at that end. Screws can be inserted through the side of the waveguide into the cavity to effect fine tuning by varying the capacitance or inductance of the cavity. Although simple in concept, the design of the obstructions necessary to achieve the desired filter pass-band and stop-band amplitude and phase responses is a science in its own right.

There have been enormous advances in filter design, with the emphasis on synthesis techniques using computerized mathematical modelling. Currently, a very active interest is being taken in linear-phase waveguide filter design with which, by unique design principles, the requirement for external group-delay equalization is minimized.

A typical bandpass waveguide filter, in current use for channel separation at 6 GHz, consists of 7 cavities and gives an overall Chebychev response. This has a bandwidth of 56 MHz to the half-power points.

Channel selectivity depends mainly on the IF filtering in the receiver. At 70 MHz, lumped-element filtering is used. An IF filter for an 1800-channel 6 GHz receiver is inserted between the IF pre-amplifier and main amplifier; it typically has a Chebychev response with a 3 dB bandwidth of 40 MHz, and high attenuation points tuned to ±29 MHz to give good rejection of the residual adjacent-radio-channel energy after the RF multiplexing and filtering.

Reference 45 gives a useful description of the current state of the art of filter design.

FEEDER SYSTEMS

Apart from the 2 GHz band, where coaxial cables are still usable, waveguide is normally used to connect the aerial on the tower to the equipment in the building. In the early days, rigid rectangular waveguide operating in the dominant H_{10} mode was used. The waveguide was manufactured either in brass or, more usually copper sections, typically 4 m long. Each section was bolted together by means of a flange and a waveguide run involved many joints. One such feeder is required for each polarization of the aerial launch unit. Clearly, such a system requires careful planning of the waveguide route, but inevitably, because of small on-site variations, field jointing is necessary.

To avoid the ingress of moisture, it is normal to pressurize waveguide systems with dry air. A disadvantage with rigid sectionalized waveguide is that, with time, the joints may leak and corrode. The corrosion can cause non-linear impedances, which give rise to intermodulation problems. The typical loss of rectangular waveguide is about 0·06 dB/m. Where very long waveguide runs are required in conjunction with 1800-channel systems, this loss can be unacceptably high.

In the 1960s, when wideband horn aerials were introduced, circular waveguide was adopted because of its wideband properties and low loss. If circular waveguide is operated in the H_{11} mode, but has a diameter greater than the minimum required to support this mode, the guide is said to be *over-moded* and can support several frequency bands; the transmission loss is extremely small, typically 0·01 dB/m at 6 GHz. Further, because the waveguide is circular in cross section, it can support 2 planes of polarization. The waveguide was manufactured in 5 m sections, which were bolted together. Circular waveguide presented very severe electrical and mechanical problems; for example, mode conversion and the need for straight runs on the tower but it did reduce the number of waveguides required.

Apart from the main feeder run, consisting of jointed sections, there is a need for a flexible connexion. Flexible waveguide can be achieved fairly readily, as illustrated in Fig. 27. The construction consists of a number of small sections, which move relative to each other. The entire grouping is held within a rubber casing. It is also possible to produce twistable flexible waveguides, but these are not favoured by the BPO because with use they tend to introduce additional intermodulation.

The engineering problems of rigid waveguide were alleviated with the development of elliptical corrugated bendable waveguide. Basically, this is a natural progression from very-high-frequency coaxial cables, which often have corrugated outer conductors. If the inner conductor and dielectric are removed,

(*a*) Flexible waveguide
(*b*) Bendable elliptical waveguide
(*c*) Rigid waveguide bend
(*d*) Bendable elliptical waveguide with flange

Fig. 27—Typical waveguide sections

there remains a corrugated circular waveguide. But energy transmitted by such a waveguide tends to rotate and, to avoid this, the circle is compressed into an ellipse. Fig. 27 shows an example of bendable elliptical corrugated waveguide, with a rigid waveguide termination. This new type waveguide can be manufactured in long lengths, transported on a drum in the same way as coaxial cable, and installed on site without precise pre-engineering. The losses are similar to those incurred by using rectangular waveguide.

At the 19 GHz frequency, there is interest in the use of helically-wound H_{01} circular waveguide for connecting the aerials to the equipment. Such waveguide would not be subject to the difficulties experienced with the earlier type of circular rigid waveguide.

AERIALS

Aerials are required to match the RF energy from the waveguide to free-space impedance. Ideally, all the energy should be restricted to a very narrow beam of say 0·7°. However, the design of any equipment depends upon the technology available and is usually a compromise between cost and acceptable performance. In practice, some 60% of the total energy is concentrated in the main beam.

The power gain with reference to an isotropic aerial is proportional to $4\pi KA/\lambda$, where K is the aperture efficiency, A is the aperture area and λ is the wavelength. Therefore, for an aerial of fixed frequency, power gain can be improved only by increasing A and/or K. Increasing the size of the aerial sets constraints on the tower because of increased wind loading, and so the BPO uses an aerial of 3·7 m diameter for most systems now being installed. Increased aperture efficiency is more difficult to attain, but improvements have been made over the years. Table 7 lists some of the types of aerial used by the BPO.

In an attempt to improve electrical performance such as the sidelobe, front-to-back and cross-polar discrimination parameters, many innovations have been adopted on the aerials; for example "blinker" plates, wideband microwave absorbing materials and quarter-wave notches or castellations fitted to the outer rim of the reflector. In the case of the latest Cassegrain reflector, blinkers and absorbent material are attached to the aerial to reduce sidelobe radiation. The castellations improve the front-to-back ratio by a figure of 7–10 dB by redistributing the energy spilling over the edge of the reflector (see Fig. 28).

A greater understanding of the cross-polar characteristics of aerials and the ability to measure these on reflection-free test ranges have led to better designs. As with the much larger satellite earth-station aerials, computer-aided design allows the performance targets to be met with only limited programmes of construction and testing of experimental aerials.

DIVERSITY

To counteract propagation difficulties, the BPO favours height diversity with phase-combining techniques,[35] although a switched type of height diversity has been used. In a height-diversity system, 2 receive aerials are placed on a tower at heights carefully chosen so that, when one aerial has minimum signal strength, there is a high probability that the other has a usable signal. In a phase-combining system, the signals from the 2 aerials are aligned in phase and added together in a wave-guide directional coupler. To effect the phase alignment, the difference in time delay between the signals is minimized by ensuring that the waveguide runs are the same length and

TABLE 7
Typical Microwave Aerials used by the BPO

Type of Aerial	Polarization	Year of Introduction	Typical Power Gain* (dB)	Typical Aperture Efficiency (%)	Remarks
3 m diameter paraboloid	Monopolar	Pre-1960	39·4 (4 GHz)	55 (4 GHz)	Heavy cast reflector, poor sidelobe performance
Large horn[46] (9 m high)	Bipolar	1961	45 (6 GHz)	52 (6 GHz)	Wideband (4–11 GHz), good electrical performance, mechanical construction creates maintenance problems
Early Cassegrain (3·7 m diameter)	Bipolar	1963	43 (6 GHz)	35 (6 GHz)	Single frequency band, good sidelobe performance, low efficiency
Focal plane paraboloid (3·7 m diameter)	Bipolar	1965	44·5 (6 GHz)	45 (6 GHz)	Single frequency band, light spun-aluminium reflector, inexpensive to produce
Latest Cassegrain	Bipolar	1975	45·8 (6 GHz)	68 (6 GHz)	Single frequency band, good electrical performance, high aperture efficiency obtained by slotted taper feed and optimization of secondary reflector
Future	Bipolar	1979	Design objectives yet to be determined		Dual upper 6 GHz and 11 GHz frequency band, good electrical performance with high efficiency

* Measured relative to the gain of an isotropic aerial

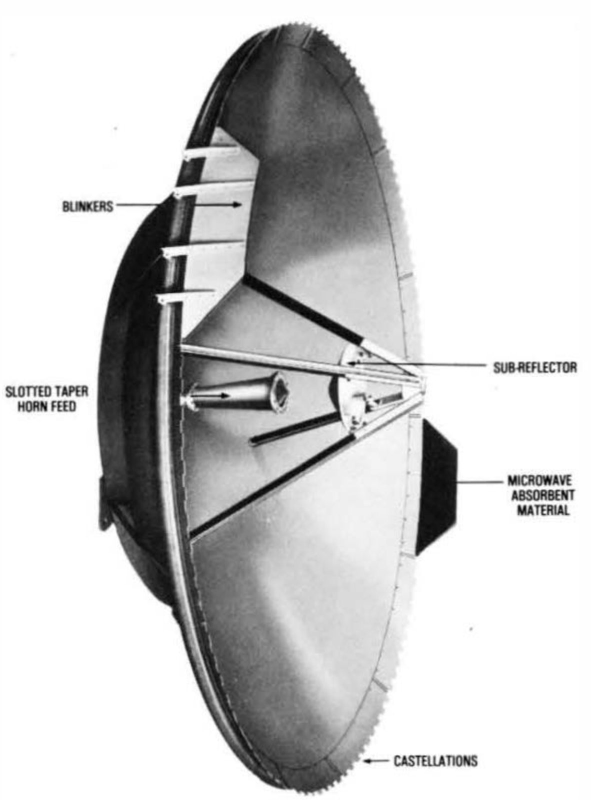


FIG. 28—Latest 6 GHz Cassegrain aerial

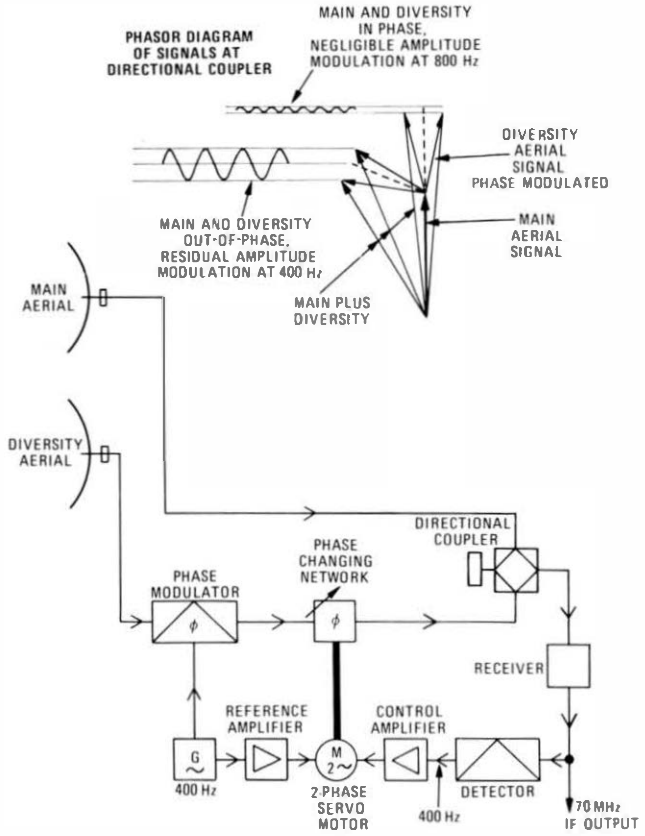


FIG. 29—Principle of phase-combining height-diversity system

a variable phase-changing network is incorporated in one of the feeders. This variable network is adjusted by a servo motor to maintain phase alignment during changing propagation conditions.

To generate a control signal, a ferrite phase modulator is included in one of the feeders; this operates at a low frequency, for example 400 Hz. Fig. 29 shows that, if one of the signals is phase-modulated and added to the non-phase-modulated signal, there is a residual AM of 400 Hz when the 2 signals are out of phase. This forms an error signal which is used to drive the servo motor and this, in turn, adjusts the phase-changing network. When the 2 signals are in phase, the residual AM error control signal virtually disappears, leaving a mainly second-harmonic component of the 400 Hz signal.

One advantage of the phase-combining diversity technique is that the combination of the signals ensures that there is no break in transmission that would occur with switched types of diversity. A second advantage is that only one receiver is required, whereas in the switched-diversity system, it is normally necessary to have a receiver for each aerial, with consequent problems in setting the switching thresholds.

IF AMPLIFIERS

Most of the gain in the receiver is provided at IF. The early links naturally used electronic-tube amplifiers, initially at 34 MHz and later at 60 MHz, prior to the international standardization on 70 MHz. The amplification was in 2 stages: a low-noise pre-amplifier usually, but not always, of fixed gain of 20–25 dB, followed by the main multi-stage IF amplifier with automatic gain control (AGC); this provided a variable gain controlled by the incoming receive signal level and variations in the range 5–55 dB were typical.

These early amplifiers used multi-stage bandpass-coupled tuned circuits with pentode tubes. It was not difficult to apply AGC to the stage, but great care was necessary to control group-delay distortion, which arose at the edge of the band from the tuned circuits. The use of electronic tubes also caused stability problems.

The availability, in the early-1960s, of bipolar transistors with a cut-off frequency in the 300 MHz region permitted the design of non-tuned flat amplifiers with filters providing the selectivity; this marked the introduction of solid-state amplifiers. The application of AGC in such circuits presents a problem. One manufacturer's approach was to use amplifying stages in a common-base configuration, with inter-stage coupling using torroidal transformers to effect the necessary impedance match between the stages; inter-stage limiting provided a form of AGC. The gain per stage was 2 : 1 (6 dB) maximum. In practice, this technique gave high levels of AM–PM conversion, of which designers were becoming increasingly aware at that time. Experience showed that, as a general rule, whenever a variable impedance was shunted by a reactance, AM–PM conversion could occur. Transistor input stages and limiters certainly produced these effects.

By the late-1960s, better transistors with a cut-off frequency of 1·5 GHz became available and this allowed common-emitter circuits to be designed at 70 MHz, at which frequency the current gain was 20. The availability of pin diodes allowed a *variolosser* technique to be introduced for AGC. In this approach, each stage has a fixed gain of about 15 dB and is interconnected to the next stage via a variable-loss attenuator of up to 20 dB controlled by pin diodes. AM–PM conversion was much reduced by this approach, but noise was a problem at high signal levels when maximum attenuation was inserted between each stage.

Later designs comprise an input stage, followed by 5 identical wideband amplifier stages and an output stage. Each stage is formed by 2 transistors connected as a feedback pair, with a pin diode included in the emitter load of the output. DC through each diode controls its impedance at 70 MHz and, in turn, the gain of each stage, which can be varied between 0–10 dB. This modern amplifier has a residual group-delay variation of only 1 ns over a 30 MHz bandwidth, and an AM–PM conversion factor of less than 0·5°/dB. Future designs of IF amplifying stages may ultimately use either thin-film or thick-film technology, but as yet, because there is no volume production for this type of equipment, it is not economically justified. The introduction of integrated-circuit design in IF stages would bring a further reduction in size and even greater reliability.

Receiver IF pre-amplifiers are normally designed for low-noise amplification (typical noise factor 1·5 dB) which, when considered in conjunction with the mixer circuit, achieves an overall receiver noise factor of about 8 dB referred to the mixer input.

Compared with the main receiver IF amplifier, the transmitter IF amplifier is less demanding; a fixed-gain circuit is sufficient since it is only required to generate a large voltage swing to drive the up-converters. Otherwise, the design concepts are similar.

EQUALIZATION

As explained in Part 2, group-delay distortion should ideally be equalized at the point at which it occurs. Individual units of modern equipment design include equalization as part of the design. Nevertheless, it is usually necessary to incorporate into the receiver on each repeater section a group-delay equalizer and, sometimes, an amplitude-response equalizer.

Group-delay equalization relies on the properties of the lattice inductance-capacitance network,[47] in which the phase/frequency response varies widely with variation of component values while, in theory, the amplitude/frequency response remains constant. The balanced lattice network is transformed into the unbalanced bridge-T form for operation in the IF stages, where equalization is normally effected for both RF and IF distortion.

Responses requiring delay equalization are predominantly parabolic in shape. A modern equalizer consists of 3 bridge-T stages in tandem, separated by buffer amplifiers. Each stage provides equalization for a parabolic shape over a frequency range of ± 6 MHz; with one equalizer centred on 70 MHz and the others centred on each side of 70 MHz, the combined action of the 3 stages can equalize a frequency band of 60–80 MHz. If the group-delay/frequency response has a linear slope, an additional tilt equalizer may be necessary. Tilts can occur due to waveguide feeder dispersion or reflections from adjacent channel filters in the RF multiplexing process.

A high-frequency-derivative equalizer is sometimes used (see Part 2), which is essentially a combined amplitude and group-delay equalizer designed to cancel the particular responses that, when interacting with any AM–PM conversion, give rise to differential-gain or high-frequency-derivative distortion.

ANCILLARY EQUIPMENT

Protection Switching

Stand-by plant is usually provided to cover equipment failure. In the original links, every receiver and transmitter was duplicated and RF switches selected the stand-by equipment when required. This hot-stand-by system was replaced by the dedicated protection channel concept, requiring switching of the traffic at terminal stations only. Some administrations and most private users, however, still use the hot-stand-by method, mainly because it saves the allocation of an additional frequency purely for protection purposes. In the late-1950s/early-1960s, protection switching was effected by relays at baseband frequency, but by the mid-1960s, all-solid-state switching at the 70 MHz IF was adopted. The switches and associated logic circuitry followed normal transmission equipment practice fairly closely, and the switching equipment normally occupied a 51-type rack or, in later years, part of a 62-type rack. IF switching has been described in an earlier article in this *Journal*.[30]

To operate the switching, telemetry signals must be transmitted between the 2 terminal stations. This is usually achieved by the use of voice-frequency tone combinations transmitted over dedicated audio circuits. Because there is also a need for engineering speaker circuits for operational purposes, several audio circuits are provided by normal multiplex techniques. The bearer circuit used may be a separate auxiliary radio channel or, preferably, a sub-baseband part of the traffic channel that would otherwise be unused.

The BPO's policy is to aim for an availability for these service channels one order better than that necessary for the traffic they protect. A double protection arrangement is achieved by using the sub-baseband on 2 radio channels, which are themselves individually protected by the normal protection switching.

Supervisory and Control Equipment

Alarms from every station, terminal and repeater must be provided in cases of equipment failure and also, because of the automatic switching of traffic, the maintenance engineer must have supervisory indications of the traffic routing through the switches. For operational reasons, it must also be possible to override manually the automatic switching. Finally, because radio stations tend to be in remote locations, a supervisory and control point is desirable and this is often located several kilometres away from the terminal radio station. Radio systems therefore require telemetry circuits between the remote control point and the radio stations. Many novel means have been developed for this purpose and have been described in this *Journal*[31]. They tend to be variants of voice-frequency-tone signalling over audio circuits. The equipment therefore follows normal transmission and telegraph principles.

BUILDINGS, ROADS AND STRUCTURES

Buildings have progressed from tin huts located at the top of lattice steel towers, to unit-automatic-exchange type of buildings sited at ground level near the structures, and finally to the modern single-storey extendable buildings adjacent to the structure. The present-day single-storey building is designed with a flat roof so that it is inconspicuous on the top of a hill. Facing stone in keeping with the surroundings can be used to accord with local planning authority wishes. The building is modular, having a steel frame and a concrete roof, and modules can be added systematically as future expansion demands (see Fig. 30).

A module is some 3·3 m long by 8 m wide. The most usual initial building provision comprises 2 parts:

(*a*) a section 19·5 m long (6 m welfare facilities, plus 4 modules of radio apparatus room), and

(*b*) a section 19·5 m long (6 m battery room and waveguide pressurizing room, and 13·5 m power room housing the stand-by generator and waveguide pressurizing plant).

Access Roads

It is usual to provide a metalled carriageway to give access from a public road to the radio station.

Structures

The design of aerial-supporting structures for microwave stations in the BPO has been given a comprehensive treatment in this and related *Journals*.[48,49] The structure, with aerial clusters, is the symbol of a microwave station and is the one thing about which everyone has a subjective opinion. It is a very personal judgement whether a particular structure is regarded as elegant or hideous. The BPO aims to minimize

FIG. 30—Typical BPO radio station

impairment of the environment and to provide the most economical design that meets with local requirements as expressed by the planning committees. But no single design is ever acceptable to all tastes or all the differing site requirements.

SUMMARY

In the 1930s, there was great interest in the use of microwave frequencies for radio communication, and experimental links were built and tested in the field. However, it was the stimulus of nationwide television coverage, which created the demand, and the technology spin-off from war-time radar development, which provided the means, that enabled a viable microwave radio-relay system to be put into operation by the BPO some 25 years ago. Since then, a comprehensive network of stations has been built up, so that microwave systems carry not only most of television distribution but also a significant proportion of trunk telephony.

During this period, system planning principles and basic engineering concepts have changed little, but there have been great changes in technology and improvements in detailed design. The most dramatic change came from the application of solid-state technology, drastically reducing both equipment size and power consumption. The noise and distortion performance has greatly improved. Shorter repeater sections are now preferred, but careful frequency and route planning is essential to guard against short-term and long-term interference. A high degree of service availability is achieved by the provision of automatically-switched redundant channels, which can be usefully employed on a part-time basis for other traffic; for example, Confravision.

The introduction of time-division-multiplex techniques into the main high-frequency transmission network in preparation for the adoption of digital switching has produced the need for a digital radio system. Such a system is in course of development for the 11 GHz band, which will provide a medium-distance to long-distance digital transmission capability, while using the existing network of stations and the large capital investment in sites, buildings and towers this represents. Above this frequency, interest lies in a 19 GHz system, which uses a short-hop concept because of the additional path attenuation caused by heavy rain.

Looking further into the future, it is likely that still higher frequency bands will be used for short-hop radio systems, but probably not for long-distance links. One possibility is to use radio at frequencies above 25 GHz for local distribution of telephony, telemetry, data and video services.

As the digital network grows and the demand for further analogue capacity declines, it may be necessary to exploit the existing network of radio stations by re-using the lower frequencies (2–7 GHz) for digital systems. Efficient usage of the spectrum would be vital, and so would a scheme for smooth transition from analogue to digital working on any route. This subject and the host of new problems are currently undergoing study. Should the outcome be favourable, radio could be in for another interesting phase in its history. In the meantime, it is certain that microwave radio still has a role to play in the transmission network.

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The Move of Research Department to Martlesham

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The transfer of some 1400 Research Department staff and their families to the new Research Centre at Martlesham, is now complete. This article reviews organizational aspects, and the social and administrative problems related to the move. Detail of the advance moves to temporary laboratory accommodation and the distribution of families now settled in Suffolk is also included.

INTRODUCTION

The planning and basic design concepts for the new British Post Office (BPO) Research Centre at Martlesham and the services provided have been described in a recent article* in this *Journal*. However, these aspects represented only part of the project of moving the Research Department from London to East Suffolk. The staff also had to be moved, and this more human aspect with its administrative and social problems forms the basis of this article, which complements the previous description of the Martlesham project.

A research unit relies on the quality and experience of its personnel more than most organizations. The BPO Research Department had an excellent staff that had been built up over many years, and it was essential to the BPO that, as far as possible, this team should move in its entirety to the new location. So, from the start of operations, the Director of Research urged that all research staff were expected to move to Martlesham. In the event, nearly all of them did, but some interesting problems were faced before this result was achieved.

THE MARTLESHAM MOVE COMMITTEE

The difficulties that led to the abandonment, in 1963, of the proposal to move the Research Department to Harlow, had arisen because of breakdown in consultation between the Engineering Department Management and the Research Department Staff. The lessons drawn from this were studied carefully. In particular, it was realized that close liaison was needed between management and staff early in the stages of planning. So, a standing committee, known as the *Martlesham Move Committee*, was set up under the Director of Research, with the terms of reference "to consider all aspects affecting staff arising from the move of Research Department and to recommend action where necessary".

Originally, the Move Committee was responsible to the Engineering Department Engineering Whitley Committee, but after the first meeting, held at Dollis Hill in 1964, only members of Research Department sat regularly on the Move Committee. A new small division of Research Department (R10) had been set up to plan and co-ordinate the move. A major duty of the new division was to run the Move Committee. Research Department staff associations provided 10 representatives. Specialists were co-opted as needed.

The original terms of reference remained substantially unchanged throughout the entire project until the official opening in November 1975. The Move Committee met monthly (it held 130 meetings in all), and provided a vital link between the management and staff unions. During the design years, 1965–68, the Move Committee provided an invaluable forum for obtaining staff opinion on many features of laboratory and workshop details; for example, dimensions, lighting, furnishing and necessary services, and on the facilities preferred in restaurants, welfare rooms, the library and a host of similar matters. The data obtained featured significantly in the information fed back by the Move Division to the architect and the project design team. From 1968, the work of the Move Committee necessitated the setting up of 4 specialist sub-committees that provided liaison between management and staff on the following matters:

(*a*) accommodation on the Martlesham site,
(*b*) housing for staff,
(*c*) welfare, and
(*d*) education and school facilities.

The work of these specialist committees is discussed later in this article.

In 1969, when the BPO ceased to be a Department of State and became a public corporation, the Move Committee suffered organizational discomforts from disagreements between the national headquarters of various BPO staff unions and, to keep the work flowing, had to function in duplicate. This inefficiency was removed when the Council of Post Office Unions (COPOU) was established and the Move Committee became part of the Joint Consultative Committee structure between the BPO and COPOU.

In all Move Committee work, the aim was to encourage the interchange of ideas between members. Meetings always started with a brief report from the Chair giving progress on any aspects of the move project that were currently of outstanding interest. These always included progress on the design and construction of buildings and, when people were about to transfer, anything likely to affect families arriving in Suffolk. From experience, it was found that liaison was improved if a brief progress report was issued to members a few days ahead of each meeting.

MARTLESHAM NEWS-LETTER

The importance of maintaining good channels of communication between management and staff in dispersal moves cannot be over-emphasized, especially as a way of scotching rumours and improving morale in a project affecting the lives of hundreds of families. For example, delays in the building contractor's programme due to a national strike of builders' men, followed by dislocation caused by the contractor's financial difficulties, had to be clearly explained to families whose future could be affected as a result. Staff

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[†] Mr. Floyd was Head of the Division responsible for the planning of the Martlesham Research Centre and for organizing the move from Dollis Hill, from the beginning in 1964 until his recent retirement

[*] C. F. Floyd. The Design of Martlesham Research Centre, Parts 1 and 2. *POEEJ*, Vol. 69, p. 146, Oct. 1976 and p. 258, Jan. 1977

morale in Research Department ebbed and flowed like the tide with each recession of the predicted completion date. Many people viewed the move with scepticism: "it will never happen" was often heard in conversations at Dollis Hill. To counter this attitude, every opportunity was taken to place accurate up-to-date information in the hands of each individual in the Research Department, by means of a Martlesham News-Letter written with the support and agreement of the Move Committee. A copy of this letter, produced in distinctive format, went to everybody at approximately quarterly intervals. The News-Letters were invaluable for reporting progress and dispelling false rumours.

INFORMATION BOOKLETS

The shock effect on the staff of the prospect of an enforced move to a country environment was slow to develop; but demand gradually built up for authoritative written information on housing and educational facilities in the Martlesham area, and the financial conditions pertaining to this "dispersal move"; that is, a move essential to permit expansion of BPO research but also under central Government direction. Therefore, the Move Division, with the help of the Move Committee, compiled 3 authoritative handbooks that were given to all staff participating in the move to Martlesham. The handbooks dealt with the following topics:

(*a*) removal expenses,
(*b*) housing, and
(*c*) education.

The booklets were printed in a format similar to standard Research Department publications; correction sheets to up-date the information were included as necessary.

INFORMATION ROOM

Information was obtained from agents in Suffolk offering houses for sale, or rooms to let. Data were also obtained from local authorities on planning proposals for the locality. This information was made available to the staff and was also displayed in a small information room at Dollis Hill, where a member of the personnel section of the Move Division was in attendance to answer questions.

STAFF DISCUSSIONS

The move to Martlesham was completed in stages, spread over a period of 7 years; each new area of completed accommodation, whether temporary or permanent, was greedily ear-marked for use by a particular duty as soon as a date for availability was fixed. Therefore, it was necessary to brief members of individual work groups as the date for departure approached. This was first done, in general terms, at question-and-answer sessions with whole Divisions, about a year in advance, and again more specifically to smaller groups, 6 months in advance, when a firm date for transfer to Martlesham was given to each person.

Considerable experience was gained on how people reacted under the stress of an enforced move. Behaviour patterns were quickly recognizable and this enabled individuals to be helped more effectively. A man usually accepted the need to move with his work, but his family often resisted at first because of the fear of losing old friends and familiar environments. For families with children, the need to change schools sometimes presented problems, as did the need to remain close to elderly relatives. On the other hand, life in Suffolk offered attractions that did not exist in London.

PUBLIC RELATIONS

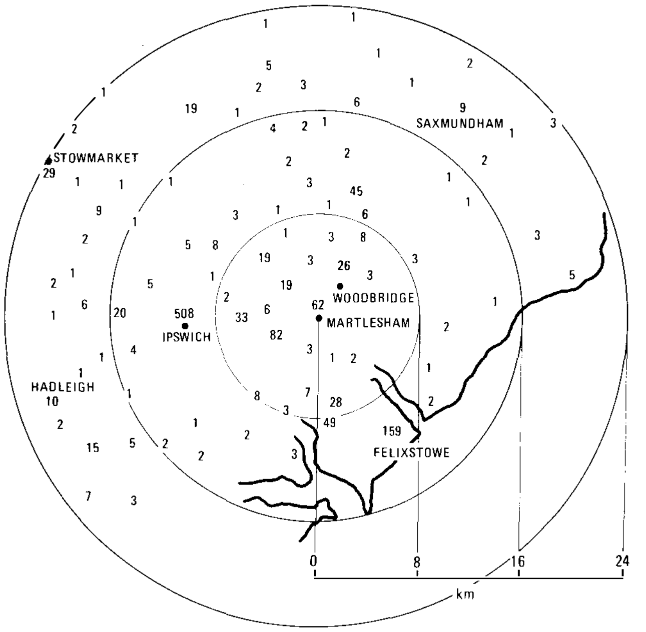
It was realized that the first impressions the new arrivals gave to the local residents and the local authorities could affect the whole social atmosphere for Research Department staff and their families for years ahead. A sense of well-being is essential amongst research staff, who are most likely to work creatively in a congenial atmosphere. Every opportunity was taken, therefore, to foster good public relations between the Research Department and East Anglians. The work of the laboratories was explained at talks given to local authorities and societies, including many professional and commercial organizations. Technical colleges and schools were very interested in the work of the Research Department, and were particularly attracted by the career prospects for young people when the Research Centre became fully operational. Research Department personnel also contributed to the Ministry of Employment career functions in East Anglia and spoke at their conferences. The effect of all this effort to become favourably established was accumulative. There was immense curiosity about the role of the Research Centre in the BPO and there were the wildest rumours about why Martlesham was chosen. The lectures, talks and discussions, soon dispelled the uncertainties and removed fears that the area would be ruined by a flood of "boffins".

The new arrivals found homes over a radius of up to 32 km from Martlesham and soon integrated with the local communities. Some wives, already trained teachers or nurses, were able to return to work, being welcomed in Suffolk, and the Research Centre offered employment to many non-professionals as well as young people seeking an engineering or scientific career.

HOUSING

With some 1400 staff moving out of London, about the same number of additional homes were needed in East Suffolk. Martlesham is in the country; the nearest town is Woodbridge (population about 10 000), which is 4·8 km away, with Ipswich (population 123 000) 11·3 km and Felixstowe (population 22 000) 14·5 km away. Many of the new arrivals chose to live in country villages, and the impact in this sparsely populated county was quite noticeable. Before the move from Dollis Hill started, a questionnaire on individual housing requirements was sent from the Move Division to all members of Research Department. The replies received were not in any way binding, but they gave some indication of accommodation needs. Over a 1000 staff expected to buy their own houses, and initially some 300 were interested in seeking local authority houses to rent. The rest, many of them single, would "wait and see". The Housing sub-committee of the Move Committee acted to liaise with the 3 local authorities that bordered on Martlesham (Deben, Woodbridge and Felixstowe), who found that an additional 300 council houses would be quite a heavy burden on their finances. Nevertheless, all co-operated, each promising to make some houses available to rent to families as they arrived. In the event, only about 120 families, out of the original estimate of 300, have taken up local authority houses, the remainder deciding to become house owners themselves.

Although the contractual delays that occurred in the new laboratory building work, which effectively extended the span of the actual move to about 7 years, greatly eased the housing problem, some short-term difficulties were created. There happened to be an upsurge in demand for private housing in the Ipswich/Felixstowe district during 1972 due to the arrival of large commercial organizations from London, and the sudden phenomenal growth in activity at Felixstowe docks. These made more impact on the housing market at that time than did the arrival of BPO research staff. The effect of inflation and shortage of money for mortgages predominated, particularly from 1972 onwards when houses in London were becoming difficult to sell. Bridging loans, enabling staff to secure the purchase of a new property before the completion of the sale of their existing property, were in



Note: The numbers represent the families in that parish

FIG. 1—Distribution of families of Research Department in Suffolk

demand. The special terms attached to a dispersal move enabled the BPO to offer some financial assistance to those who were forced to take out bridging loans.

There was a shortage of suitable houses in the area for some time but, fortunately, in 1970, Research Department had started its own preparations to safeguard against possible housing shortage, by acquiring a number of small modern houses that could be rented temporarily to staff for up to 6 months as staging-post houses. This idea had much merit in that it enabled a man to move to Suffolk on his appointed date and yet give his family time to decide where to live, or to await completion of a house still under construction. A total of 49 houses was purchased for this purpose and the added flexibility was of inestimable value to the move during the years 1971–75. The need for those houses has since passed, and they will be sold on the open market; the project was self-supporting during the 7 years that the houses were let.

The original expectation that most of the staff would choose to live near to Martlesham has not been borne out. Road traffic is light in Suffolk, and the majority of staff have chosen to live within a 24 km radius of the Research Centre; some live even further away. Those families with children have tended to live near Ipswich, where more schools, shops and social facilities are available than in smaller communities. Many families prefer village life, and Suffolk is one of the best counties in England for this. A number of people have already made a second move of house to take advantage of the wide variety of houses now on offer. Fig. 1 shows the general distribution of the staff of Research Department over the area around Martlesham.

ADVANCE MOVES INTO TEMPORARY BUILDINGS

Now that the move of the Research Department to Martlesham has been completed and the whole project of setting-up the Research Centre can be seen in perspective, the importance of the measures taken on the site in the early days before the main building contract was started can be assessed. It is worth recording some of this history, for the BPO obtained considerable benefit from the engineering research that was then carried out, despite the fact that move plans were being held back by building delays.

The Martlesham Research Centre has been built on the site of an airfield that was abandoned by the Royal Air Force before the BPO signed a lease in 1966 for the 0·4 km^2 site. The site contained some small buildings that were sound in construction, and with the help of the then Ministry of Public Buildings and Works a few of these were adapted for temporary use as laboratories. In April 1968, Research Department transferred its first advance party of laboratory staff to Martlesham; among the early projects were waveguide experiments, for which an 800 m plot of open ground was needed. Pressure on accommodation was thereby relieved at Dollis Hill and, at the same time, there could no longer be any doubt that the Research Department was serious in its assertion that it was moving to Suffolk. Only 30 volunteers were in the advance party, but it was a most successful venture, and some outstanding research work was carried out. These temporary laboratories functioned well for 8 years.

Because there were no catering facilities in the vicinity, a restaurant was essential from the outset. So, the disused RAF sergeants' mess was refurbished and suitably equipped to BPO catering standards. The BPO Eastern Region catering service operated the restaurant most efficiently on behalf of Research Department until the new main restaurant opened in 1975.

When it became clear that the contract for the main laboratory buildings would not be completed on time, some flexible contingency plans were devised to give temporary increases in accommodation at or near Martlesham. The erection of factory-built single-storey systematized timber-frame buildings of a type much used for schools and temporary hospitals was recommended by the architect. The first of these timber buildings (effective area: 2322 m^2) was opened in October 1969. A second building (3252 m^2) was attached to it in the following year and an extension was added to the first building. These timber buildings were grouped in the north-west corner of the site where they would not interfere with the contractor's access to the enclosure surrounding the new main building works. Over 400 staff were transferred from London into these and the ex-RAF buildings as they were completed, so keeping up the momentum of the move through 1970–72. Although these timber buildings were not part of the original Martlesham plan, and had to be introduced to keep essential research projects advancing, they have since proved valuable because they are easily adaptable to special project work. They are not air-conditioned and have mediocre sound-attenuation properties, but some "expendable buildings" can sometimes provide cheaper accommodation for special short-term projects than the main buildings. For example, a part of one of these buildings has recently been converted to a suite of laminar-flow "clean" rooms for use in semiconductor technology. Another is to be reserved for fume cupboards for work involving toxic materials that could offer a hazard if conducted in an air-conditioned building.

In early 1972, a clear path to completion of the main buildings by the middle of 1973 could be foreseen. However, the national strike of building workers, followed by the financial failure of the main contractors soon upset that vision, so that a further delay was inevitable, perhaps of 2 years. The most economical solution was to rent temporary accommodation in near-by towns and adapt them for Research Department use. Suitable buildings were found in Ipswich for 150 staff, and Felixstowe for 75 staff. Some limitation on the permissible range of laboratory work had to be accepted, but it proved possible to retain the pace of experimental work and, at the same time, maintain the momentum of the move from Dollis Hill. Another advantage was that it was possible to honour the promised move dates for most of the staff, despite the contractual delays. The rented buildings were released in 1976 as soon as the work in them could be transferred to the new main laboratory building.

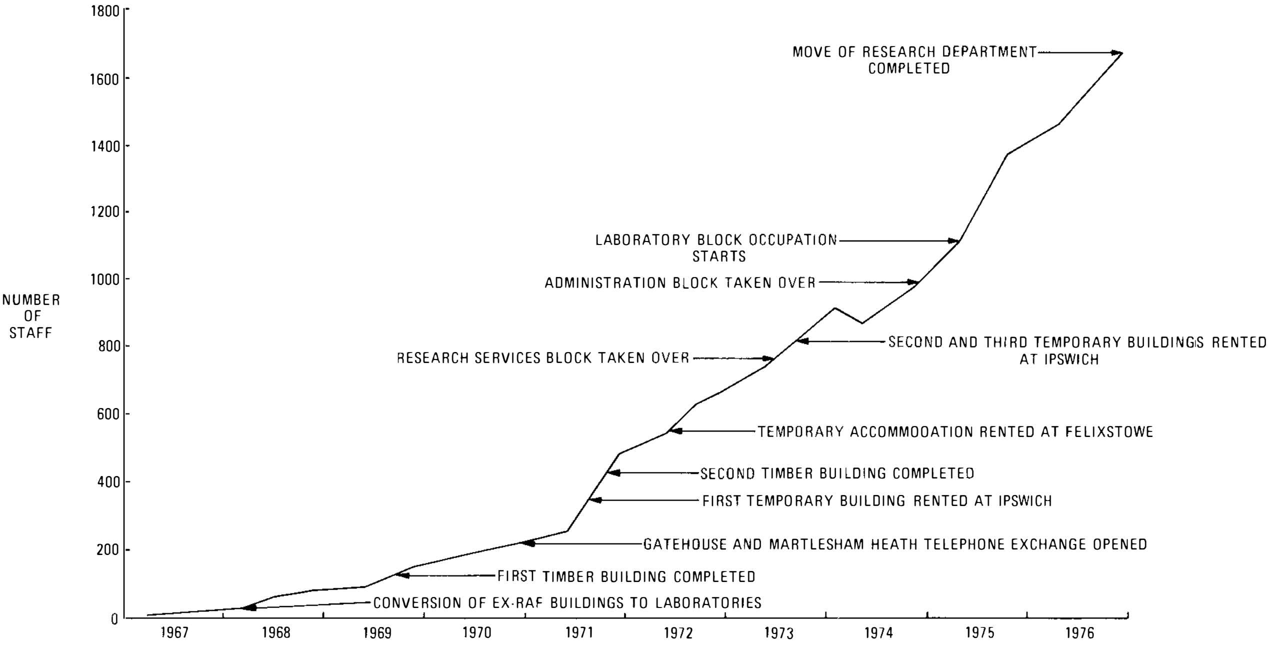


FIG. 2—Build-up of Research Department staff at Martlesham

THE MOVE PLAN

The early announcement by the Director of Research of an "order of moving" was essential to enable Heads of Divisions to programme their long-term work. Most research work requires the use of special equipment, some of which may be portable, but much of the equipment is of great complexity and requires suitably designed accommodation; for example, clean-air rooms and acoustic suites with anechoic chambers. Provision of such facilities had to be put late in the order of moving because it relied on the contractor's building completion dates and, for reasons already explained, these became less predictable as the contract progressed.

Initially, a long-term Move Programme was drawn up for the 20 or so Divisions in the Research Department. This covered a 4 year period, by which time it was hoped that the main buildings would be finished. The Move Division was to be responsible for the site and all move arrangements until the move project was completed. Then, with the closure of Dollis Hill, a more compact organization of services for the Research Centre could be set up to meet current needs. During the years of build-up, all the support services existing at Dollis Hill—workshops, stores, transport, cashier, staff duty, a small library and of course a security duty—were to be instituted at Martlesham so that the new Research Centre would be independent of facilities at Dollis Hill.

Adequate warning had to be given to all individuals of the date when they would be expected to move their work to Martlesham. As far as possible, whole research groups, say 20–30 men, were moved as one unit; an advance party, in which this group was represented, having already prepared the laboratories and any special accommodation. The timing of the move of a group had to be carefully phased with its work programme so that the inevitable interruption to research was minimal.

Each man was expected to arrange his personal and family affairs so that he could comply with the official transfer date previously agreed with him, but there was considerable give-and-take on both sides. The Research Department's staging-post houses were an enormous help as one of these could be rented by a family embarrassed because a hitch had occurred in its housing negotiations. The rate at which staff was transferred to the Martlesham area is shown in Fig. 2: also shown is the accommodation that was made available to enable the expansion to take place.

Most of the staff were headquartered at Martlesham itself, although during and after 1971, some were placed temporarily in the Ipswich and Felixstowe rented buildings until they could enter the new main laboratory block. The plan to continue to transfer work groups was severely restricted during the period September 1973 to December 1974 because the contractor was late in completing the interior of the laboratory building, but ways were found of accommodating many individuals and small units, the aim always being to "keep the move going". Part occupation of the non-air-conditioned section of the research services block was arranged from June 1973, and this enabled the workshops, the 2 loading bays (which were temporarily adapted as offices) and some ancillary rooms and stores, to open. The next large-scale staff movement was in December 1974, when the Administration Building opened, giving accommodation for a further 100 people.

THE MOVE IS COMPLETED

The first laboratory in the main laboratory building opened on 1 April 1975 and, after that, groups were able to move into their new premises at a carefully scheduled rate over the following year. The last part to open was the anechoic-chamber suite.

The BPO Research Centre was officially opened by Her Majesty the Queen on 21 November 1975.

The rented buildings in Felixstowe and Ipswich were vacated early in 1976, so that all the staff could be concentrated on the one site at Martlesham. This completed the project—the Move of the Research Department from Dollis Hill to Martlesham—which had taken overall nearly 12 years. The Move Division, which had then completed its task, was disbanded and its groups redeployed.

Research Department closed its gates at Dollis Hill for the last time on 31 December 1976.

Regional Notes

EASTERN REGION

Injection-Welded Unidiameter Joint

The combination of an old jointing technique and the latest injection-welding system was used recently to facilitate completion of a cable-diversion scheme.

Buckinghamshire County Council had announced its intention to demolish a bridge carrying the A431 Buckingham–Banbury road over a defunct railway at Tingewick (see Fig. 1). This made it necessary to shift telephone cables contained within a single self-aligning duct on the southern side of the bridge, and in a 2-way multiple duct on the northern side. Initially, this appeared to be a routine task but, after discussions with the Council's engineers, it became apparent that diversion outside the line of the proposed road works was not practicable. A major problem then arose when it was realized that a suitable length of twin screened cable for diverting a junction cable carrying pulse-code-modulation systems was not readily available. After Telex enquiries throughout the British Post Office, 2 short lengths of a suitable polyethylene-sheathed cable were all that could be found. By this time, the method of duct replacement had been agreed, and it was impossible to perform an *in-situ* joint because the jointing point coincided with a steel duct onto which the bridge was to be collapsed. After considering the alternatives, it was decided to resort to the old technique of unidiameter jointing. Present techniques for closing unidiameter joints were thought unsuitable for polyethylene-sheathed cable, but it was known that the External Plant Development Division of the Operational Programming Department, Telecommunications Headquarters (THQ), had a very successful injection-welding closure system (formerly known as *injection moulding*—see *POEEJ*, Vol. 69, p. 127, July 1976). Thus, an approach was made to THQ for an opinion on the possibility of injection-welding a sheath onto a unidiameter joint and drawing it into the duct. After discussing the problem, THQ staff agreed to modify the welding equipment to cope with the unidiameter joint.

FIG. 1—The bridge before demolition, viewed from the level of the old railway track

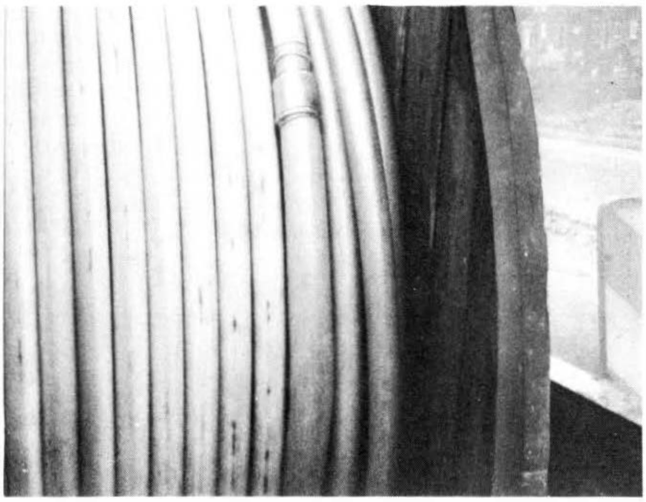


FIG. 2—Diversion cable on drum, showing weld at one end of the unidiameter joint

A length of sheathing, longer than the joint length, was slid over the cable sheath next to the jointing position. The cable pairs were then jointed by the conventional twist-and-solder method, leaving a rather longer joint than normal to keep the diameter to a minimum. The extra piece of sheathing was slid over the joint and welded to the cable sheath at each end by THQ experts using a modified mould designed originally for Jointing Sleeves No. 4. The joint, when completed, was 1·25 m long, with the extra sheathing standing only slightly proud of the original cable diameter of 56 mm. The completed cable was then redrummed, pressure tested and stored (see Fig. 2).

Four steel ducts were laid under the bridge to take the cables. The ducts were encased in motorway crash-barriers, held in place by steel straps, and the whole nest was covered with soft sand. These precautions were necessary because the Council workmen intended to allow masonry to drop from the bridge. The total length of duct used was 140 m, and 2 extra-depth jointing chambers were placed at intersection points used to gain access to the route.

When the ductwork was complete, the drummed cable was delivered to the site. The cable was laid out for a visual inspection of the unidiameter joint, and was then drawn into the duct. The cable length was successfully pressure tested, and only one pair was found to be lost during the electrical tests. The change-over was carried out successfully, and the bridge was demolished onto the new duct route a few days later (see Fig. 3).

A. SADLER (0865 44844)

FIG. 3—Demolition of the bridge, with masonry being deposited on the new duct line

SOUTH WESTERN REGION

Difficult Recovery of Mobile Exchanges

Between November 1973 and October 1976, over 2000 customers in Gloucester received service from 7 mobile non-director exchange (MNDX) units and one mobile tandem exchange (MTX) unit. The mobile exchanges were provided over a period in an L-shaped compound of some 325 m^2, adjacent to a new telephone exchange. As the map in Fig. 1 shows, the only entrance to the compound was a vehicular access-way from Longsmith Street along the eastern side of Ladybellegate House. This building was the old Gloucester health clinic, but has been acquired by the British Post Office (BPO) for an extension to the old Gloucester telephone exchange. The clinic, which boasts ornate ceilings, is the subject of a preservation order and, in January 1976, to stabilize a somewhat unsafe structure, elaborate buttressing was found necessary along the eastern wall. The buttressing was custom-built around mobile units 7 and 8, and so obstructed the entrance that only pedestrian access to the compound was possible. This made removal of the units in the traditional way difficult, if not impossible.

Transfer of customers' lines from the mobile units to the main exchange took place on 20 September 1976, and the scene was set for recovery of the mobile units.

The manager of a crane-hire firm was invited to the site to discuss the possibility of lifting the units from the compound. The only clear air space above the compound within reach of a crane was on the eastern edge of the compound, between the exchange building and the buttressing. It would be necessary to close Bull Lane to traffic to position a 25 t telescopic crane within an operating radius of 6–7 m of unit No. 6, the first to be lifted.

It is worth noting that mobile exchanges released from service in one Telephone Area are normally required by other Areas, and that transportation is the responsibility of the releasing Area. In this case, only one unit had been earmarked by another Area; the remaining 7 were destined to remain in store at Cirencester Telecommunications Engineering Centre (TEC), some 29 km away. An additional complication was that the MTX, destined for Southampton, could be received only on a nominated Wednesday because of traffic problems.

The commitment to recover the mobile units by crane was made and, after consultations with the Police and the Local Authority, Sunday 3 October 1976 was chosen as the recovery date. The Transport Division of Purchasing and Supply Department (P&SD) was advised of the recovery and, after much discussion and a visit to the site, recommended that 3 low-loading transporters should be used, and that Gloucester TEC, approximately 3 km away, should be used as a transit depot; it was thought that there would be insufficient time on the day to transport the units direct to Cirencester. A 15 t crane would be required at Gloucester TEC for unloading the units so that the transporters could conveniently be used in a shuttle arrangement. The 15 t crane would also be used on Monday 4 October for the transfer of the units from Gloucester TEC to Cirencester TEC.

A programme was compiled covering all the work required over a 2 d period. The whole operation would involve 27 lifting operations, and we had been advised by the crane's owners that the BPO would be liable for any damage to their cranes and equipment, and that third-party insurance would be prudent. This insurance, however, did not cover the lifted goods, the estimated value of which was £35 000 for each unit. Insurance would have cost £1500, and so the BPO decided to stand the liability. Staff, equipped with a Land Rover, tractor and winch, road signs, radio sets, a block and tackle, and other necessary equipment, were organized for Sunday 3 October. The transporters were to arrive on Friday 1 October, and park in readiness at the TEC.

The 25 t crane arrived at Bull Lane at 07.30 on the Sunday and, to set the crane in the correct position for lifting, it was necessary to protect the pavement with boiler plates. The crane was manoeuvred into position by degrees until the rear wheels were positioned on a gravel embankment flanking the eastern edge of the compound. One outrigger on the embankment would be experiencing the greatest load, and it was necessary to build up the bank with railway sleepers. Having removed the side and front fencing, mobile units 8, 7 and 6 were winched towards Longsmith Street so that unit 6 sat equidistant from the buttressing and the exchange building. This ensured that unit 6, the first to be lifted, would clear the overhanging face of the building.

Fig. 2 shows details of the hoisting arrangements. The crane was equipped with a spreader bar and 4 steel hawsers. The spreader bar was positioned above and transverse to the mobile unit, and the hawsers were coupled to 2 steel slings under the chassis. Each sling was positioned to the outside of an axle mounting to ensure that it would not move inwards during the lift. Wooden packing pieces were placed between the slings and the sides of the mobile unit to prevent damage to the coach-work.

While attempting the first lift, difficulty was experienced in stabilizing the mobile unit in the slings, and this was due to an excessively long spreader bar. After some deliberation and experimentation, a method of rigging the unit in a stable state was achieved. The slings were adjusted under the unit

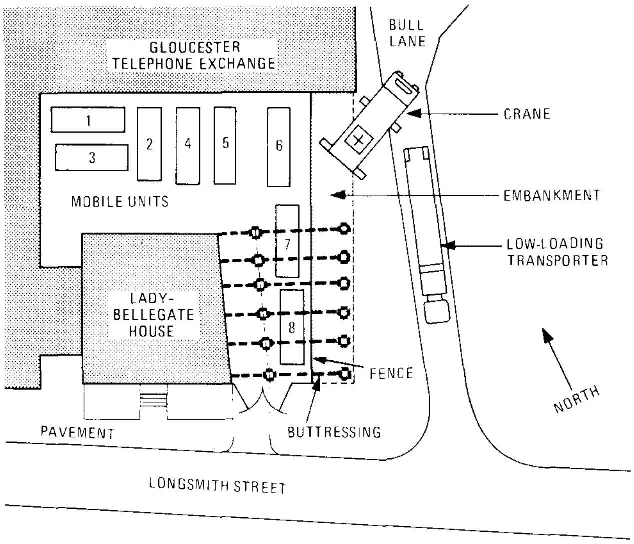
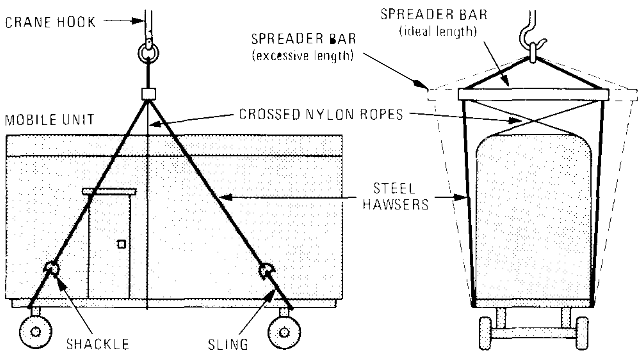


FIG. 1—Gloucester exchange compound, showing the positioning of the crane and transporters for removing the mobile exchanges



Note: Initial instability caused by the excessive length of the spreader bar was overcome by the crossed nylon steadying ropes

FIG. 2—The hoisting arrangements

FIG. 3—Mobile unit 7 being removed from the compound

until balance was obtained and, to maintain stability, nylon ropes were tied to the ends of the spreader bar and crossed above the unit, the ends of each rope being tied to the chassis. The lift was recommenced and, with the aid of guy ropes, the unit was guided clear of the compound through the gap between the crane and the buttressing. The first of 3 transporters had, in the meantime, reversed along Bull Lane, and was parked with its trailer adjacent to the crane. The mobile unit was lowered onto the trailer and lashed down ready for transfer to Gloucester TEC.

The 15 t crane at the TEC was equipped with a spreader bar and slings for unloading the units. The spreader bar used, although still wider than the units, was shorter than that used at the exchange compound. Consequently, the difficulties described above were not evident at the TEC. However, as a precaution, crossed steadying ropes were still used.

Mobile unit 7 was winched into the gap previously occupied by unit 6 and lifted onto the second transporter (see Fig. 3). Operations were then suspended for refreshments, with the satisfaction of knowing that success could be achieved. The afternoon passed quickly. Unit 8 was winched to the lifting position and lowered onto the third transporter. This left sufficient room to drive a Land Rover into the compound and use it to manoeuvre each of the remaining units in turn into position beneath the buttressing. The tractor was then used to winch each unit in turn to the lifting position. It was not possible to use the Land Rover for the whole operation because control would have been difficult on the uneven ground in the compound. By late afternoon, the last unit had been lifted from the compound, and the whole area restored to normality.

At Gloucester TEC, the first 5 units were unloaded without incident. The sixth was left on its transporter ready for transfer to Cirencester the following day. The last 2 (one MNDX which was to stay at Gloucester TEC, and the MTX destined for transportation out of the Area) were unloaded, and the transporters were reloaded with 2 units intended for storing at Cirencester. All this work was done under conditions of strong winds and heavy rain.

On Monday 4 October, the 3 loaded transporters and the 15 t crane proceeded in convoy to Cirencester TEC. The unloading of 3 transporters, in the light of the previous day's experience, was comfortably achieved in 30 min. Each transporter was manoeuvred into such a position that the crane could lift the mobile unit clear of the transporter's rear wheels, and the transporter driven from beneath. The unit was then lowered to the ground.

The convoy returned to Gloucester to load the remaining 3 units for Cirencester, and the exercise was repeated. Late on Monday afternoon, 2 transporters remained at Cirencester in readiness for the recovery of 5 mobile units being released from Swindon the next day. These were to be loaded and unloaded in what is perhaps a more conventional way; that is, by breaking-down each transporter and winching each mobile in turn either on or off the trailer. The third transporter and the crane returned to Gloucester to load the MTX ready for transfer to Southampton on the Tuesday, so that the Wednesday deadline could be met. The loading of this mobile unit completed a programme involving 27 craning operations, and was accomplished, with polish, in 8 min.

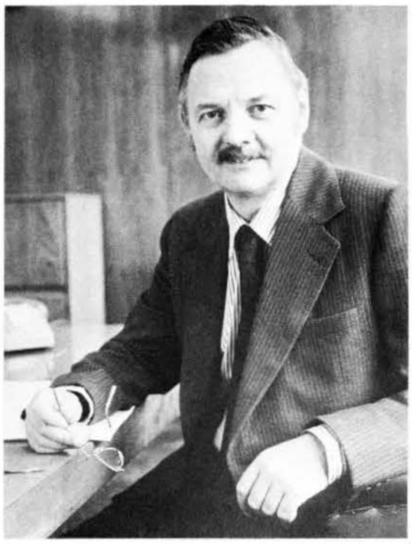
In conclusion, and for those who should find themselves with a similar problem in the future, may I suggest that the use of a crane for lifting mobile exchanges should not be greeted with apprehension. Difficulty had been experienced in keeping the units stable in the slings, but this was attributed to the excessive length of the spreader bar. Ideally, the spreader bar (which is needed to prevent the steel hawsers from crushing the coach-work during lifting) should be approximately 300 mm wider than the unit. A spreader bar of any greater length will, of course, prevent the hawsers from damaging the units, but will make stabilization more difficult by allowing the unit more scope for lateral movement. It is also recommended that crossed steadying ropes be used to help prevent lateral movement of the units in the slings.

The author would like to acknowledge the help of the P&SD Transport Division, the staff of Gloucester Telephone Area, and all those who contributed to the success of this operation.

C. J. PERKS (0452 20166)

Institution of Post Office Electrical Engineers

Professor J. H. H. Merriman, C.B., O.B.E., M.SC., F.K.C., D.SC.(HON.), M.INST.P., C.ENG., F.I.E.E., F.I.T.E.



Mr. J. S. Whyte, C.B.E., M.SC., C.ENG., F.I.E.E.

RETIREMENT OF PROFESSOR J. H. H. MERRIMAN

Among the many distinctions held by Professor Merriman when he retired from the British Post Office (BPO) in December 1976 was that he had been President of the IPOEE for one of the longest tenures of office in the history of the Institution, being challenged only by Col. Sir Thomas Fortune Purves, who held office in the 1920s.

Jim Merriman entered the BPO Research Department in 1936, and became officer-in-charge of the Castleton Radio Laboratories in 1940. There, he became involved in fundamental studies of transmission and radio techniques that were to assume great importance in the post-war years, notably frequency modulation and very-high-frequency radio, the latter finding practical realization in one of the first long-distance television links from London to Wenvoe.

He returned to London as Assistant Staff Engineer in the Radio Branch in 1951, and rapidly built up an international reputation for his expertise and foresight in all aspects of radio communication. He spent one year at the Imperial Defence College in 1954, and was appointed Deputy Director in the Treasury's Organization and Methods Department in 1956, where his seminal work on computer applications was largely responsible for the rapid growth of automatic data-processing methods in Government departments.

On his return to the BPO, he soon became involved again in the radio field. This was the time of the expansion of the trunk microwave network for telephone and television transmission, of the establishment of colour television standards, of hectic CCIR† activities, and of the birth of commercial satellite communications.

His appointment as Senior Director: Engineering (later retitled Senior Director: Development) came in 1967, and he became the BPO Board Member for Technology in 1969.

In the last decade, Jim Merriman has directed the engineering work of the BPO in one of the most exciting periods in telecommunications history, covering such diverse activities as the digitalization of the transmission network, the exchange modernization programme, the use of sophisticated data networks and the emergence of System X. He was appointed Visiting Professor of Electronic Science and Telecommunications at Strathclyde University in 1969, and was President of the Institution of Electrical Engineers in 1974–75.

Professor Merriman has always taken a deep interest in the lives and careers of BPO engineers and in the affairs of the Institution of Post Office Electrical Engineers. In spite of his heavy load of official duties, he has frequently responded to requests for talks to Centres all over the country; the requests were always well rewarded—he is a brilliant speaker on scientific and engineering subjects.

A life of idleness is not in Jim Merriman's nature and, among many other activities, he has been appointed Chairman of the National Computing Centre. His many friends and colleagues in the BPO wish him every success in yet another phase of his distinguished career.

NEW IPOEE PRESIDENT: MR. J. S. WHYTE

All members of the Institution will wish to congratulate John Whyte upon his appointment as Senior Director: Development, and to welcome him as their new President.

Mr. Whyte's work in the BPO first attracted wide attention as a result of his activities at the Radio Laboratories in Castleton between 1949–1957, where he was a member of a team working on modems and intermediate-frequency equipment for microwave radio systems, and where he developed a wide range of radio test equipment, including the white-noise equipment which soon became universally adopted.

In 1957, he moved to the Research Laboratories at Dollis Hill, where he studied transmission techniques; in particular, one which was to have a profound effect on the future of telecommunications—pulse-code modulation.

Between 1965–1968, he was Assistant Secretary in the Treasury's Organization and Methods Department, and energetically pursued the adoption of modern systems-analysis methods and the use of computers in Government departments.

On his return to the BPO as Deputy Director of Engineering, he assumed the leadership of the Long-Range Studies Division and fostered a number of studies that were to be significant in future BPO plans, including a fundamental study of the trunk network and the exchange-modernization programme. He became Director of Operational Programming in 1971 and then Director of Purchasing and Supply.

In addition to his demanding official duties, he has taken an active part in the affairs of the Royal Institution, and was Vice-President from 1972–1974.

John Whyte has a deep knowledge of a wide range of BPO activities and a keen desire to see the BPO amongst the forefront of telecommunications administrations. The Institution is fortunate in having him as its President at one of the most critical periods in the history of BPO engineering.

D. W.

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† CCIR: International Radio Consultative Committee

RETIRED MEMBERS

The following members, who retired during 1976, have retained their membership of the Institution under Rule 11(a).

J. H. W. Sharp, 21 Baillieswells Crescent, Bieldside, Aberdeen.
V. C. Meller, 19 Drowning Road, Fetcham, Surrey.
L. S. Hughes, 2 Blackthorne Road, Great Bookham, Surrey.
R. B. Hoult, Heath Cottage, Gatwick, Shackleford, Surrey.
M. Mitchell, 14 Shandon Close, Tunbridge Wells, Kent.
J. R. Tillman, Brindles Warren, Hill Lane, Aldeburgh, Suffolk.
R. S. Frances, 86 Coast Road, West Mersea, Essex.
N. Walker, 49 College Drive, Ruislip, Middlesex.
P. W. F. North, 101 Beechcroft Avenue, New Malden, Surrey.
A. H. Hearnden, 17 Wykeham Road, Kenton, Harrow, Middlesex.
R. Vernon, 30 William Road, Bournemouth, Dorset.
D. W. Pyle, Oakhurst, Hazler Road, Church Stretton, Shropshire.
L. J. Matthews, 53 Willersey Road, Moseley, Birmingham.
R. S. I. Ogden, 26 Ashfield Avenue, Kings Heath, Birmingham.
A. F. Stollard, 7 Melplash Avenue, Solihull, West Midlands.
J. Greenall, 72 Ferndown Road, Solihull, West Midlands.
E. S. Silvester, 60 Dean Road, Birmingham.
F. E. Williams, 48 Murven Road, Sutton Coldfield, West Midlands.
A. D. Clayton, 25 Stanshalls Lane, Felton, Bristol.
P. W. Crouch, 92 Lockingwell Road, Keynsham, Avon.
R. J. Turner, 40 Grove Wood Close, Chorleywood, Rickmansworth, Hertfordshire.
F. D. A. McEvoy, 99 Meole Crescent, Shrewsbury, Shropshire.
T. J. Prole, 11 Percy Place, Grosvenor, Bath, Avon.
F. Eaves, 80 North Lane, Haxby, York.
J. F. Goodger, 4 Silverdale, Keymer, Hassocks, Sussex.
V. W. Bullen, 54 Mount Road, Canterbury, Kent.
T. C. Harding, 83 The Drive, Rickmansworth, Hertfordshire.
H. D. Bickley, 4 The Orchard, Welwyn Garden City, Hertfordshire.
R. H. Q. Fowler, Hazeld, Horsham Road, Cranleigh, Surrey.
E. A. R. Coustick, 23 Wood Vale Road, Hall Green, Birmingham.
C. F. Floyd, The Hook, 1 Rosebery Road, Felixstowe, Suffolk.
E. Dweck, 66 South Terrace, Surbiton, Surrey.
S. H. Sheppard, Silver Lea, Scotland Street, Stoke-by-Nayland, Suffolk.
T. H. Whitaker, 13 St. George's Road, Harrogate, Yorkshire.
E. R. Scholey, 3 Leadhall Avenue, Harrogate, Yorkshire.
I. R. Finlayson, Ellengowan, West Dean, Salisbury, Wiltshire.
J. D. Rae, The Cottage, Lammins Lane, Mareham-le-Fen, Boston, Lincolnshire.
D. G. Bennett, 50 Meadowhouse Road, Edinburgh.
E. W. Hince, 13 Belmont Road, Bramhall, Stockport, Cheshire.
A. J. Stevens, Apple Tree Cottage, Haytesbury, Warminster, Wiltshire.
F. Haworth, 37 Linton Rise, Leeds.
D. R. B. Ellis, 78 Woodcote Grove Road, Coulsdon, Surrey.
N. F. Felton, 2 Oaks Avenue, Hanworth, Feltham, Middlesex.
H. J. S. Mason, 94 Village Way, Pinner, Middlesex.
K. A. Brown, 18 Gladsdale Drive, Pinner, Middlesex.

A. B. WHERRY
Secretary

Associate Section Notes

DUNDEE CENTRE

Our 1976–77 programme continued in November with an environmentalist's look at the work done by the British Gas Corporation when laying pipelines. The talk, given by Mr. M. Lynch, British Gas Environmental Officer, was well attended, as indeed it deserved to be.

November also saw the final of the Scottish heats of the National Quiz, when Dundee defeated Edinburgh by 28½ points to 23½ points in a face-to-face confrontation.

Our December talk was given by Messrs. I. Kirkland and J. A. MacFarlane, from Dundee College of Technology, who produced an extremely light-hearted look at *Music, Mathematics, Electronics and all that Jazz* in a format that even non-musicians could understand.

The year finished on a high note with a very narrow victory over Nottingham Centre in the quarter finals (second round) of the National Quiz. The heat, held over Confravision, was hard fought to the last question, with Dundee narrowly winning by 36½ points to 33½.

G. K. DUNCAN

EDINBURGH CENTRE

On 20 October 1976, we had a most interesting and informal talk, *Police Communications*, given by a member of the Edinburgh City Police communications staff at Blackford Hill transmitting station. The difficulties of community communications were discussed and many questions arose on the subject. We finished the visit with a tour of the radio station, and of the repair centre where police pocket radios are repaired.

The Forth Purification Board Headquarters at Colinton Dell in Edinburgh was our November visit. The 12 members who attended were amazed by the highly sophisticated electrical equipment used, and the extent to which analysis is used to determine our river classifications. Both the chemistry and physics laboratories provoked a great many questions, and we finished the visit with a greater respect for our natural waterways.

J. L. M. ALEXANDER

NOTTINGHAM CENTRE

Visits to the Royal Ordnance Factory, Nottingham, and RAF Waddington were well received, and full attendance at both reassured the committee of the support throughout the Centre. In November, members from Nottingham and Mansfield represented Nottingham Centre at Leicester, where the Midlands Region Centenary Lecture was held.

The Nottingham quiz team, representing the Midlands Telecommunications Region, did battle with a team from Mold, representing Wales and the Marches. Although we were successful in that event, we were eliminated in the subsequent contest with Dundee, in a closely fought competition held over Confravision. In spite of the result, spirits were high, and I am sure that the team are all the more determined to do well next year.

At the time of writing, the programme for the rest of the 1976–77 session includes 2 talks, a film evening, a visit to the Reliant Motor Company, and, of course, the annual general meeting. Next year's programme is already being arranged, and suggestions from members would be most welcome.

R. H. MARSH

Notes and Comments

CORRESPONDENCE

Traffic Planning Division,
General Manager's Office,
Preston Telephone Area.

Dear Sir,

In your interesting article entitled *The Junction Network* (*POEEJ*, Oct. 1976), I feel you should have mentioned, in the section on growth forecasts, the split responsibilities in the British Post Office (BPO) for junction forecasting. Current practice is that the shorter-distance routes (under 8 km or between exchanges in linked-numbering schemes) are forecast by engineering staff. The longer-distance routes (generally, non-linked-numbering-scheme routes over 8 km), and also routes in the main network, are forecast by traffic staff.

It is probably fair to say that a future development will be to bring these 2 responsibilities into one hierarchy, though whether this will be within the existing BPO grade structure or in a revised structure is, of course, a matter of some speculation.

Yours faithfully,
M. Clemitson
(Telecommunications Traffic Superintendent)

The author of the article referred to has commented that, although Mr. Clemitson raises a matter which has been under discussion for some time, it is not directly relevant to a technical dissertion on the junction network. This is not meant to imply that technology is above such questions as "who does what?", merely that these are better dealt with elsewhere.

Publication of Correspondence

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

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 the publication date, it will be possible to consider letters for publication in the July issue only if they are received by 16 May 1977.

Letters intended for publication should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

ARTICLES FROM AREAS AND REGIONS

The editors would like to reiterate their desire to devote more of the *Journal* to the day-to-day activities of Areas and Regions.

Several very interesting and well-presented items from Telephone Areas have been published in recent issues of the *Journal*, as short and full-length articles, and under Regional Notes.

Anyone who feels that he or she could prepare an article suitable for the *Journal* is invited to submit a draft to the Managing Editor for consideration. The editors wish to emphasize that articles do not have to be highly technical to qualify for publication; an unusual problem with an unusual or ingenious solution makes an excellent theme.

GUIDANCE FOR AUTHORS

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal's* printer and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

All contributions to the *Journal*, including those for Regional Notes and Associate Section Notes, must be typed, with double spacing between lines, on one side only of each sheet of paper.

As a guide, there are about 750 words to a page, allowing for illustrations, and the average length of an article is about 6 pages, although shorter articles are welcome. Regional Notes are generally up to about 500 words in length, and longer contributions will be considered for publication as short articles. Articles and Regional Notes should preferably be illustrated by photographs, diagrams or sketches. Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints and slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at organizational level 5 (that is, at General Manager/Regional Controller/THQ Head of Division level), and authors should seek approval, through supervising officers if appropriate, before submitting finalized manuscripts.

Contributions should be sent to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08 River Plate House, Finsbury Circus, London EC2M 7LY.

SPECIAL ISSUES AND BACK NUMBERS

Copies of the April 1974 issue covering sector switching centres, and the October 1973 special issue on the 60 MHz transmission system, are still available.

Back numbers can be purchased, price 70p each (including postage and packaging), for all issues from January 1972 to date, with the exceptions of July 1972 and January 1973.

Copies of the July and October 1970 issues are also still available.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG. Cheques and postal orders, payable to "*The POEE Journal*", should be crossed "& Co." and enclosed with the order. Cash should not be sent through the post. A self-addressed label, accompanying the order, is helpful.

CORRECTIONS

In Table 1 of the article *The Junction Network*, published in the October 1976 issue of the *POEEJ*, the maximum loss for a local-exchange-to-principal-local-exchange circuit should be 4·5 dB.

The price of the *Journal* including postage and packaging was incorrectly shown as 67p on the inside front cover of the January 1977 issue. The correct price is 70p.

ISSN

This issue of the *Journal* carries on its spine a code known as the international standard serial number (ISSN).

ISSNs are allocated by the UK National Serials Data Centre at the British Library, and each ISSN is unique to the publication to which it is assigned. This means that ISSN 0032-5287 identifies the *POEEJ* in any language in any part of the world. The value of the ISSN is that it is particularly useful to libraries having computerized acquisition, loan, and catalogue reporting and listing systems.

A separate number, ISSN 0309-2720, is assigned to the Supplement, and is shown on the title page.

SYMBOLS FOR UNITS OF TIME

The international system (SI) of units is used throughout the *POEEJ* (with exceptions only in special cases), and the units and their symbols are now quite familiar.

There is also a range of units outside the SI of such practical importance that it is retained for use with the SI. Although, once again, these units are well known, some of the symbols recommended for them by the British Standards Institution are less familiar.

In particular, the units *day* and *hour* are causing confusion, and it should be noted that the recommended symbols for these are d and h respectively.

Post Office Press Notices

GOLDEN ANNIVERSARY FOR TRANSATLANTIC TELEPHONY

On 7 January 1927 in New York, Mr. W. Gifford, President of the American Telephone and Telegraph Company, lifted his receiver at 08.45 (New York time) and asked for Sir Evelyn Murray of the British Post Office (BPO) in London. He was immediately connected and, in his greeting to Sir Evelyn, said, "Today, as a result of very many years of research and experimentation, we open a telephone channel of speech between New York and London. Over 3000 miles of ocean, individuals in the 2 cities may, by telephone, exchange views and transact business instantly, as though they were face to face."

In reply, Sir Evelyn said, "The opening of a public telephone service across the Atlantic between London and New York is a conspicuous milestone on the road of telephone progress." Sir Evelyn spoke of the co-operation that made the venture possible, and of the prospect of transatlantic conversation being available to every telephone subscriber in both countries. He concluded with the words, "I now declare this service open to the public."

In this quiet way was launched one of the most outstanding events in the history of the telephone. Until that day in 1927, communications between Britain and the USA were limited to telegrams. Lt.-Col. A. G. Lee, who later became Engineer-in-Chief to the BPO, commented at the time that, "there is something which appeals to the imagination in being able to converse with another English-speaking nation 3000 miles across the seas."

The fiftieth anniversary of the inauguration was celebrated on 7 January this year in another simple ceremony, again linking London and New York—a ceremony that brought together, by telephone, 2 old friends who have never seen each other. Miss Rose De Palma, now 73, of Florida, and Miss Ivy Baker, now 74, of Thornton Heath in Surrey, spoke together for the first time in many years over a special 5000 km link between London and New York to mark the golden anniversary of the transatlantic telephone service. In 1927, Miss De Palma was an operator in New York, and Miss Baker an operator in London. They connected many of the early transatlantic calls, and a friendship across an ocean built up. They came to know each other's voices intimately but, even now, they have never met.

1977's link-up was vastly different to that of 1927. Besides being connected by operators, calls in those days were made over long-wave radio circuits. It was not until 1956 that the first transatlantic telephone cable was laid. Nowadays, of course, a high proportion of calls are routed via satellites orbiting 36 000 km above the earth. The cost of a transatlantic call in 1927 was £15 for 3 min, equivalent to £135 at present money values. Today, a self-dialled 3 min call costs £2·25, and ISD is available to about 75% of the UK's 21-million telephones.

EURODATA FOUNDATION FORMED

Seventeen telecommunications authorities, including the British Post Office (BPO), have formed a new body to work together to study and meet the needs of Europe's rapidly expanding data-communications market.

The organization is called the Eurodata Foundation, and has its head office in The Hague. Its creation stems from a massive study in 1972, when the 17 authorities pooled their resources to produce a report on Europe's data-communications needs—the *Eurodata Study*.

The main role of the Foundation is to take over from the consultants of the 1972 Eurodata Study the custody and maintenance of the Eurodata database. Through its ownership and upkeep of the database, the Foundation will offer to clients—both telecommunications departments and external bodies—a range of information services within the field of data communications and related telecommunications. It will also conduct and control market studies for clients.

The Foundation aims to be financially self-supporting, and will charge all clients commercial rates for its services.

The chairman of the Foundation's general board is Dr. M. Benedetti of Italy, the vice-chairman is Mr. I. Walhstrom of Sweden, and the treasurer is Mr. N. M. Biezen of the Netherlands. For the time being, Mr. G. Dale, Head of the BPO's Data Communications Division, will act as the Foundation's manager.

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Subscriptions and Back Numbers

The *Journal* is published quarterly in April, July, October and January, at 45p per copy, 70p per copy including postage and packaging (annual subscription: £2·80; Canada and the USA: $6·00).

The price to British Post Office staff is 36p per copy.

Back numbers will be supplied if available, price 45p (70p including postage and packaging). At present, copies are available of all issues from July 1970 to date, with the exceptions of January, April, July and October 1971, July 1972, and January 1973.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

Employees of the British Post Office can obtain the *Journal* through local agents.

Binding

Readers can have their copies bound at a cost of £4·25, including return postage, by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17.

Remittances

Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

Advertisements

All correspondence relating to advertisement space reservations, copy, proofs etc., should be addressed to Miss S. McCarthy, Advertisement Manager, The Kemps Group, 1–5 Bath Street, London EC1V 9QA (telephone: 01-253 5314 or 01-253 3871).

Distribution and Sale

Correspondence relating to the distribution and sale of the *Journal* should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG.

Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Model Answer Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Details of the books available are given at the end of the Supplement to the *Journal*. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

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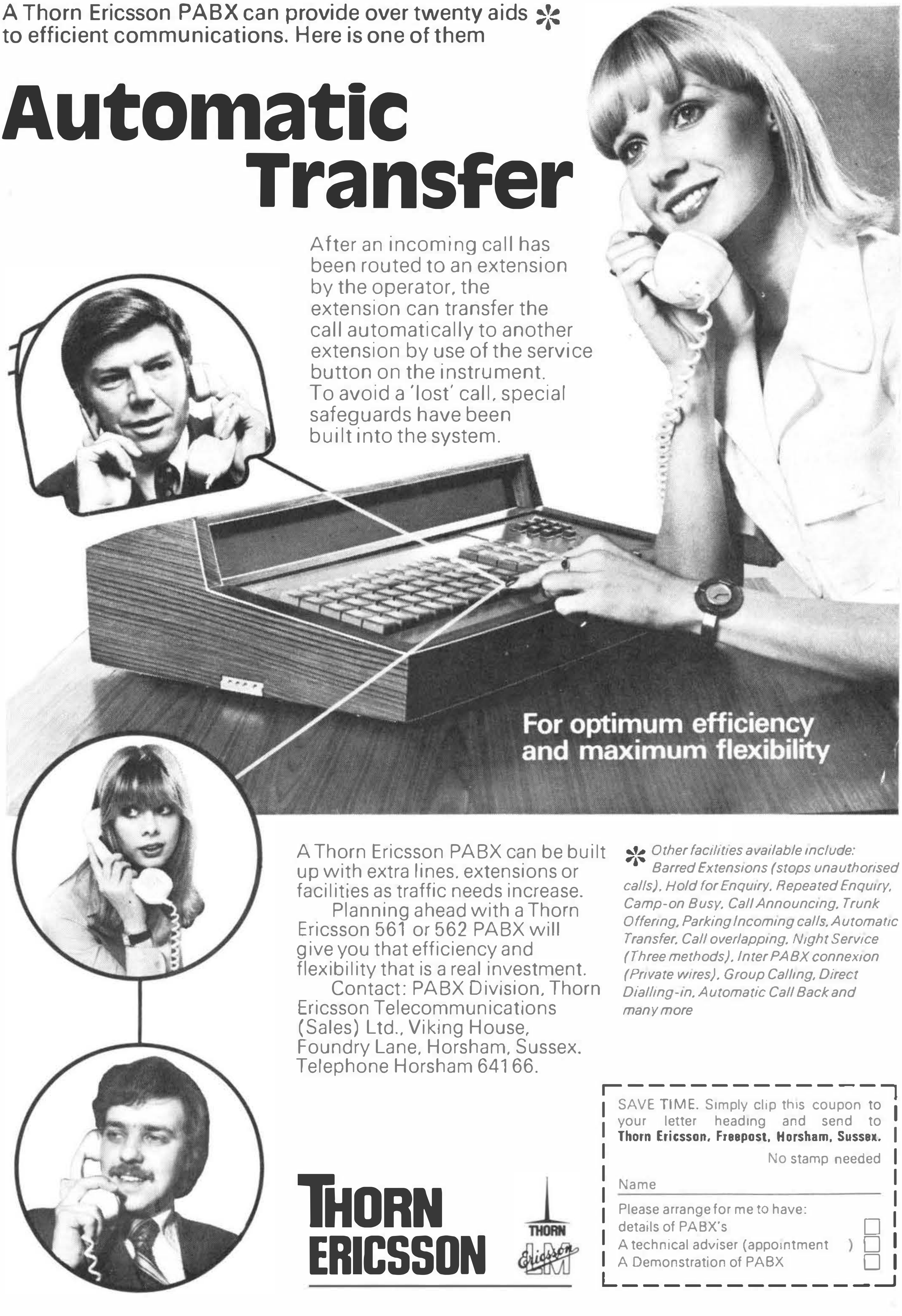

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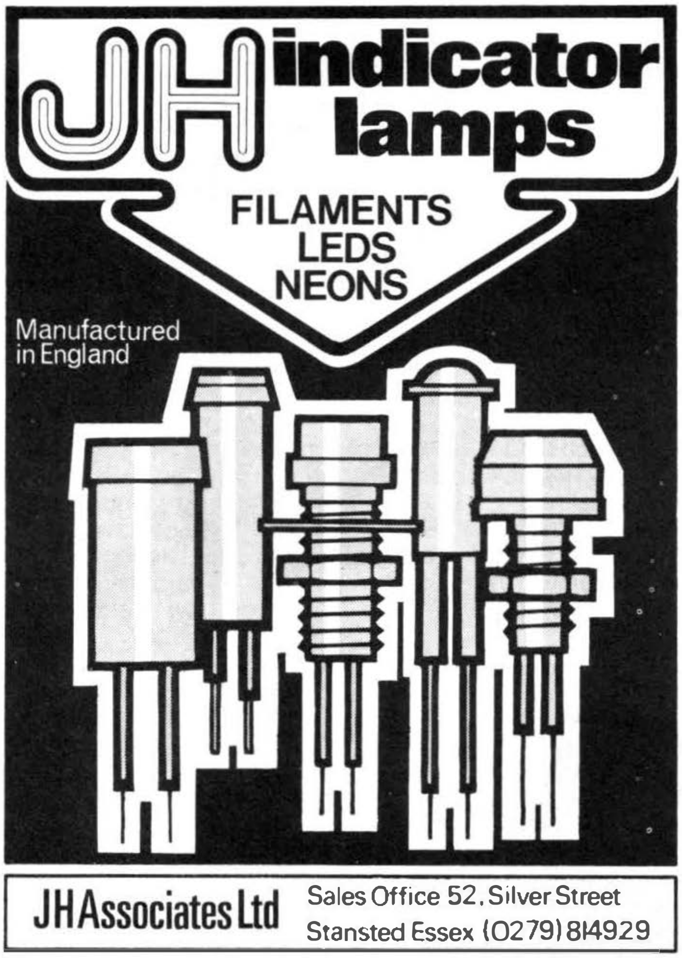

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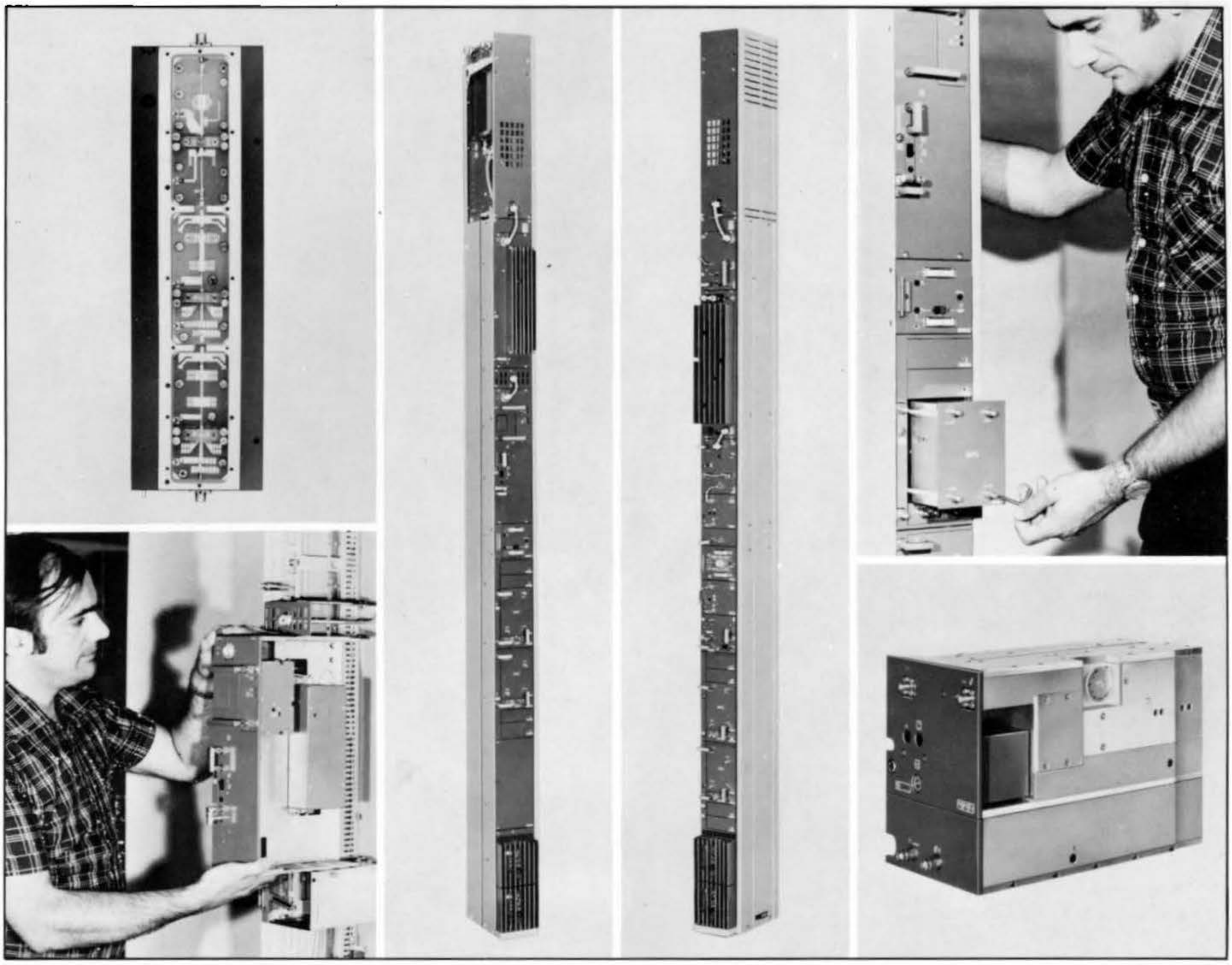

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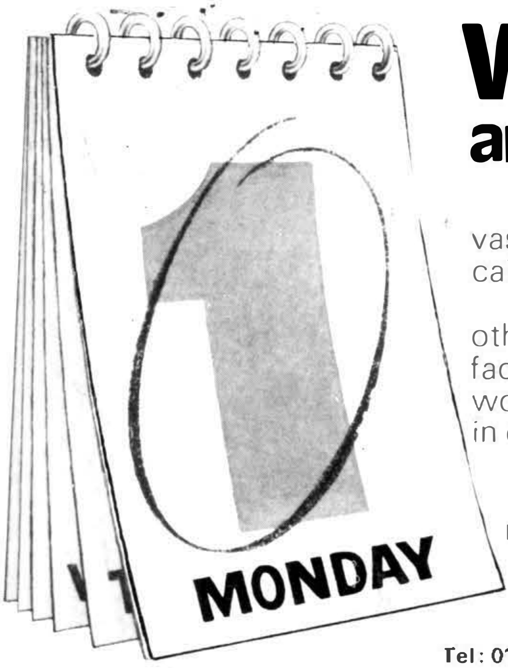
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