The Post Office Electrical Engineers' Journal

R. A. Roe
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SPECIAL ISSUE

THE 60 MHz F.D.M. TRANSMISSION SYSTEM

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Contents

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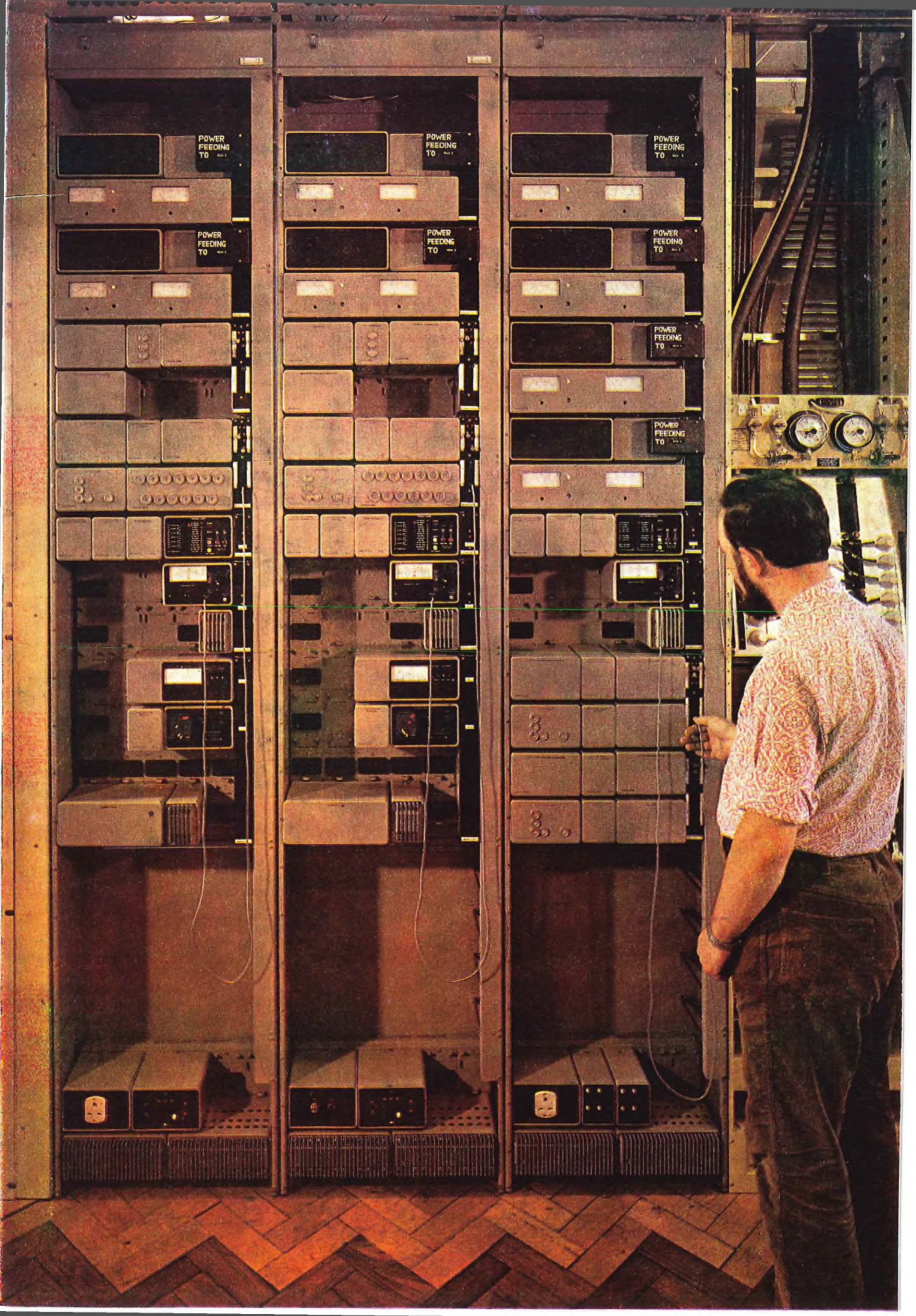
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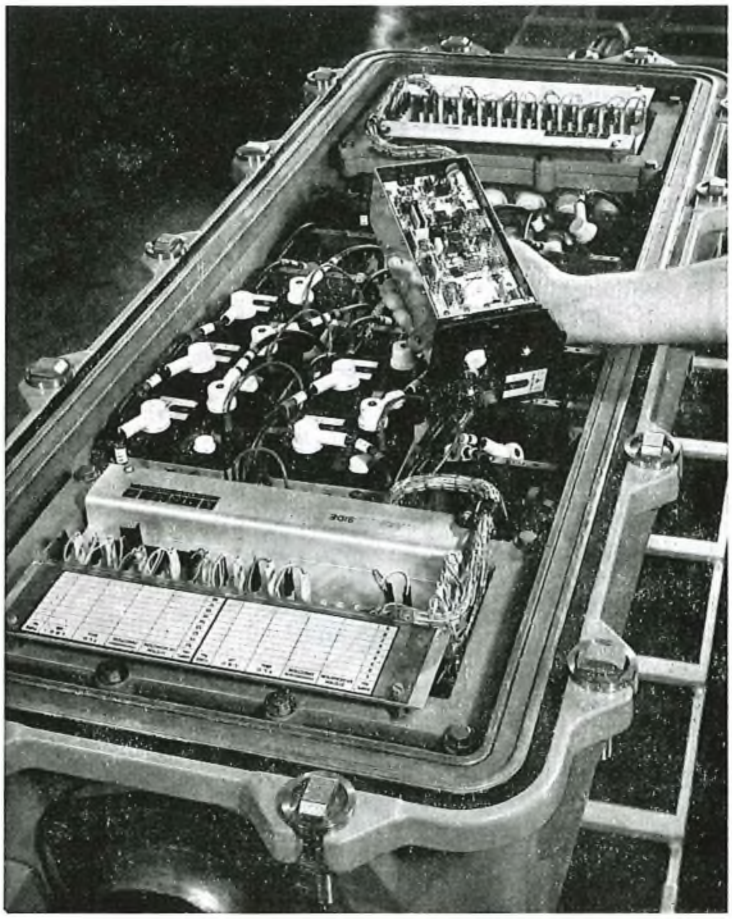

The photograph on the left shows a commissioning engineer checking 'regulation' on terminal and main station equipment at Marlborough.

Repeater unit and housing with covers removed.

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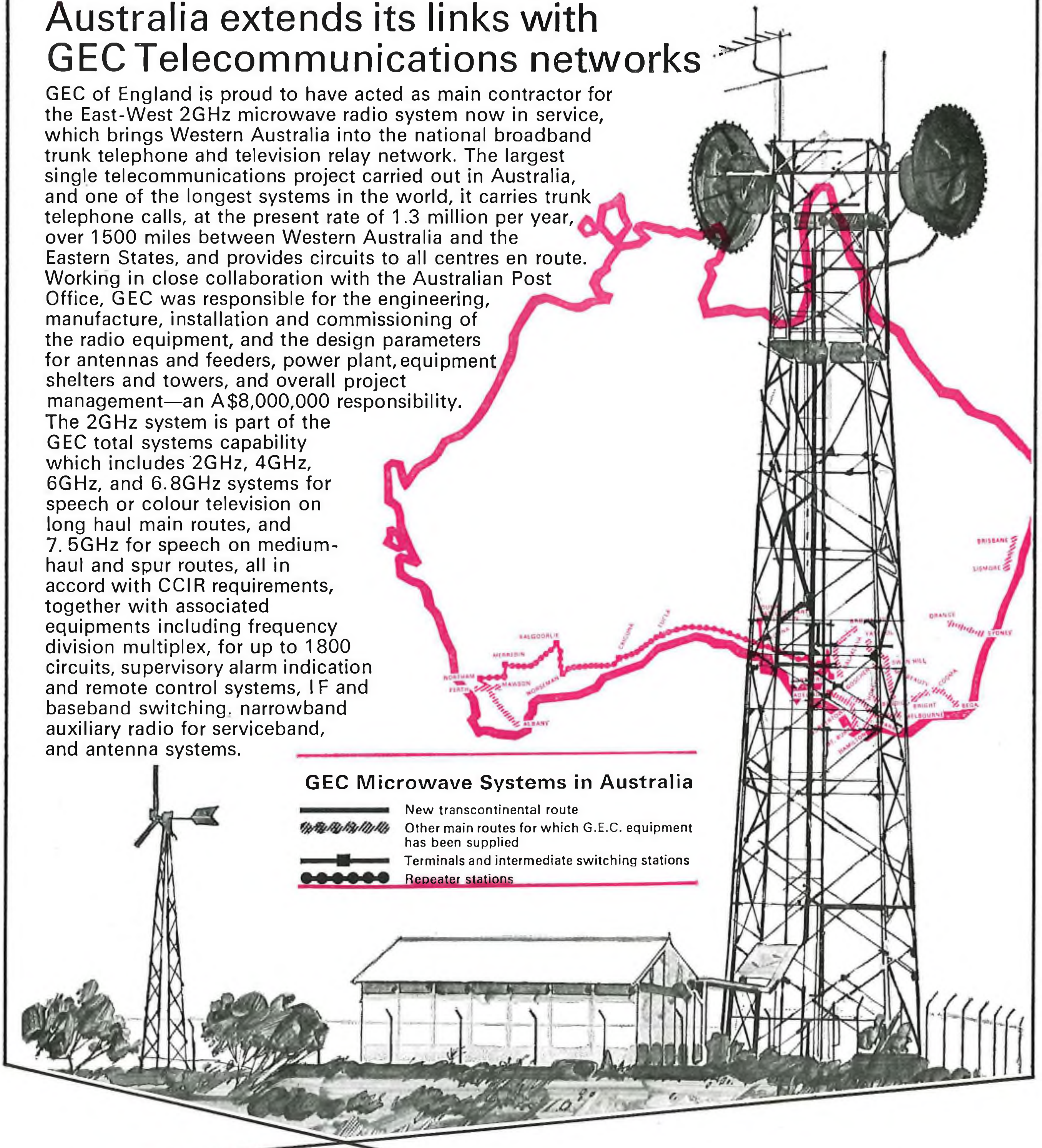
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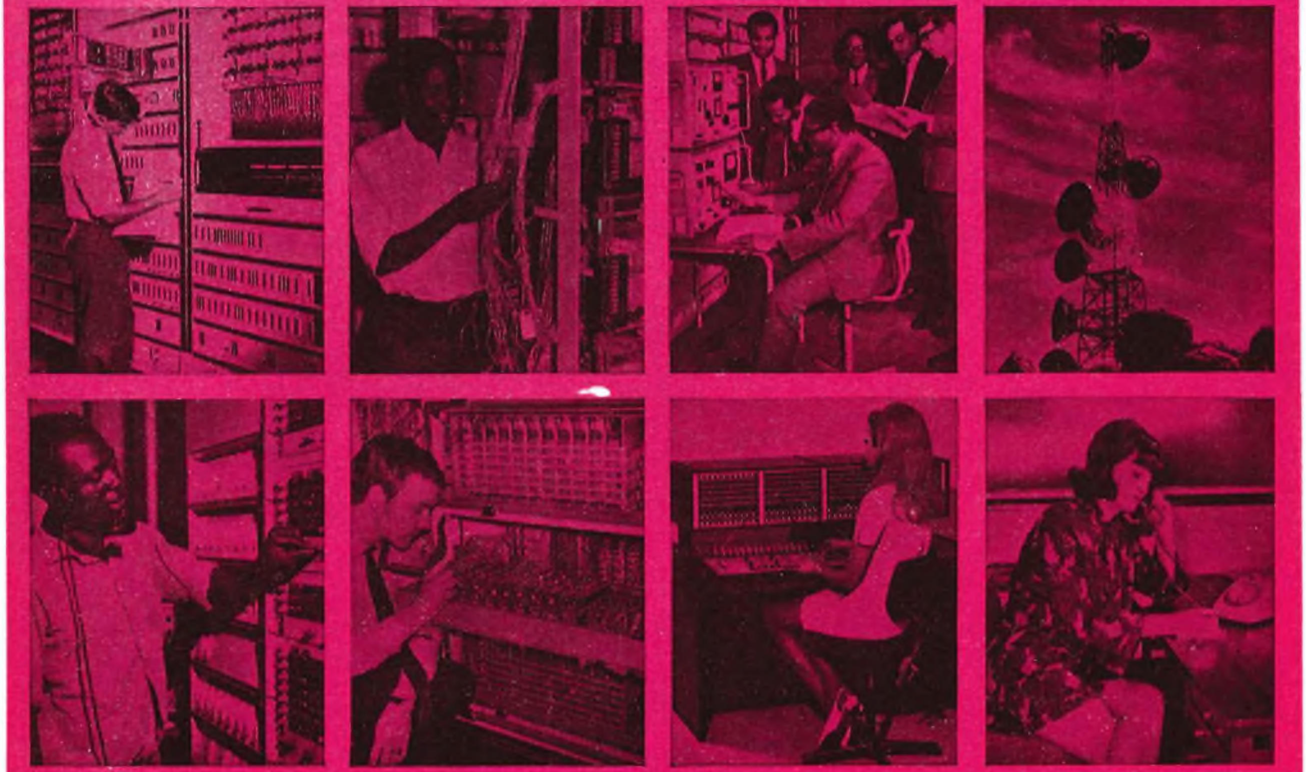

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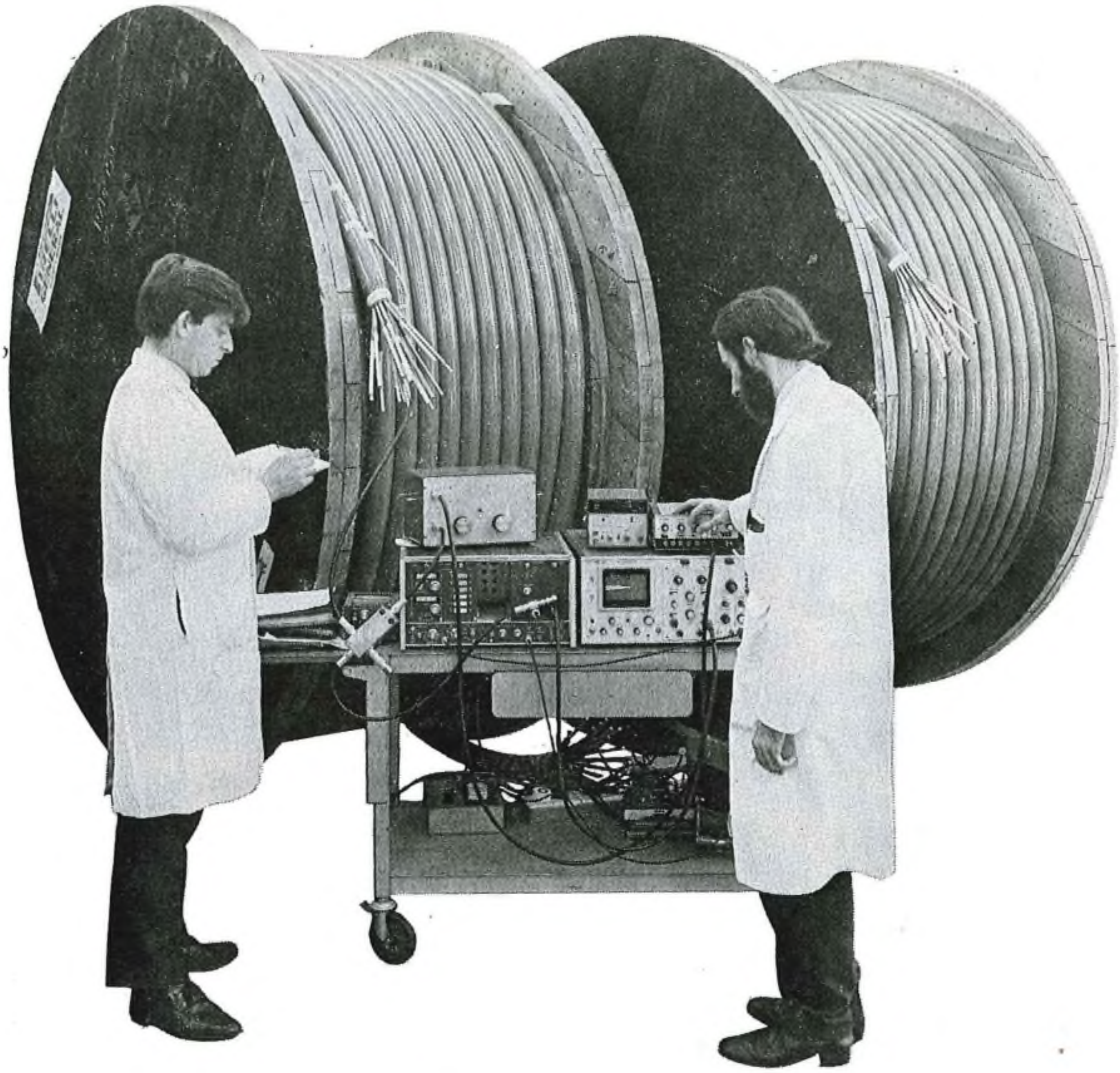

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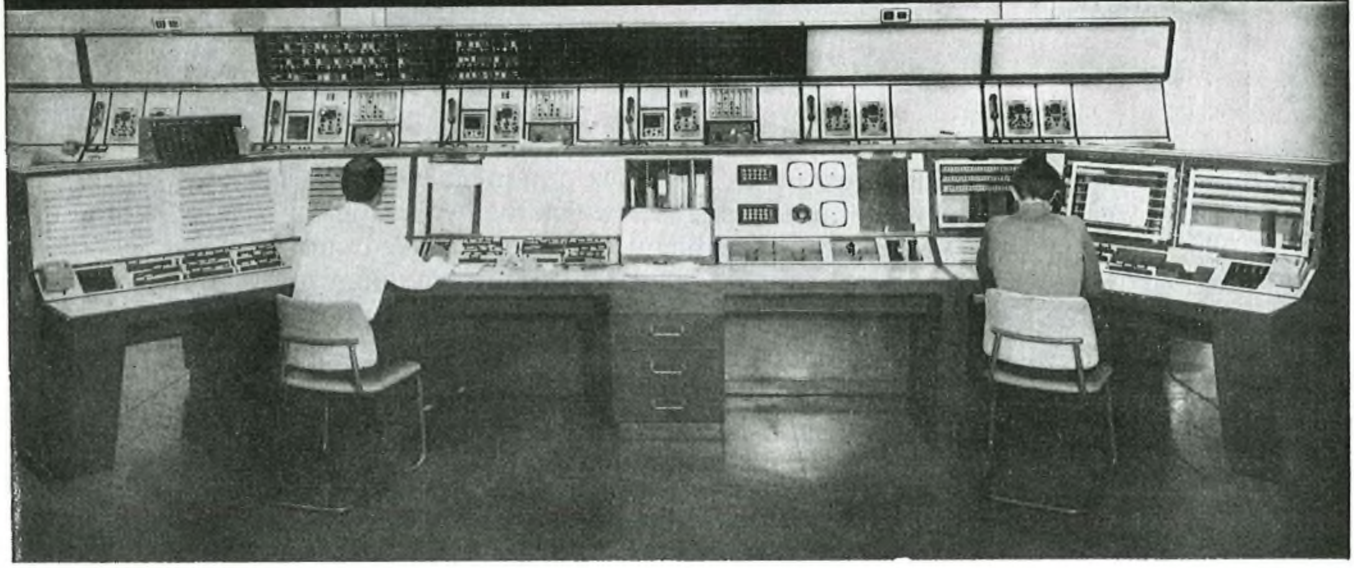

The Post Office Electrical Engineers' Journal

This issue of the *Journal* is devoted to articles describing the new British Post Office 60 MHz analogue transmission system. The design is the latest in a line of succession, starting with the first coaxial cable system introduced into the U.K. trunk network in 1938. Initially the succession of designs used thermionic valves, but the limit of economic exploitation of valves was reached at a bandwidth of 12 MHz. Development of the transistor favoured the economics of wideband cable systems and this, together with the limited availability of microwave spectrum, increased the attraction of wideband cable systems in recent years.

The 18-pair cables to be used on main inter-city routes incorporate an improved version of the Standard 2·6/9·5 mm coaxial pair. The enormous capacity of such cable systems, carrying as they do 86,400 telephone circuits or their equivalent, means that special arrangements will be needed to ensure their security and reliability. These factors, coupled with the advances in technology needed to create the various elements of the system, have demanded co-operation from a wide range of interests in the British Post Office and the Telecommunications Industry. This co-operation has been freely given.

Will this be the last in the line of succession for high capacity analogue systems? Will the next increase in capacity be with digital transmission on coaxial pairs, hollow guide or optical fibre? Only time will tell as the economics of new system designs can be more closely assessed. What is certain is that this system will form the backbone of inter-city communications in the United Kingdom for some years to come, and the British Post Office and the Telecommunications Industry can be justly proud of their achievement.

J P Thomas

Chairman of Board of Editors
Director of Network Planning

The 60 MHz F.D.M. Transmission System: Foreword

W. G. SIMPSON, B.SC., C.ENG., M.I.E.E.†

U.D.C. 621.394.44.029.62:621.315.212

This issue of the *Journal* is entirely devoted to the 60 MHz f.d.m. Transmission system which is the latest development in land-type coaxial-cable systems. The art of coaxial-cable transmission has advanced gradually over the years since the first systems appeared in the U.K. trunk network in 1938. These pioneer systems had a 1·3 MHz bandwidth and carried 320 telephone circuits. Improvements in valve technology and amplifier-design techniques led to systems of greater bandwidth until, in 1960, the valve technique finally reached a capacity of 12 MHz yielding 2,700 telephone circuits. About this time the advent of the transistor resulted in a similar pattern with initial system bandwidths of 1·3 MHz. Later advances in transistors allowed systems of 4 MHz and 12 MHz to be produced in 1965. Each new system has been a significant step forward but none has involved quite the breadth of co-operative development that has been applied to the 60 MHz system. Quite apart from the line system itself, new methods of power feeding, cable design, manufacture, installation and jointing, duct route planning and of maintenance repairs have been developed, and articles appear in this issue on most of these topics. Much of this development work is capable of wider application, the technique of duct lubrication, to facilitate long-length cabling, for example.

The requirement for high-capacity transmission systems in the U.K. was foreseen several years ago when our major trunk routes were growing at the rate of 4 broadbands* per year. They are now growing at 6 broadbands per year and by 1985 are forecast to be expanding by 10 broadbands per year. These figures exclude any requirements for new services such as Viewphone which could further increase these requirements. To provide for such growth with existing systems would require the laying of a new cable every two or three years between our major cities, together with the associated duct work. In these circumstances, the practical arguments for a 60 MHz system are compelling and for growth rates in excess of about 5 broadbands per year the economics are advantageous.

On the fastest growing routes in our network—London–Birmingham, Birmingham–Manchester—it is planned to lay cables having 18 coaxial pairs equipped with 60 MHz systems together with similarly equipped 8-pair cables on spur routes terminating at Reading and Leeds. Each 60 MHz system has a capacity of 10,800 circuits and thus the 18-pair cable has a total capacity of 97,200 circuits. However, one 60 MHz system in each cable will be reserved to afford protection to the other systems within that cable so that the net capacity is, therefore, 86,400 circuits. This capacity is roughly equivalent to the combined capacity of all other existing routes between the centres concerned. Special attention to system reliability is, therefore, necessary. The design objective for an individual 60 MHz system, 100 miles in length, is an availability of 99·99 per cent with a mean time between failures of four years. In other words, faults must not occur, on average, more than once in four years and should not cause a loss of service in excess of 52 minutes per year on average over the whole life of the installation, assumed to be 25 years for this purpose. Such an objective puts stringent demands not only on the plant itself, but also on the environment in which it is installed.

A total systems concept has been adopted in the design, engineering and planning of the 60 MHz systems resulting in the improved techniques described in this issue. Planning for reliability has involved a number of departures from usual practice. Terminal equipment will be installed in accommodation reserved for 60 MHz purposes only and fed from an independent power supply of high reliability. The duct track (including manholes) will be completely segregated from all other B.P.O. external plant. Furthermore, the duct will be laid at twice the normal depth (or given equivalent protection) and on routes specially selected to minimize the risk of interference from other activities. All systems on any one cable will be co-terminal (i.e. no cable spurs will be made) and, as mentioned earlier, one system in a cable will give automatically-switched protection against the failure of any other system within the cable. These measures are calculated to afford the reliability required of the overall installation.

Attention nowadays is increasingly being directed towards digital techniques and it may well be that the 60 MHz system is the last major development of an analogue cable transmission system for the U.K. network. The improved cable which has been developed as the transmission medium may ultimately have to play a part in a future digital network. Special attention has been given to evolving a cable design favourable to later exploitation by means of high-speed digital systems.

The co-ordination of the development and planning of this project has required a considerable effort, involving, as it has, both the cable and equipment industries and many duties in the British Post Office Headquarters, Regional and Area offices. The outcome is a tribute to all concerned.

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† Network Planning Department, Telecommunications Headquarters.

* A broadband has a bandwidth of 4 MHz and a capacity of 900 circuits.

The 60 MHz F.D.M. Transmission System: Some of the Design Problems

L. J. BOLTON, B.SC., C.ENG., M.I.E.E.* and J. PRITCHETT, E.R.D., B.SC.(ENG.), C.ENG., M.I.MECH.E., M.I.E.E.

U.D.C. 621.394.44.029.62:621.315.212.001

The decision to introduce 60 MHz f.d.m. transmission systems working over 2·6/9·5 mm coaxial cables has posed a number of special problems. This article identifies some of the problems, and later articles in this issue show how they have been solved.

INTRODUCTION

The introduction of an f.d.m. transmission system operating at much higher frequencies than existing systems has posed a number of exceptional problems. Some of these arise from the difficulty of working at 60 MHz and others result from the need to ensure that such a high capacity system is sufficiently secure. This article outlines some of these problems.

REPEATER DESIGN

In the 60 MHz system, repeaters are required at intervals of only 1·5 km and thus it is particularly important for their cost to be kept low. This can best be accomplished by reducing to a minimum the amount of equipment in each dependent repeater, a process which also increases the overall reliability and availability. What's not there can't go wrong—and the most reliable component is the one that isn't there. With this philosophy in mind a regulation system, new to the B.P.O., was applied, one of its major advantages being a reduced number of components.[1]

Another major problem of repeater design arises from the need to obtain a stable performance, the traditional approach being the application of negative feedback. At 60 MHz, to keep the feedback negative, the loop path has to be very short. Conventional transistors with their lead-out wires would give too long a path. All the transistors, therefore, have been mounted on to one small ceramic substrate and the circuit configuration arranged so that the necessary interstage couplings could also be provided on the substrate. It is worthy of note that, although major design and construction problems in the repeater design have had to be solved to take a repeater from the previous limit of 12 MHz to the present 60 MHz, the present design approach is applicable to frequencies appreciably higher and, already, 200 MHz systems are being talked of in some quarters.

POWER FEEDING

The B.P.O. has always been very careful to ensure the safety of those who have to work on cables or equipment. In recent years this has been achieved in line systems by application of certain rules to the power feeding of dependent repeaters, one principal requirement being a maximum current of 50 mA d.c. Using this current on the 60 MHz system, it was found not possible to obtain an adequate level of linear output. A new power-feeding circuit had, therefore, to be developed which, together with agreed safe operating procedures, has resulted in a system at least as safe as the earlier ones. Again the solution evolved for the 60 MHz system will be applicable to any other line system of the future either analogue or digital.

RELIABILITY/AVAILABILITY

One consequence of introducing a line system carrying a greater number of telephony channels than any previous one is that a fault on the new system may result in interruption of service to a greater number of telephone conversations than would have been so with the smaller capacity system. Unfortunately, higher capacity involves higher bandwidths which, in turn, means more dependent repeaters because they have to be more closely spaced. A 60 MHz system provides 4 times the number of telephony channels as does a 12 MHz system and requires 3 times as many dependent repeaters (assuming 2·6/9·5 mm cable). A 12-fold increase in reliability is thus needed to achieve comparable results on the individual telephony channel. One design approach, namely that of reducing the number of components, has already been mentioned. Another has been the provision of a spare system with automatic changeover on an end to end basis in the event of failure of any one of the (up to) eight working systems in an 18-pair coaxial cable.[2] One disadvantage of this arrangement is that all systems have to pass through a common switching equipment—a site of extreme vulnerability. Very special measures have been taken—including facilities for rapid manual patching of the 60 MHz hypergroups in the unlikely event of the switching apparatus going faulty. It is, however, noteworthy that experience has shown that the major cause of outage time arises from cable damage, rather than faults on transmission apparatus and so it is on the cable aspects that there is most scope for improvement of the availability.

TRANSLATING EQUIPMENT AND FREQUENCY GENERATING EQUIPMENT

Many of the solutions found for problems in the line system were also applied to the translating equipment, e.g. design of suitable amplifiers[3]. To meet, at 60 MHz, the overall

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* Telecommunications Development Department, Telecommunications Headquarters.

† Operational Programming Department, Telecommunications Headquarters.

frequency deviation permitted, frequency generating equipment of a higher order of stability than previously necessary has had to be designed.[4] To avoid the necessity for distributing very high frequencies around repeater stations where the translating equipment is housed, the final derivation of the required frequencies is carried out on the translating equipment racks. This is a practice new to the B.P.O.

ROUTE CONSTRUCTION

The importance of the 60 MHz system justified a critical review of the route environment. The damage rate currently suffered by existing trunk cables would be unacceptably high for a single 18-pair cable carrying up to eight working systems each with a 60 MHz bandwidth. Damage to existing cables is mainly due to roadworks, works by other undertakings on their own plant and works on other B.P.O. plant. The main requirements for the new cable are, therefore, physical separation from other plant and, where possible, avoidance of routes along roads that might be subject to later widening. The main design features of the new route thus became:

(*a*) the avoidance of routes clearly subject to hazards to the cable,
(*b*) the adoption of increased depth of cover (or equivalent protection),
(*c*) isolation from other plant.

In order to meet these requirements it was clearly necessary to examine the whole field of past, present and possible future construction methods, bearing in mind the need for standards high enough to ensure satisfactory service reliability. At an early stage the possibility of using an armoured cable installed by moleplough was considered but it was realized that special plant would have to be developed to handle the long and heavy lengths of cable which would be needed. A study showed that the nature of the projected routes would allow only limited scope for moleploughing and that development of the necessary plant could not be justified. Calculations showed that a ducted cable would be less costly to install and simpler to maintain, and tests revealed that the duct would provide adequate mechanical protection for the cable.

Cable for high-integrity routes (sometimes called *hard routes*) have been installed in America by trenching and direct burial, while a moleploughing technique has been adopted in Australia.[5] Both methods are appropriate for a cross-country environment but neither would be widely applicable to the U.K. because of the shorter route lengths involved and the nature of the terrain.

Polyvinylchloride (p.v.c.) duct with 102 mm inside diameter was chosen as this size allows the use of rod-pushed gas-leakage detectors. From trials it was known that 500 metre lengths of the 18-pair coaxial cable could be pulled in without excessive tension provided the cable was lubricated. Repeater spacing at 1,500 metres then requires two joints per section although practical difficulties in siting jointing points may increase the number of joints. The cable joints and repeater housings will generally be installed in manholes, but in special circumstances they may be buried directly in the ground and suitably protected against damage.

PRODUCTION AND INSTALLATION OF CABLE

The various types of 2·6/9·5 mm coaxial cable in current production in the U.K. are all suitable for use with a 60 MHz f.d.m. transmission system despite the fact that the original design was intended for lesser systems. It is historically true that every cable—of whatever kind—which has been installed for a particular purpose for the B.P.O. has been successfully converted at some time or other for use at a higher frequency than that originally intended. This is to be expected in an ever-developing cable network[6] and the fact that such conversions can take place at all indicates that the quality of the original product was high enough to match the rapid development of telecommunications technology.

The decision to use the 2·6/9·5 mm coaxial cable for the new 60 MHz system gave the opportunity to review the possibility of extending its electrical performance even further and to assess its potential for eventual use with digital systems. It was soon apparent that the current cable designs could, indeed, be exploited in this way but there was some doubt that the digital transmission rate achievable would make such use economic. It was realized that anything which could be done at a reasonable cost to enhance the digital capability of the cable would probably be worth while in the long run. A review of the current cable designs and manufacturing processes showed that such an enhancement would be possible without making any radical changes to the fabrication machinery and this has now been done with the full co-operation of the British cable makers.[7]

Improved installation techniques have had to be developed to suit the needs of the new cable, whether for use on public highways or across country and with proper preparation there is every reason to suppose that the integrity of the routes will be amply high enough to meet the service requirements of the system.

Much of the development which has been done on the cable design itself, on the production processes and on the installation techniques will eventually influence other parts of the cable network. Already the technique of lubricating the duct rather than the cable has found its way into the local network. Furthermore, fundamental thoughts on the reliability of 60 MHz routes are being increasingly applied to the wider telecommunications field.

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The 60 MHz F.D.M. Transmission System: The Line System

B. HALL, and J. D. BUFFIN†

U.D.C. 621.395.457.029.62:621.315.212

This article describes the development of the 60 MHz line system giving a total capacity of 10,800 telephone circuits on two 2·6/9·5 mm coaxial pairs. Compared with earlier narrower-band systems, the noise performance has been improved and the reliability enhanced.

INTRODUCTION

The 60 MHz f.d.m. transmission system has been designed to provide over two coaxial pairs 10,800 high-quality telephone circuits to C.C.I.T.T.‡ standards or the equivalent quantity of television and data signals. For television and data signals, facilities for one-way transmission are desirable and the power-feeding and supervisory systems have been designed so that the equipment associated with each coaxial pair is self-contained and independent of the other direction of transmission.

The system has been designed to operate on 2·6/9·5 mm type coaxial cable, with a maximum length between terminal stations of 278 km. Main stations (power-feeding stations) are required after 66 km, and, with dependent repeaters spaced at 1·5 km intervals, there is a maximum of 43 repeaters between power-feeding points. The principal component parts of the system are shown in Fig. 1.

MAIN FEATURES

A dominant consideration in the design of the line system was its availability, that is, the proportion of time that the system performs satisfactorily, and to achieve this, the objective for reliability was set at one fault per 160 km of bothway system per 4 years.[1] To meet this target, three main measures were taken.

(*a*) The amount of active equipment underground has been kept to a minimum, and so the dependent-repeater equipment has been designed to be as simple as possible. The more complex equipment has been confined to the surface stations where it is readily accessible and replacement of faulty items can be affected fairly rapidly.

(*b*) The cable has been buried to a depth of 1·2 m, which is twice the depth of existing cables. On present line systems, cable faults account for a major proportion of the system outage time, due to the vulnerability of the cable environment and the difficulty of locating and repairing such faults quickly.

(*c*) All systems within the same cable sheath are co-terminal and each cable has been equipped with one standby system. In the event of a fault on a working system, automatic changeover to the standby takes place.[2]

The main features of the system are that

(*a*) the nominal repeater spacing is 1·5 km on 2·6/9·5 mm coaxial pair,

(*b*) the distance between main stations is 66 km maximum,

(*c*) the power-feeding system is safe,

(*d*) the spread of the overall gain/frequency response on a 278 km route is less than 0·5 dB,

(*e*) over a cable temperature range of 0–20° C, the change in insertion loss of the system does not exceed 0·5 dB for a 278 km route length,

(*f*) the total psophometrically weighted noise in any telephone channel does not exceed 1·5 pW/km, assuming a mean absolute power loading of −15 dBm0 per channel on all channels, and

(*g*) the system supervision is routed over the coaxial pair.

POWER-FEEDING SYSTEM

Power is fed to the dependent repeaters over the inner conductors of two coaxial pairs. Power-feeding equipments for coaxial line systems used by the British Post Office (B.P.O.) have always been designed to ensure the maximum safety of personnel working on such systems. With valve systems, high voltages and currents were necessary and very elaborate power interlocks were needed.[3] These precautions were expensive and irksome to operate. With the advent of the transistor, it became possible to operate line systems from a direct current of 50 mA with a voltage limitation of 250 volts to earth. It has been accepted that, provided the current through a man (assumed to be 2,000-ohms resistance) touching a power-feeding conductor is reduced to 50 mA or less within 250 ms of contact with the line, precautions are not necessary to prevent the man coming into contact with the line.[4] To achieve an adequate linear output from the dependent repeaters, it has been necessary to use a power-feeding current of 110 mA for this system. In addition, as the voltage drop across each dependent repeater is approximately 21 volts with repeaters spaced at 1·5 km intervals and a spacing between main stations of 66 km, a maximum power-feeding voltage of about 1,000 volts is required. The safety requirements of previous systems have been fully respected in a new power-feeding equipment that has been designed for the 60 MHz f.d.m. transmission system but which may be used in other systems. This will be fully described in a later issue of this journal.

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† Telecommunications Development Department, Telecommunications Headquarters.

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

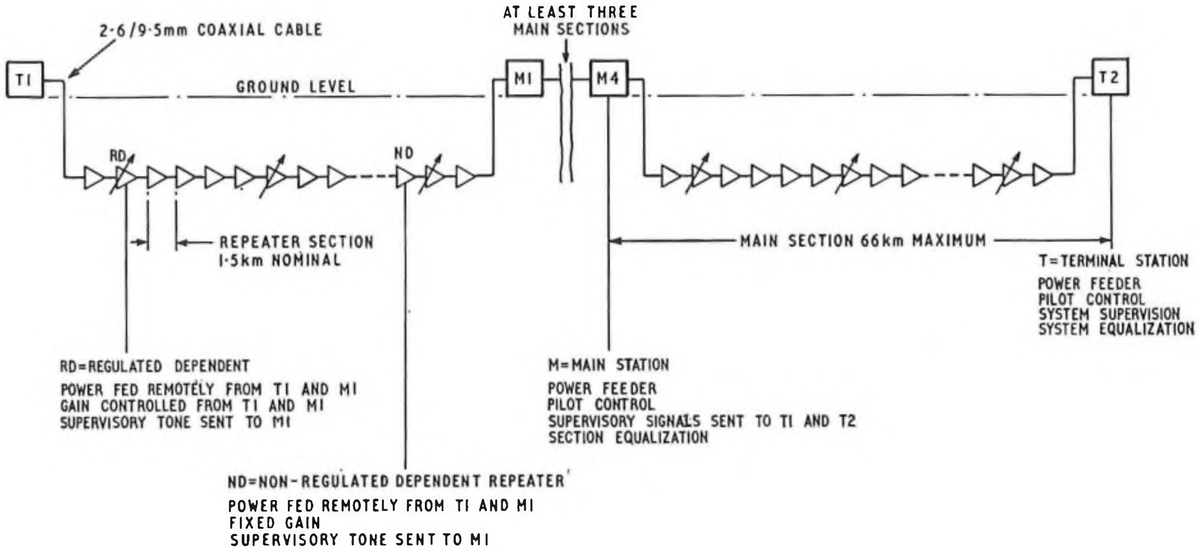

FIG. 1—Block diagram of the line system

A simplified block diagram of the power-feeding arrangement is shown in Fig. 2. Under normal conditions, the inner conductors of the two coaxial pairs are used to complete the power-feeding loop and the four generators are connected in series aiding.

As the power-feeding circuit for each coaxial pair is similar, only one coaxial pair need be considered to understand the principle of operation, see Fig. 3. The normal voltage distribution along the coaxial pair is shown in Fig. 4. This shows that, at one point between stations A and B, the voltage to earth (coaxial outer) is zero. Accidental contact of a man between the inner conductor and earth can be represented by a resistance R shown in Fig. 5. Under these conditions, the power-feed current I_1, from station A, flows through resistance R. In addition, the power-feed current I_2, from station B, also flows through resistance R, but in the opposite direction. The power-feed generators are designed to give a constant current ouput of 110 mA and, with resistance R connected between the inner and outer conductors of the coaxial pair, the output voltages of the power-feed generators automatically and rapidly adjust so that the voltage gradient along the coaxial pair is as shown in Fig. 6. Because currents I_1 and I_2 are designed to be equal for all loads, the current through resistance R and the voltage across it will both be theoretically zero. However, in the practical design, it is not possible to make the currents I_1 and I_2 always exactly equal and a small residual current flows through resistance R, but, under the most adverse conditions, this unbalance current does not exceed 30 mA. Similar arguments apply for accidental contact of a man between the inner conductors of the two coaxial pairs shown in Fig. 2.

Both generators must be present and working correctly if the current through resistance R is to be reduced to a minimum. To this end, a control system is provided to ensure that both generators are operating correctly at all times. See Fig. 7.

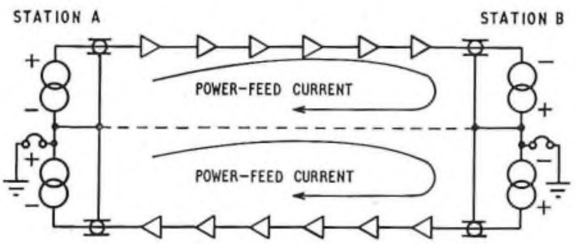

FIG. 2—Simplified block diagram of the power-feeding system

The Control System

The power-feed system can be switched on from either end of the section. On operating the start key at the appropriate station, a switch-on tone f_0 is transmitted to the other station and, because it is a low frequency (6·3 kHz), it can traverse the system unamplified and bypass the line amplifiers via the power-feed path. The f_0 detectors at both stations operate, disconnecting the generators from the line, and connecting them to their dummy loads. Once each generator is delivering the correct current into its dummy load, a monitor tone, f_1 or f_2 according to the station, operates the local f_1 or f_2 detector. At the same time, the monitor tone is transmitted to line. The receipt of this tone at the other end of the power-feed section operates the appropriate detector. The operation of both detectors at both stations switches the generators to line, simultaneously. The switch-on tone f_0 is now removed and only the monitor tones, f_1 (5 kHz) and f_2 (8 kHz) are transmitted to line whilst the system is working normally.

Safety Features of the Power-Feeding Equipment

The safety features of the power-feeding equipment are summarized below.

(*a*) If either of the control tones f_1 or f_2 fails to arrive, the generators do not switch to the line and close down after a short period during which they are connected to their dummy loads.

(*b*) If the line is not continuous, then the switch-on tone f_0 will not be received, and nothing happens at the receive station. At the send station, the generator is connected to its dummy load and, after a short time, it automatically closes down.

(*c*) Should an additional load, for example, a man, be connected in series with the line, the level of the switch-on

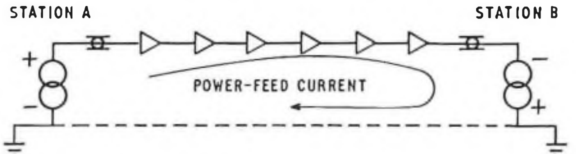

FIG. 3—Power-feeding over one coaxial pair

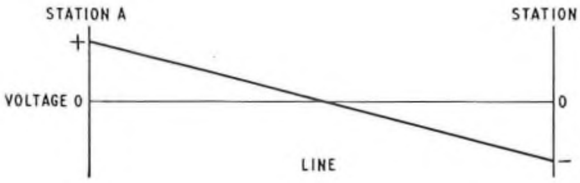

FIG. 4—Normal voltage distribution along the coaxial pair

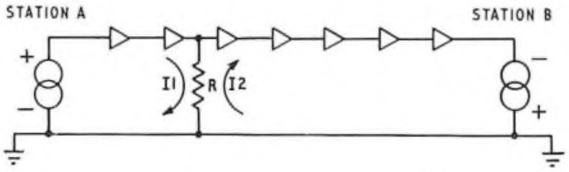

FIG. 5—Balancing of power-feed circuit during a fault

tone f_0 will be attenuated and be below the operate threshold of the detector. At the receive station, the generator is not energized and the generator at the send station closes down.

(*d*) The line current is monitored continuously and alarms are given if the line current deviates by more than 2 per cent. The power-feeding system closes down if the line current deviates by more than 7 per cent.

(*e*) The control-logic circuitry has been designed so that the balancing action of the generators is maintained at all times and, if this is not possible, then the system is closed down.

AUTOMATIC LEVEL REGULATION

To compensate for the change in cable attenuation due to the change of cable temperature, the gain of about one in five of the dependent repeaters is regulated. The regulation is controlled by a 61·16 MHz pilot which is transmitted over the full length of the system and monitored at all main stations and the receive terminal. If the level of the pilot changes by more than ±0·2 dB from its nominal level, it is corrected by adjusting the gain of the pilot-controlled regulated amplifiers at these stations. At the same time a remote-regulation system is brought into action by transmitting a command signal in the reverse direction over the transmission path. The command signals are either 14 kHz or 17 kHz and can traverse all the dependent repeaters between two surface stations, unamplified, in the reverse direction via the power-feed path. See Fig. 8.

At the transmit station, these command signals are received and used to control a variable oscillator operating in the range 8–32 kHz. Receipt of the 14 kHz signal decreases the frequency of the variable oscillator, whilst receipt of the 17 kHz signal increases its frequency. The frequency produced by the variable oscillator is amplitude modulated onto a 2·9 MHz regulating pilot which is then transmitted from that station to the next main or terminal station. Regulated dependent repeaters are sited at intervals between these stations. Here, the modulation signal is detected and the derived d.c. signal is used to control the gain of that repeater. The frequency of the modulating signal, nominally 20 kHz for a cable temperature of 10° C, increases for higher temperatures and decreases for lower temperatures. The amount of correction being applied at the main or receive station is evenly distributed to the dependent regulated repeaters in that section and the gain of the pilot-regulated amplifier at the main or the receive station is restored to nominal. All regulated dependent repeaters obtain the same information and, hence, change their gain by the same amount. The 2·9 MHz

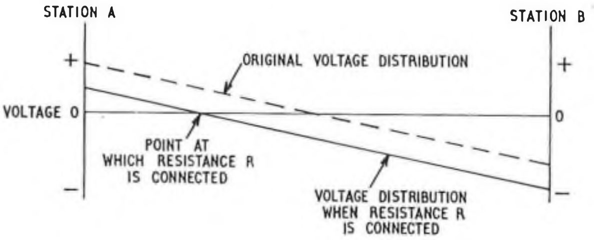

FIG. 6—Redistribution of voltage during a fault

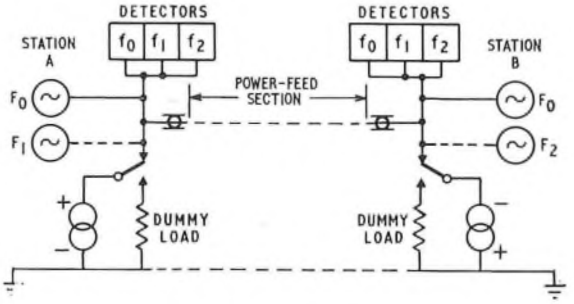

FIG. 7—The control system

regulating pilot is suppressed at each main station and so each power-feeding section is self contained.

The command signals are only transmitted whilst a change in gain is required, but the modulated 2·9 MHz regulating pilot is transmitted continuously. If the 2·9 MHz regulating pilot or the modulating frequency fails, the dependent regulated line amplifiers automatically switch to a low-gain setting to prevent overloading of subsequent systems. Failure of the 61·16 MHz pilot, however, results in the receive regulated amplifiers in the main stations and the receive terminal switching to nominal gain and the command signals being inhibited. Thus, the dependent regulated line amplifiers remain on the same gain setting as they had before the failure occurred.

Pre and Post Regulation

On existing B.P.O. line systems, post regulation is used, that is, the change in cable attenuation due to change in cable temperature is fully compensated for by the regulator at the receiving end of the section. It can be seen from Fig. 9 that, if post regulation were used on the 60 MHz line system, the level of the 61·16 MHz pilot received at each regulated repeater would deviate by ±2·8 dB from nominal for a ±10° C change in cable temperature, and the pilot level would be restored to nominal at the output of each regulated repeater. This would result in the overall system having a higher intermodulation noise in winter, when the output level of all unregulated repeaters would be higher than nominal, and a higher thermal noise in summer, when the gain of the regulated repeaters would be higher than nominal.

On the 60 MHz system, pre and post regulation are used simultaneously, that is, the change in cable attenuation due to change in temperature is corrected, in part, at the transmit end of the cable section and the remainder at the receive end of the section. In this arrangement, shown in Fig. 8, at maximum cable temperature, the output level of the pilot transmitted from each dependent regulated repeater is 1·4 dB above nominal and it is received 1·4 dB below nominal at the next dependent regulated repeater. At minimum cable temperature, the converse is the case. Thus, between two main stations, not more than half of the repeaters have a lower input level than nominal and, at the same time, the other

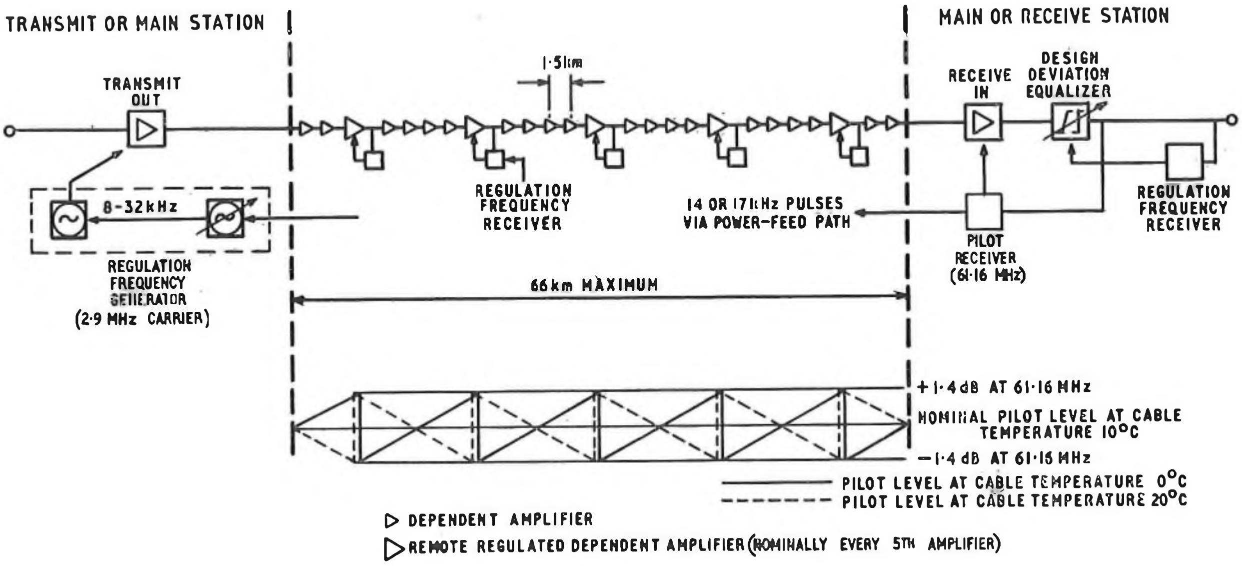

FIG. 8—Block diagram of pre and post remote regulation

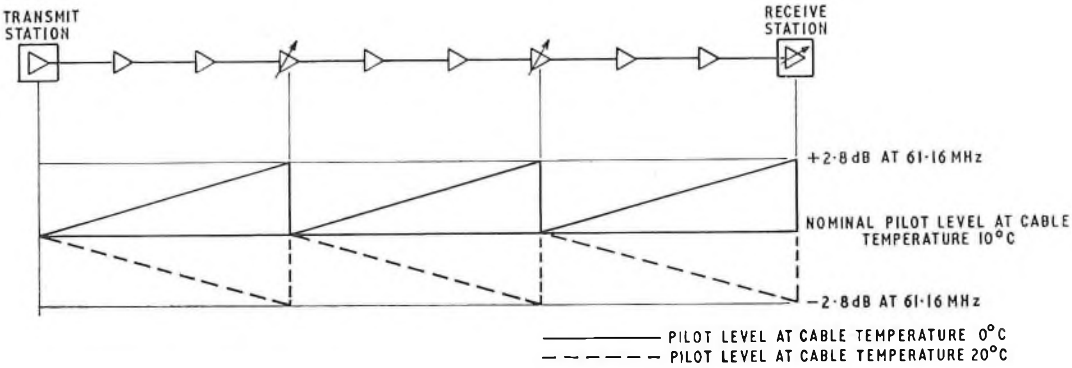

FIG. 9—Pilot level with post regulation

half are operating at higher levels. In this way, the total noise of the system is about the same at all cable temperatures.

It can be seen from Fig. 8 that a repeater sited at a mid point between two regulated repeaters has a constant output level at all cable temperatures. Therefore, by siting the regulated repeaters such that the distance from the transmit station to the first dependent regulated repeater and the distance from the last dependent regulated repeater to the receive station is half the nominal distance between regulated repeaters, the output levels of the transmit and receive terminal amplifiers can also be kept constant. The nominal signal level at these points is then independent of the seasonal variation of cable temperature.

THE DEPENDENT REPEATER

In any coaxial-line system, the major unit is the dependent repeater which amplifies the transmitted signal at regular intervals along the cable. For a 278 km route, equipped with a 60 MHz system, about 186 repeaters are connected in tandem, and the system behaviour, both in terms of performance and reliability, is largely determined by the dependent repeater. Thus, the repeater design has been kept as simple as possible and the number of components reduced to a minimum.

Each dependent repeater caters for only one direction of transmission. Block diagrams of a regulated and a non-regulated dependent repeater are shown in Fig. 10 and a photograph shown in Fig. 11. The amplifier has four stages and uses overall negative feedback to achieve the extreme gain stability required. The large amount of negative feedback necessary over the frequency band 4–60 MHz requires transistors with a high cut-off frequency, this being about 2·5 GHz and, in addition, a very short physical length of feedback loop is essential. The transistors are, therefore, mounted on a single ceramic substrate, together with small coupling capacitors, in one encapsulation 14 mm in diameter and 6 mm high. The physical length of the feedback loop is about 20 mm. A stud mounted on the encapsulation provides an efficient heat sink so that the highest junction temperature is less than 75° C at the ambient temperature that exists in the underground housing. To obtain confidence in the reliability of the transistors, batch samples of each type were subjected to accelerated-life tests and a program of stress tests at elevated temperatures was carried out jointly by the manufacturer and the B.P.O. Research Department.[5]

The amplifier has a nominal gain of 27·75 dB at 61·16 MHz and a shaped-gain characteristic which compensates for the cable attenuation, the most important characteristic being the match to the cable shape. Both the regulated and fixed-gain repeaters are similar in design; in the regulated repeater, the gain is under the control of the modulation on the 2·9 MHz regulating pilot, whilst, in the non-regulated repeater, the gain is strapped in 0·5 dB steps over the range −1·0 dB to +2·0 dB relative to the nominal. Line build-out networks of 2·5 dB and 5·0 dB are provided in both types of repeater. The repeaters can be sited so that the distance between them is in the range 1,100–1,610 m but the running average of the electrical length should always be within 55 m of 1,500 m.

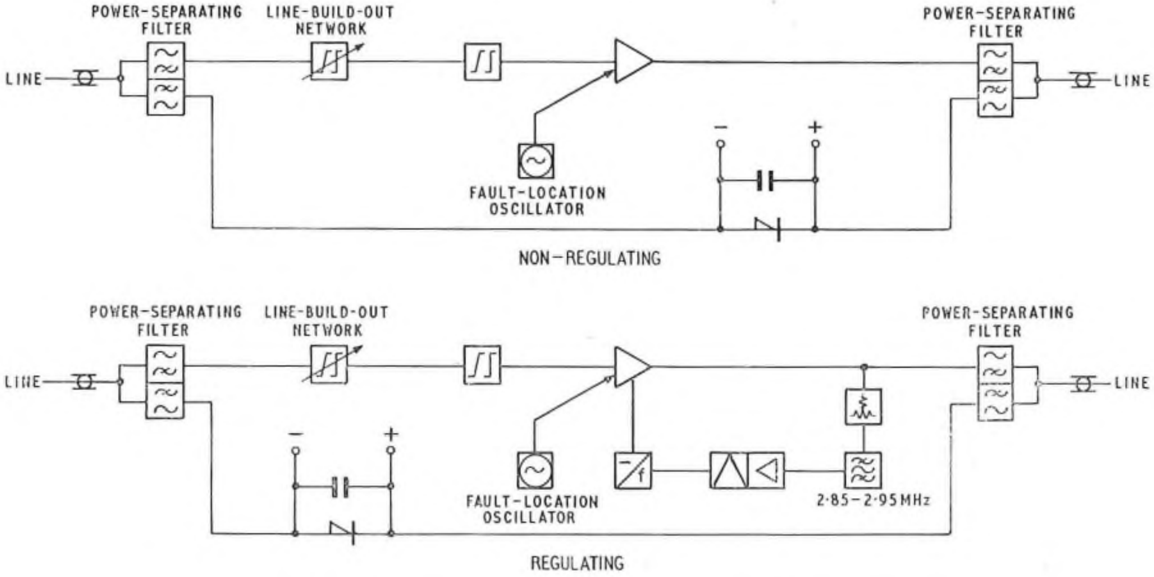

FIG. 10—Block diagrams of the dependent repeater

Planning rules have been designed to achieve this aim. The output level of the non-regulated repeater can be adjusted to be within 1 dB of nominal at 10° C, whilst the regulated repeaters should be set to have nominal output at 10°C.

In the regulated dependent repeater, the modulation on the 2·9 MHz regulating pilot is detected, and the d.c. signal produced is applied to a network in the feedback path of the amplifier to change its gain. A failure of either the modulating frequency or the 2·9 MHz regulating pilot drives the amplifier to minimum gain, that is, 4 dB lower than nominal.

The power to operate the dependent repeater is extracted from the inner conductor of the coaxial pair by means of the power-separating filters at the input and output of the repeater. Each repeater is equipped with its own fault-location oscillator, the output of which is injected at the input of the amplifier.

THE TERMINAL-STATION TRANSMIT EQUIPMENT

A simplified block diagram of the terminal transmit equipment is shown in Fig. 12. The incoming traffic is fed to the TRANSMIT-IN unit. This unit provides

(*a*) a high-pass filter to cut-off all frequencies below 3·96 MHz which could interfere with the system supervisory signals and the 2·9 MHz regulating pilot,

(*b*) a hybrid network for combining the traffic with the 2·9 MHz regulating pilot and the system alarm signals, and

(*c*) a band-stop filter to give 40 dB suppression in the 61·16 MHz pilot band and a hybrid network for combining the traffic with the 61·16 MHz regulating pilot.

The output from this unit is fed directly to the TRANSMIT-OUT unit where, after amplification, the combined signal is split into two equal outputs. One output is pre-emphasized by 10 dB, making the level of signals at 61·16 MHz 10 dB higher than the level of signals at 4 MHz. The purpose is to achieve a balance between the basic thermal noise and the intermodulation noise so that, at the output of the system, each speech channel has the same signal-to-noise performance. The signal is then equalized to correct the attenuation/frequency distortion introduced by the transmit terminal and fed to the power-separating filter unit. The second output is fed to a wideband signal monitor which indicates the traffic load being applied to the system and gives an alarm if the load is excessive.

A monitor of the 2·9 MHz regulating pilot at the output of the transmit terminal is also provided.

The power-separating filter unit combines the traffic output with the line power for transmission to line. In addition, it extracts the regulation command signals, in the frequency range 14–17 kHz, from the line and feeds them to the regulation-frequency generator where the 2·9 MHz regulating pilot is modulated with the regulation information and injected into the system via the TRANSMIT-IN unit. It also monitors the level of the regulation-frequency output.

THE TERMINAL-STATION RECEIVE EQUIPMENT

A simplified block diagram of the terminal receive equipment is shown in Fig. 13. The incoming line is connected direct to the power-separating filter unit which separates the h.f. transmission signals from the power-feeding and regulation command signals. After passing through the line build-out network, the signal is fed to the RECEIVE-IN unit. This unit contains

(*a*) the receive amplifier which has a gain/frequency shape identical to the dependent repeater, but the gain is regulated by the 61·16 MHz pilot, the regulation information being derived from the pilot-receiver unit,

(*b*) the mop-up equalizer for the section from the last main station and the de-emphasis network, and

(*c*) a variable residual equalizer, the attenuation/frequency response of which is under the control of the 2·9 MHz regulating pilot.

Because the gain/frequency characteristic of the dependent regulated repeaters cannot exactly match the change in the attenuation/frequency characteristic of the cable over the required temperature range of 0–20° C, errors occur in the overall equalized response of the line system owing to seasonal variations in cable temperature. However, as the modulating frequency present on the incoming 2·9 MHz regulating pilot is directly related to the amount of remote regulation being applied and, hence, the cable temperature, this information can be used to control the attenuation/frequency characteristic of the equalizer. By this means, the error in the overall attenuation/frequency response of the system due to seasonal changes in cable temperature can be reduced to less than 0·1 dB.

The RECEIVE-IN unit provides

(*a*) a main transmission output for connexion to the universal equalizer, this being a variable equalizer consisting

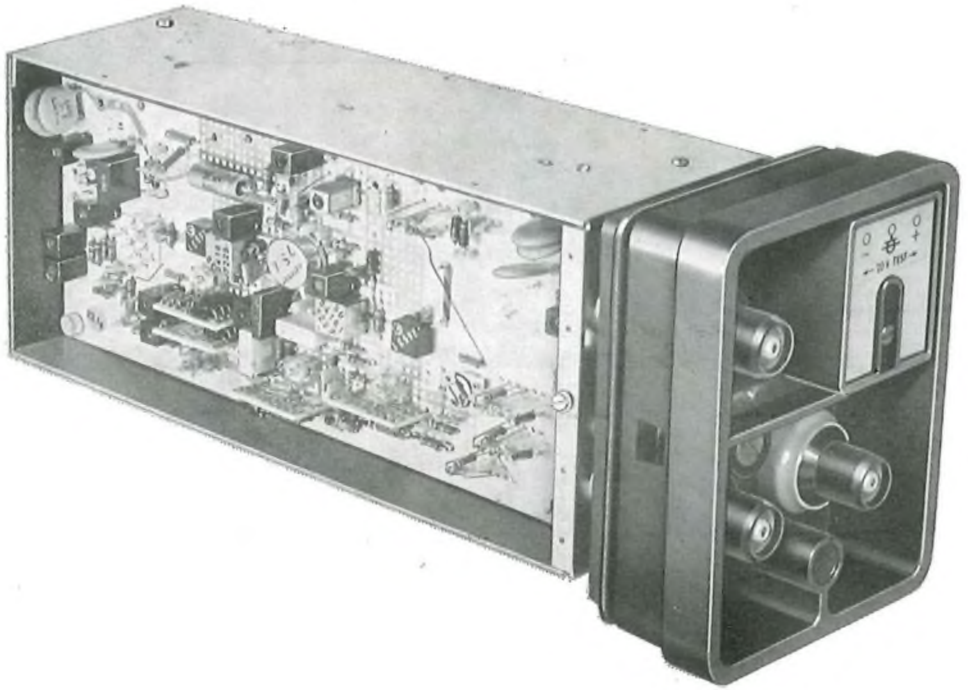

FIG. 11—The dependent repeater

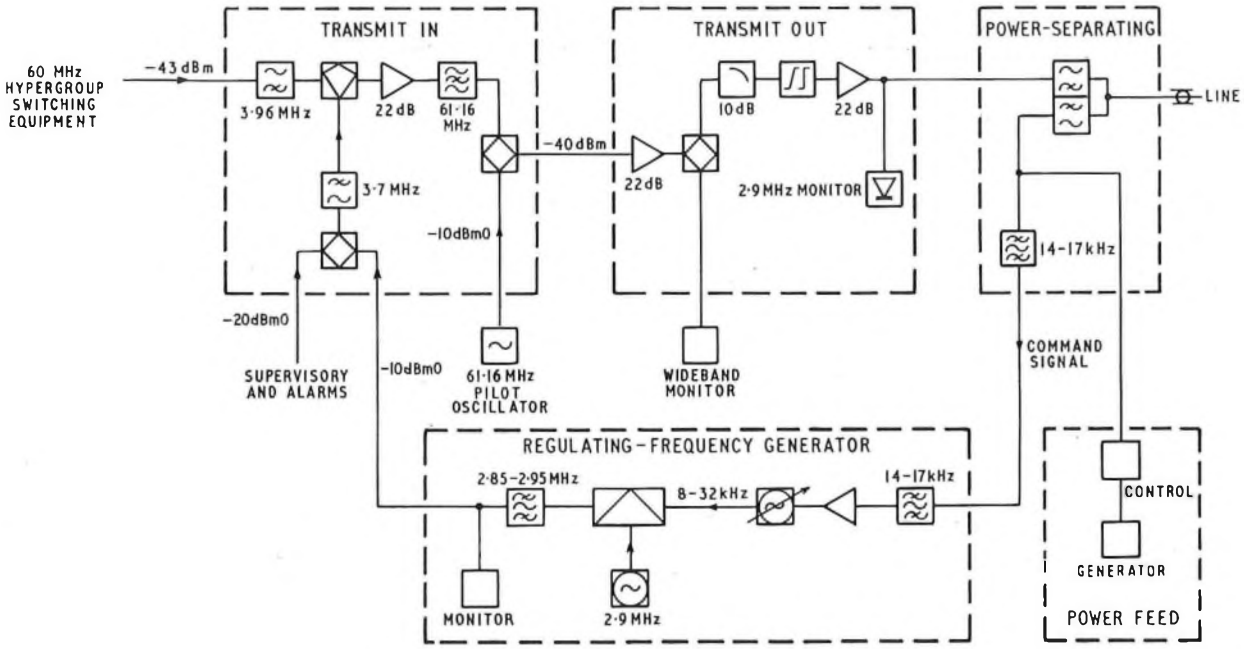

FIG. 12—Simplified block diagram of the terminal transmit equipment

of twelve cosine terms used to reduce the overall attenuation/frequency distortion of the system to less than 0·5 dB,

(*b*) an output for connexion to the wideband load monitor to check the system traffic loading, an alarm being given if the loading exceeds a predetermined maximum, and

(*c*) an output to the pilot receiver.

The RECEIVE-OUT unit provides 40 dB suppression of the 61·16 MHz pilot, extraction of the traffic band signals for connexion to the multiplex equipment via a 3·96 MHz high-pass filter which suppresses the regulation and supervisory signals and extraction of the regulation, alarm and supervisory signals for connexion to the regulation-frequency receiver. In the regulation-frequency receiver, the 2·9 MHz regulating pilot is selected via a band-pass filter, amplified and detected to provide a d.c. output signal to control the system variable residual equalizer.

The 61·16 MHz system regulating pilot is modulated with the output of a local oscillator of frequency 65·56 MHz, the lower sideband (4·4 MHz) being extracted and fed into a detector unit. One output from the detector is used to control the gain of the pilot-regulated receive amplifier. A second output is used to control the output of the unit producing the 14 kHz and 17 kHz command signals, which are routed via the power-separating filter unit to line for transmission to the transmit terminal.

MAIN STATION

Main stations are spaced up to 66 km apart and provide power feeding to the dependent repeaters on either side. Each power-feed unit is identical to those used in terminal stations and the h.f. transmission path consists of units identical to

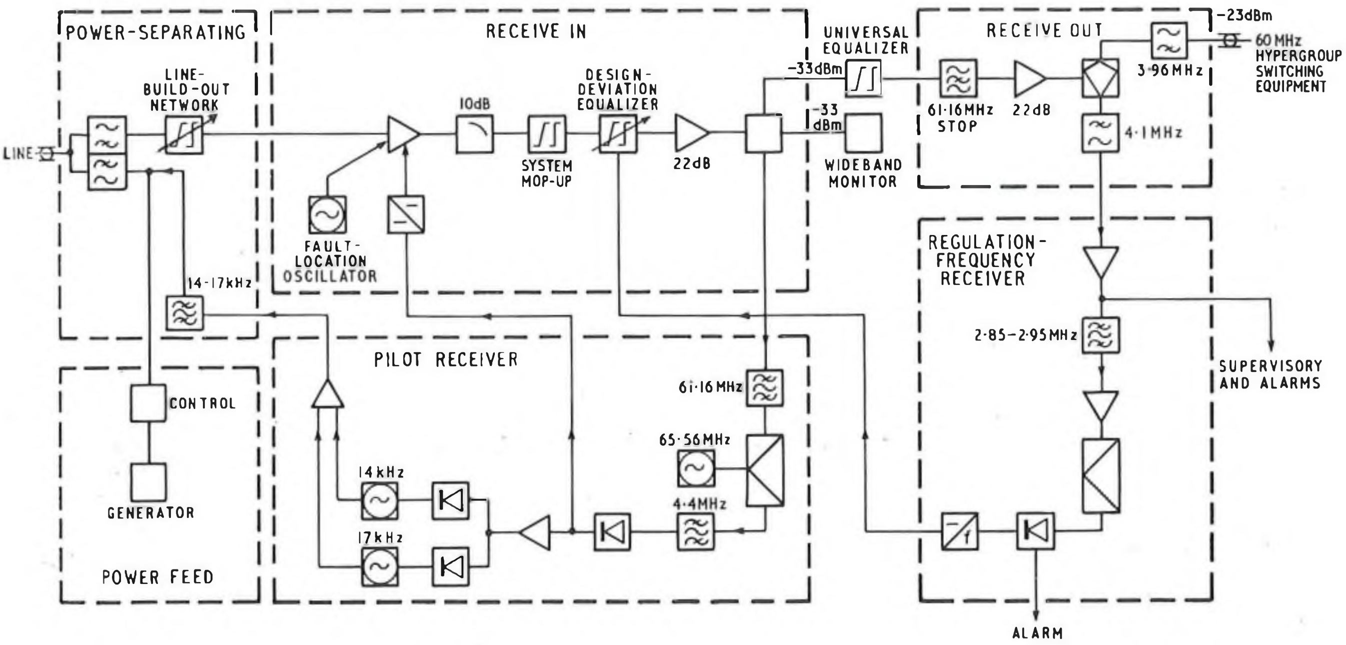

FIG. 13—Simplified block diagram of the terminal receive equipment

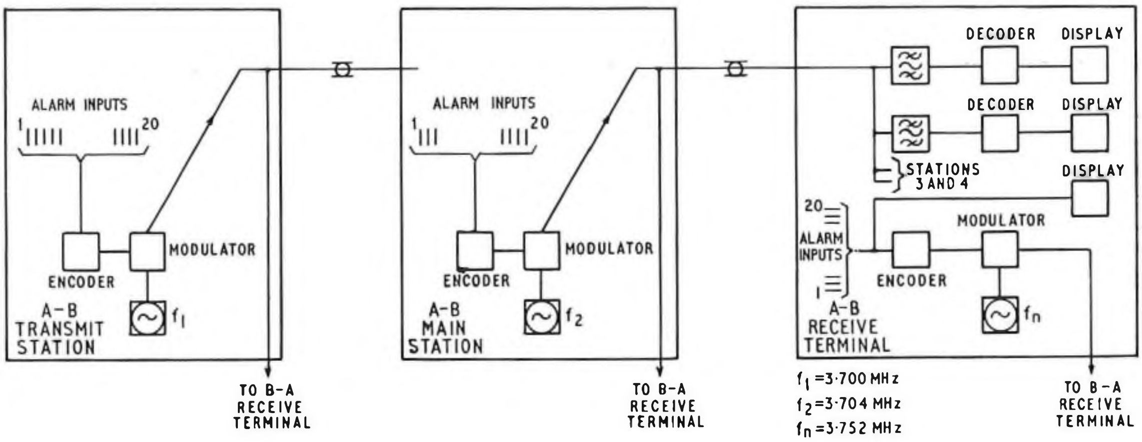

FIG. 14—Terminal and main-station alarm system

those in the terminal stations. Additional supervisory facilities are provided to isolate the supervisory tones of one regulation section from the next. Amplification of the 4-wire audio speaker, which is similar to that used on the B.P.O. standard 12 MHz Coaxial Line System (C.E.L. 4000),[6] is also provided.

SYSTEM SUPERVISION

Two distinct types of supervision are provided which can function separately and independently of each other. The first is concerned with the supervision of terminal and main station alarms and the second with supervision of the dependent repeaters.

Terminal and Main-Station Alarm System

At the terminals and main stations, a number of conditions are monitored continuously by equipment which gives an alarm if any of these conditions are outside pre-set limits. See Fig. 14. Each monitoring circuit has a standard output terminal which is normally at a reference potential designated 0 or the GOOD state. If a fault condition is detected by the monitor, its output changes to a different voltage designated 1, or the ALARM state. The outputs from all monitors are fed to a local-station alarm unit and, in addition, are fed to an alarm encoder. In the encoder, an electronic switch examines the state of each alarm wire in turn and causes a pulse to be generated, the width of this pulse being modified by the presence of an ALARM condition. Up to 20 of these alarms can be scanned by the encoder, the total alarm sequence being repeated about once per second. In this way, a series of pulse trains is produced which represents the state of all the selected alarms, at that time, as wide or narrow pulses. This information is fed to an alarm transmission system which is concerned only with transmitting the alarm information to a remote station. The pulse train is amplitude modulated onto an alarm carrier whose frequency is unique to that station. Each terminal and main station is allocated one of the following alarm carriers, 3·720, 3·724, 3·728, 3·732 and 3·736 MHz which allows sufficient spacing for the separation of each modulated carrier.

At the receive terminal, a selective detector is provided for each of the above frequencies. The recovered pulse train is decoded and the information is fed to a display showing the state of each alarm at the corresponding station. Each set of detection and display equipment is independent.

Normally, when the line system has been set up for both-way transmission, the alarm information from each station

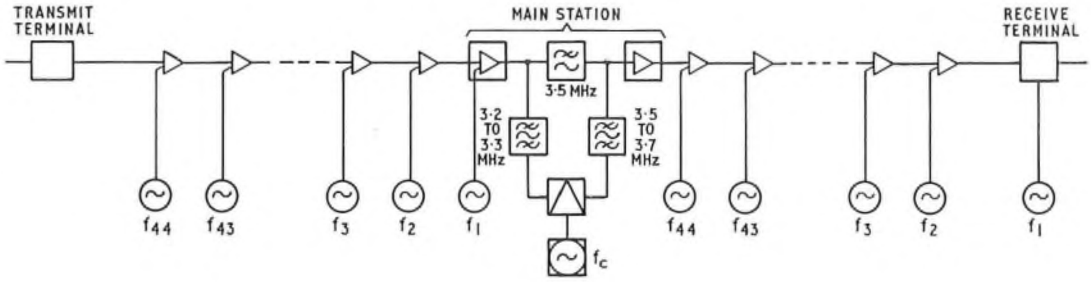

FIG. 15—Dependent repeater alarm system

will be extended in both directions, so that each terminal has information about both directions of transmission. If one-way transmission is used, for example, for television or data, such that, both coaxial pairs associated with one power-feed system are transmitting in the same direction, alarms from the transmit terminal and power-feeding stations can only be displayed at the receive terminal.

The Dependent-Repeater Supervisory System

The dependent repeaters are supervised by monitoring the frequency and level of a tone in the frequency band 3·2–3·3 MHz generated within each repeater and injected into the input of the amplifier. See Fig. 15. Every dependent repeater in a power-feed section is allocated a different frequency, enabling the source of each tone to be recognized.

The individual fault-location oscillator tones from all the dependent repeaters along one power-feed section are transmitted to the main station where they are available for direct monitoring (by additional equipment) should this be required. A high-pass filter in the main station at the receiving end of each power-feeding section, prevents transmission of the tones into the adjacent section. At each main station, the tones incoming from the preceding section are modulated with a frequency produced by a local oscillator and the side-bands extracted for onward transmission to the receive terminal. The frequencies of the local oscillators are chosen in 50 kHz steps, in the range 300–450 kHz, to place the tones from each section into a separate frequency band. This arrangement permits all the tones from each power-feeding section to be extended to the receive terminal without mutual interference.

At the receive terminal, equipment is provided which continuously monitors all these tones in a fixed sequence and gives an alarm if any one of them falls outside pre-set limits. The equipment consists of a selective receiver which can be remotely tuned to each tone in turn. The receiver is swept over the range in 1 kHz steps, pausing at each frequency long enough (approximately 20 ms) to obtain a measurement of its level, so that the 250 tones available on a maximum length system will be interrogated once every five seconds. The scanner will normally operate continuously and automatically. The presence of an alarm condition causes a 3-digit numerical display to be illuminated which shows the code number of the alarm or, for multiple alarms, the code number of the first alarm condition to be detected. A manual control is provided to enable a particular tone to be identified and monitored continuously. Equipment for monitoring the tones is normally provided only at the receive terminal. The same equipment could be installed at the main stations, if required, but this should not normally be necessary since the location of a fault can be determined from the receive terminal. Fault-location tones are not fed back to the transmit terminal.

SPEAKER SYSTEM

Four-wire duplex engineering speakers are provided on the audio quads in the cable, each bothway system having an associated speaker. Each speaker pair is loaded with an inductance of 88 mH at the dependent repeaters. Access to all the speakers is available within the dependent-repeater housing. A nominated speaker is made available externally to the repeater housing so that communication can be established with the terminal station before work is commenced. Access to all the speakers is also available on the protection switching equipment. The facilities and operation of the speaker are identical with those on the C.E.L. 4000 system.[6]

CONCLUSION

The 60 MHz f.d.m. transmission system is currently undergoing a field trial at Marlborough, Wiltshire and the results obtained so far indicate that the performance parameters specified have been achieved. The transmission-path performance is superior to that obtained with any of the earlier systems.

ACKNOWLEDGMENTS

The authors wish to thank their colleagues within both the British Post Office and the industry, whose joint efforts made the development of the system possible.

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The 60 MHz F.D.M. Transmission System: Evaluation of Active Devices

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U.D.C. 621.394.44.029.62 : 621.382.001.4

INTRODUCTION

One of the most important requirements for the 60 MHz systems was the development of suitable active devices. These had to

(*a*) be capable of being used in circuits giving the required gain to offset the cable loss,

(*b*) be sufficiently reliable to withstand the ravages of time, of lightning, and of man-made interference so that, even though several hundred are connected in cascade along a trunk-cable route, the failure rate is acceptably low (The target for the system was 1 fault per 160 km of bothway circuit per 4 years from all causes.),

(*c*) be capable of being produced in sufficient quantity and at a price low enough to make the 60 MHz system viable.

To enable overall negative feedback at 60 MHz to be maintained, interconnexions have to be very short. The design approach was, therefore, to mount all the transistors, together with interstage coupling components on to a small alumina substrate.

The large amount of experience accumulated by the British Post Office Research Department in assessing the reliability of transistors for transoceanic telephony cable systems was applied to the related problem of evaluating the 60 MHz system active devices.

Evaluation was divided into two discrete aspects:

(*a*) evaluation of transistors, and
(*b*) evaluation of assembled composite devices.

A photograph of one of the devices is shown above.

EVALUATION OF TRANSISTORS

An initial design study of the current transistor types chosen for use in the system suggested that a change from an aluminium contact system to titanium/gold contacts would provide a better long-term performance in the 60 MHz system.

To evaluate each type of transistor used, samples (of the order of about 25 of each type) were produced and encapsulated individually in the normal way (using hermetic seals). The parameters of each transistor were first measured at a case temperature of 50°C. The temperature of the case was then raised to 100°C, the transistor energized to dissipate an appropriate power and left for 20 hours. The temperature was then reduced to 50°C and the parameters again measured. The process was repeated, at each stage raising the temperature by 20°C until failure occurred. A typical definition of failure was an emitter-base (or collector base) current of 2 μA or a change of gain of 50 per cent or more.

From these measurements it was established that the current gains, leakage currents and contact resistances exhibited good stability during the tests. It was predicted that the devices as tested in their individual hermetic encapsulations would be adequate from the reliability and stability points of view for the 60 MHz system.

EVALUATION OF ASSEMBLED COMPOSITE DEVICES

Having proved that the individual transistor chips were potentially adequate, it was then necessary to prove that fixing them to their substrate, providing the necessary interconnexions (including coupling capacitors), fixing the substrate and sealing the whole into a hermetic encapsulation would not cause deterioration.

To this end, some units were fully equipped and subjected to temperature cycling from −65°C to +175°C at least 10 times and changes of performance monitored.

Other encapsulations had ceramic substrates fixed and were tested for the possible adverse effects due to moisture and metal migration.

Tests were also carried out on other batches to:

(*a*) see whether stresses caused by mechanical shock adversely affected the metal glass seals of the package,

(*b*) prove that the leads remained sufficiently flexible and solderable after being subjected to the heating associated with the fixing of the substrate, and

(*c*) to verify, by electrical means, that no hair cracks appeared in the substrate as a result of its being brazed to the base of the encapsulation.

The results of all these tests indicated that the device, with individual transistors and coupling components interconnected by titanium/gold contacts and a gold-wire interconnecting system, fitted to an alumina substrate in firm mechanical and thermal contact with the base of a hermetic encapsulation, was suitable for use as an active device on the 60 MHz system. Later, protective diodes, to prevent dangerous energies arising from lightning discharges or other surges from damaging the high performance transistors were also mounted on the substrate and interconnected as an integral part of the assembly.

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The 60 MHz F.D.M. Transmission System: Frequency Translating Equipment

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U.D.C. 621.395.452: 621.372.632

For the 60 MHz f.d.m. transmission system it is necessary to translate 15-supergroup assemblies into one frequency spectrum. This article discusses the equipment needed for this assembly and deals in particular with the line frequency spectrum.

INTRODUCTION

This article gives a general outline of the multiplex equipment required at a 60 MHz system terminal with the main emphasis on the line frequency spectrum assembly. The centralized frequency-generating equipment which forms an essential part of the multiplex function is also described in this issue.[1]

In view of the need for extreme reliability, the higher frequencies involved and the requirement for a much higher order of frequency stability, a field trial of the multiplex equipment has been established in conjunction with the 60 MHz line system also described in this issue.[2] This has enabled a complete system, i.e. master frequency-generating equipment, translating equipment and the line system to be tested in a repeater station environment.

UTILIZATION OF SYSTEM BANDWIDTH

There are numerous ways in which the line frequency spectrum of the 60 MHz transmission system can be utilized. Obvious aims are maximum channel capacity and the desire to facilitate interconnexion with existing 4 MHz and 12 MHz systems. Other considerations include the need to keep to a minimum the number of modulation and demodulation stages (to minimize their noise contribution) and to keep to a minimum the number of frequency bands handled by the translating equipment, to reduce the number of different types of filter.

To ensure good transmission performance of international circuits the C.C.I.T.T.* make recommendations for the main characteristics of transmission systems likely to form parts of international connexions, and it is evident that a standard system would have many advantages. However, the need for compatibility with existing national multiplexing arrangements and the requirement for an economic solution force a compromise. Fig. 1 shows the two multiplexing procedures recommended for assembling wideband multichannel systems. There are operational and technical advantages in being able to connect large blocks of channels from one system to another, particularly by using only filters to select the appropriate part of the frequency spectrum since additional noise contributions are avoided if no active equipment is needed. However, the bands should not be too large or too small if the block of channels is to be a suitable size for the operating needs of the national trunk networks.

From the foregoing it is apparent that there are many aspects to be considered, some of which are a function of the different and changing needs of the telephone administrations. Having chosen a 4 MHz band for assembling the 60 MHz line spectrum, the formations of the basic-supermaster group and 15-supergroup assembly No. 3 (15 s.g.a.3) have convenient similarities and each is assembled by the same number of modulation stages.

A number of technical advantages gained by assembling the line spectrum from 900-channel, 4 MHz bands instead of 2,700-channel, 12 MHz bands, are listed below.

(a) Modulators capable of translating 4 MHz bands are already in existence, and although for the 60 MHz application they are required to operate with carrier frequencies up to 68 MHz, the problems associated with the design of a suitable modulator to translate 12 MHz bands are greater due to the increased load capacity and bandwidth.

(*b*) The two sidebands produced by a single modulation process are separated by twice the lowest frequency of the input signal. It follows that the design of filters to extract one sideband is eased if the input frequency spectrum is of the order of 8–12 MHz, rather than the 0·3–12 MHz as would be the case if the existing 12 MHz line spectrum were directly modulated.

(*c*) Assembling from 12 MHz bands involves more modulation stages in the transmission path, thus introducing more noise and distortion.

(*d*) The lower load-capacity and bandwidth of 900-channel bands eases the design of amplifiers and other networks used in the translating equipment up to the broadband combining point.

One obvious disadvantage of the scheme is that a 12 MHz system must be broken down to 4 MHz bands for connexion to 60 MHz systems.

The line frequency allocations and modulation stages recommended by the C.C.I.T.T. are shown in Fig. 2. The frequency limits of 15 s.g.a.3 fall within those of supermastergroup No. 3 (s.m.g.3), and with one exception the carrier frequencies are identical for both plans. Therefore, if the basic 15-supergroup assembly, i.e. 312 kHz–4·028 MHz has first been translated into the 15 s.g.a.3 spectrum, a single design of translating equipment can be used for both plans.

To ease filter requirements, it is desirable to have as much separation between signal bands as possible and theoretically the ratio of the width of the gap to the mid-gap frequency should be constant for all gaps if the filter designs are to be of the same complexity.

In considering economy of bandwidth, it is necessary to determine the importance placed on the facility for extracting bands directly from the line frequency spectrum (direct line filtering). The plans enable the four lowest bands to be extracted directly from the line frequency spectrum, but to save bandwidth, the separation between the higher bands is restricted and these bands can only be extracted in blocks of four. The gaps for extracting these blocks need to be wider than those for separating the modulated bands from each other, and it can be seen from Fig. 2 that the plans conveniently accommodate a 40 MHz system also covered by the C.C.I.T.T. recommendations.

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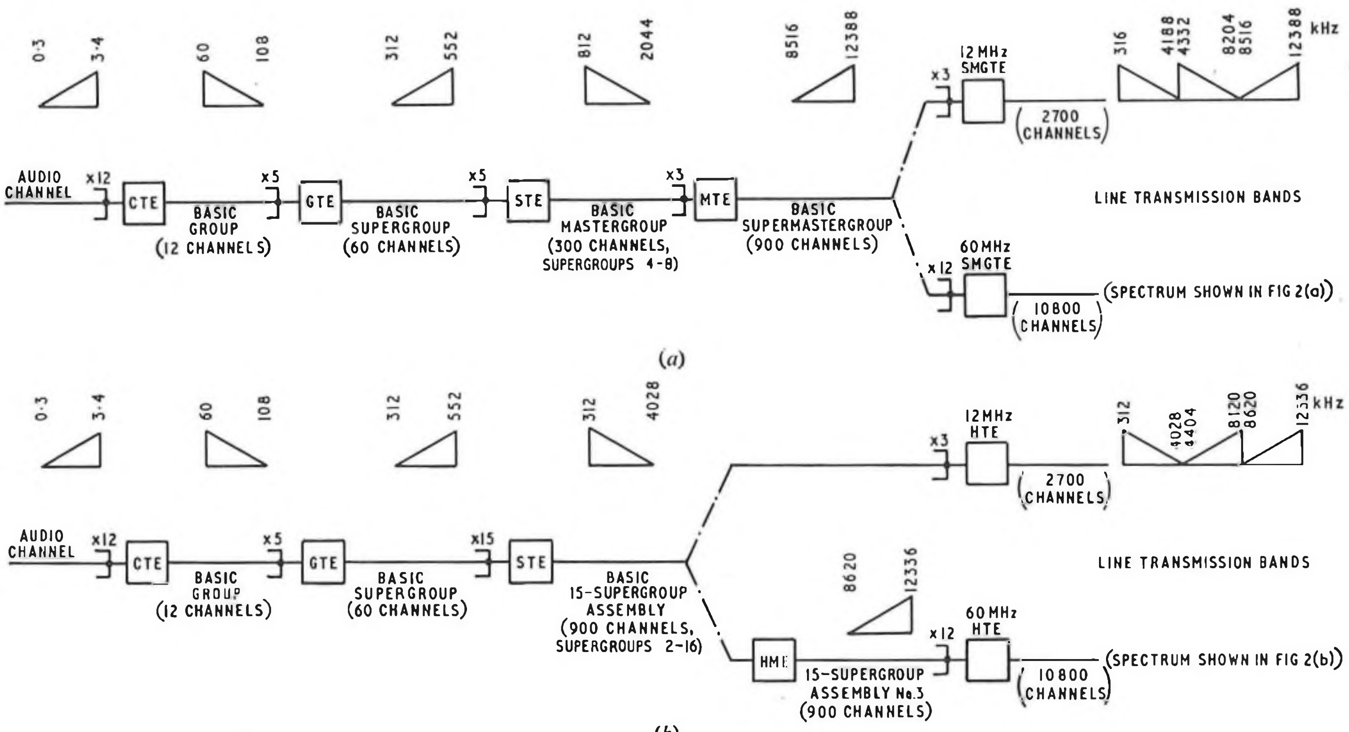
† Telecommunications Development Department, Telecommunications Headquarters.

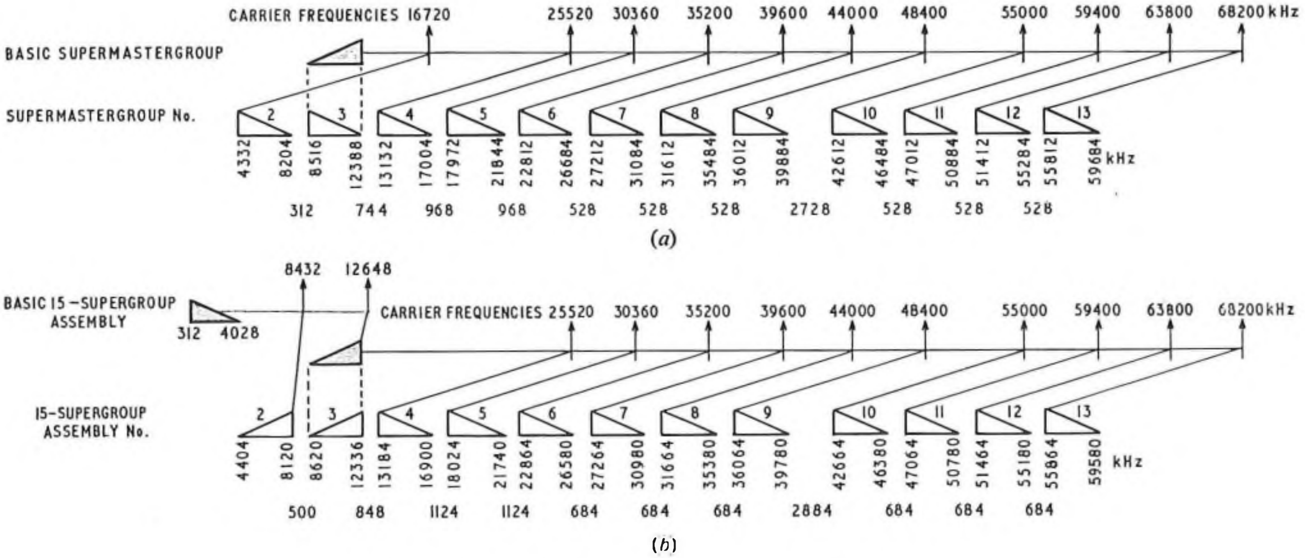
* C.C.I.T.T.—International Telegraph and Telephone Consultative Committee.



Note:
CTE—channel translating equipment
GTE—group translating equipment
STE—supergroup translating equipment
MTE—mastergroup translating equipment
SMGTE—super-mastergroup translating equipment
HTE—hypergroup translating equipment
HME—hypergroup modulating equipment

(*a*) C.C.I.T.T. Plan 1
(*b*) C.C.I.T.T. Plan 2

FIG. 1—Two C.C.I.T.T. procedures for the composition of 12 MHz and 60 MHz systems



(*a*) C.C.I.T.T. Plan 1
(*b*) C.C.I.T.T. Plan 2

FIG. 2—Line frequency allocation

EQUIPMENT DESIGNATIONS AND FACILITIES FOR INTERCONNEXIONS

In the British Post Office (B.P.O.) the basic 15-supergroup assembly, also known as a basic hypergroup, is designated *BAND 1* in the line frequency spectrum, and 15-supergroup assemblies 2–13 as *BANDS 2–13*. For the B.P.O., C.C.I.T.T. plan 2 (Fig. 2(*b*)) is appropriate and a decision was made to develop two new equipments to provide the required translation facilities. These are:

(*a*) hypergroup modulating equipment (h.m.e.) which translates the *BAND 1* frequency range to the *BAND 3* frequency range, and

(*b*) 60 MHz-hypergroup translating equipment (60 MHz h.t.e.) which accepts 11 inputs in the *BAND 3* frequency range and one input in the *BAND 1* frequency range, and translates them to form the 60 MHz line frequency spectrum. These equipments are also required to perform the complementary functions.

If the modulation stage provided by the h.m.e. had been included in the 60 MHz h.t.e., through connexions would have required additional modulation stages, and a single design to suit both C.C.I.T.T. plans would have been more complicated. Since the requirements of an h.m.e. already existed as part of the translating equipment designed for the

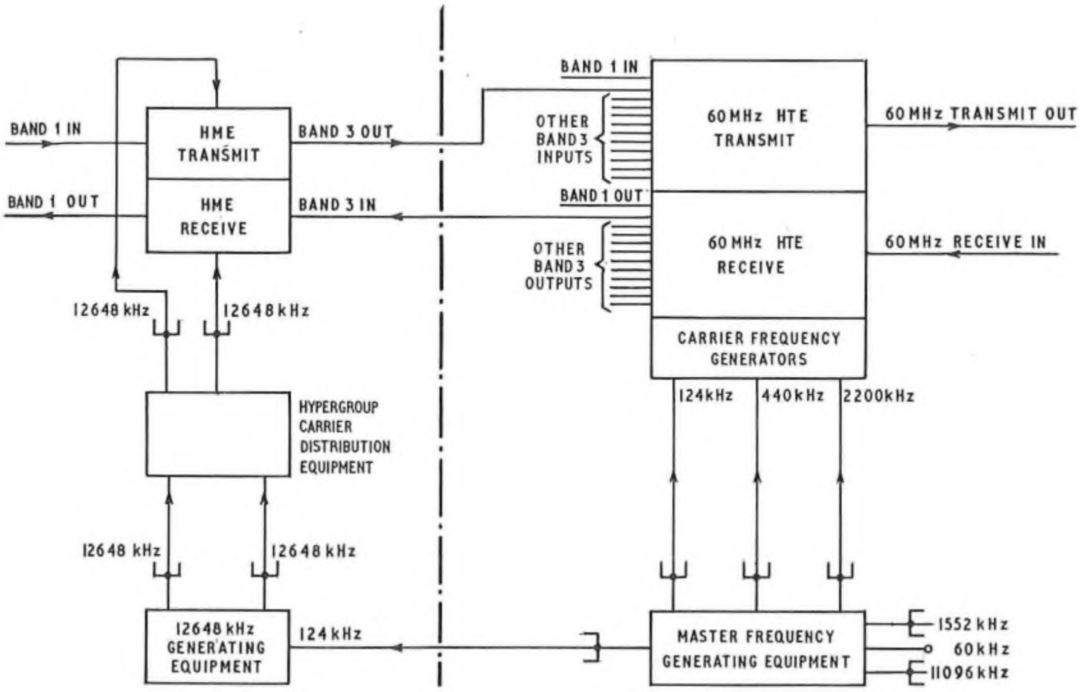
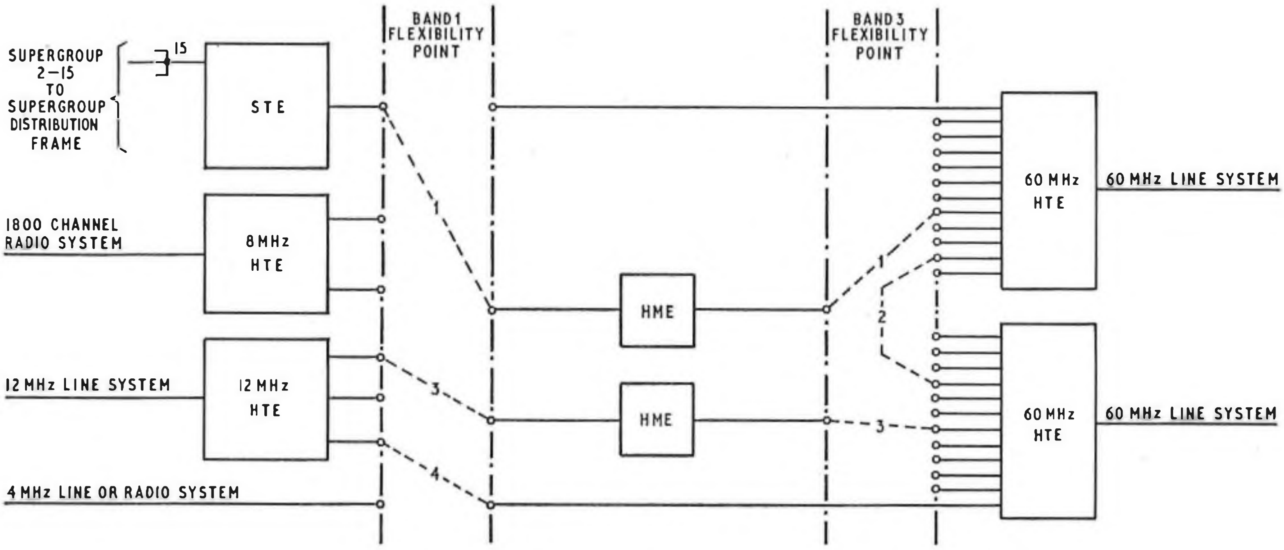


FIG. 3—Main items of 60 MHz multiplex equipment



Note: Each connexion represents both directions of transmission

FIG. 4—Interconnexion of 4 MHz bands

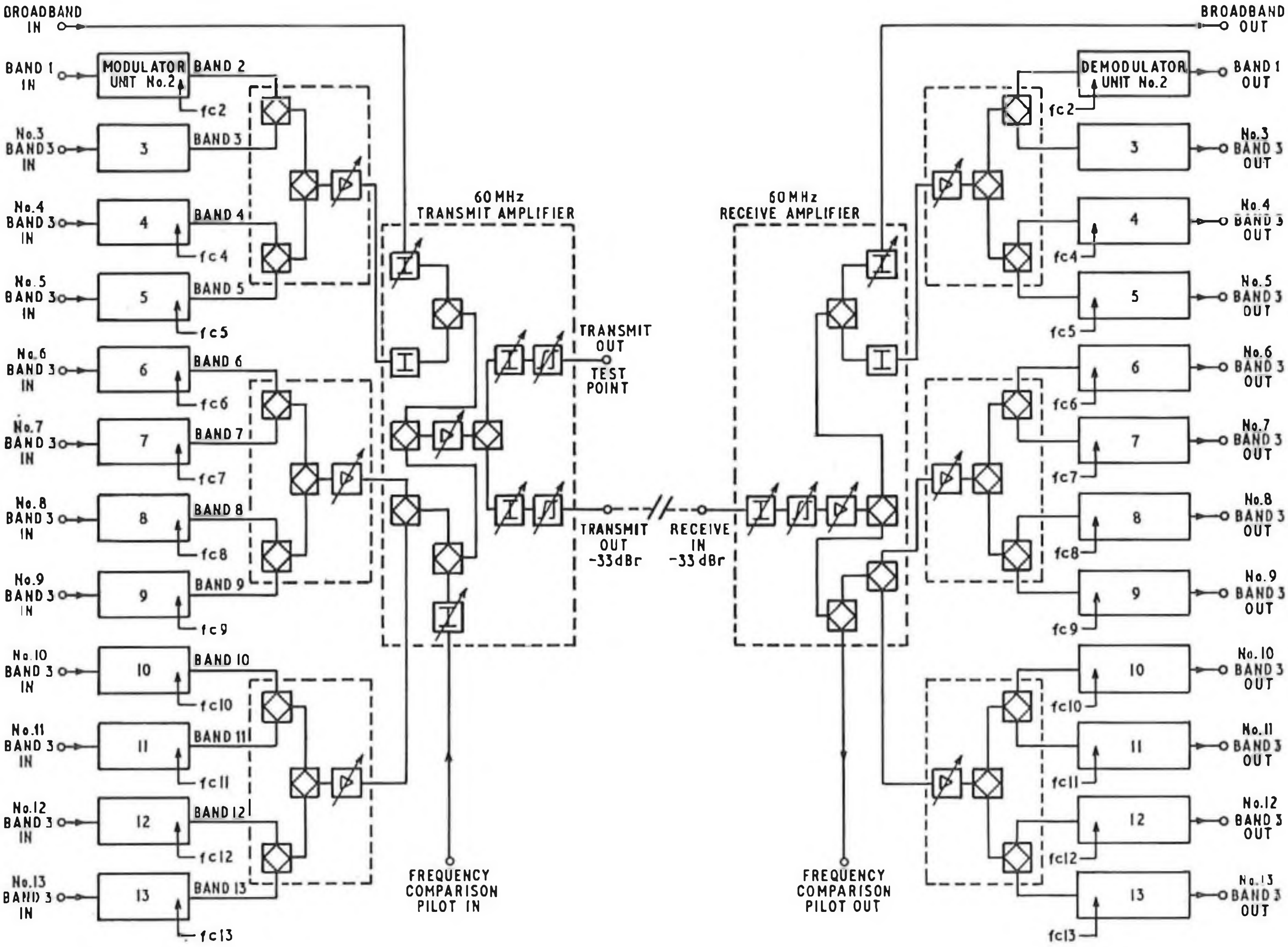
12 MHz f.d.m. transmission system, the introduction of the h.m.e. presented no difficulties, and some advantages.

The main items of translating and associated equipment are shown in Fig. 3.

Through connexions of 4 MHz bands in the B.P.O. network are at present made only at the *BAND 1* point, but with the introduction of 60 MHz systems the *BAND 3* interface will become an additional flexibility point (Fig. 4).

TRANSLATING EQUIPMENT

The general requirements of f.d.m. multiplex equipment have been reviewed in an earlier article in the *Journal*.[3] In the process of multiplexing, each channel is translated into a separate frequency band and a combined f.d.m. signal is produced. One-stage multiplexing of large numbers of channels is not normally economic, and a structure using multi-stage translation has evolved (Fig. 1). This has certain advantages, but one big disadvantage is that the spurious and unwanted products caused primarily by the modulators and demodulators have to be very strictly controlled. This can be achieved by careful system design and the use of adequate filtration. For telephony applications, the channel translating equipment has always been relied upon to provide most of the filtration and subsequent translating stages, e.g. group and supergroup, were designed with the minimum of filtration. The economic desirability of through-connecting groups and supergroups calls for special filters to prevent unwanted interference. For the 60 MHz design a decision was made to incorporate sufficient filtration to enable through connexions to be made without having to insert additional external filters. Standard input and output levels were also defined to facilitate interconnexions. However, for both technical and economic reasons this recent decision is only likely to affect the design of the higher-order translation equipments, i.e. where through connexion of basic 15-supergroup assemblies is involved.



Note 1. f_c etc. are carrier supply frequencies
2. Modulator unit 3 provides filtering function only

Fig. 5—Basic h.t.e. design

The Basic Arrangement of the H.T.E.

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

The equipment is designed on the one-stage modulation principle, but signal combining is achieved in a number of stages. The transmit path is made up of twelve modulator units, three combining amplifiers and a 60 MHz transmit amplifier. After modulation has taken place, the first combining stage produces three 4-band signal blocks. These are *BANDS 2–5*, *BANDS 6–9* and *BANDS 10–13*. The two largest inter-band gaps occur between these signal blocks, thus facilitating direct-line filtering of complete 3,600-channel blocks. The method of composition of the first block is somewhat different from the other two in that the first modulator accepts a *BAND 1* signal and translates it to *BAND 2*. In addition, the *BAND 3* position in the 60 MHz spectrum is obtained by filtering an incoming *BAND 3* signal. The remaining *BAND 3* inputs are modulated into *BANDS 4* and *5*. The second and third 4-band blocks are each assembled by four modulators, all accepting *BAND 3* inputs. The combining of the three 4-band blocks is accomplished by means of the hybrid transformers located in the 60 MHz transmit amplifier. In addition, a frequency-comparison pilot input point and a broadband injection point have been provided. The latter is to provide facilities for the injection of television signals or wideband data, if required. It can also be used for measuring and testing. The receive path is complementary.

Essential Performance Requirements

One of the most important aspects of translating equipment is the action of filtering to ensure that all the unwanted products are adequately rejected while allowing the required signals to pass without impairment. This must take place under all possible interconnexion arrangements, some of which are shown in Fig. 4. With an equipment which multiplexes twelve individual bands of telephony, the possible interconnexions are numerous and this inevitably results in an extremely long list of frequency-rejection requirements. The 60 MHz translating equipment is designed to ensure that the wanted transmission band is flat to within 1 dB (transmit looped to receive). Any possible direct interference path must be suppressed by 80 dB, while an indirect path (involving two or more stages) is suppressed by at least 40 dB per stage.

Noise is an additive impairment in f.d.m. circuits and must be kept to a minimum. The basic noise (i.e. that produced by an unloaded system) for the 60 MHz h.t.e. has to be very low, and a figure of better than −77 dBm0p for a telephone-channel band has been achieved for a combined transmit and receive equipment. It is also necessary that the equipment should not generate excessive noise (due to intermodulation) when loaded with traffic. White noise is used to simulate the condition of traffic loading, and measurements are made in a small unloaded portion of the transmission band. The increase in noise, which has been specified at 2 dB, represents

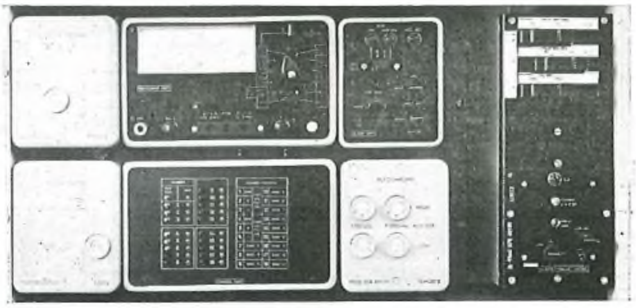


FIG. 6—Part of h.t.e., showing monitoring facilities

the extra contribution of intermodulation and other unwanted signal paths. First-order intermodulation products have been specified at −75 dBm0, but, in general, considerably better performance is required if the equipment is to meet the white-noise specification.

The crosstalk-to-signal ratio is always expected to be considerably better than 80 dB.

Any specification usually contains a number of secondary performance parameters and among those specified for this equipment are the generation of stray electromagnetic fields, interference that might be caused by extraneous radiation and power-borne interference. In addition, due to the frequency-dependent losses of station cables, special equalizers have been developed for each band so that frequency-independent interconnexions can be made at the *BAND 1* and *BAND 3* connexion points. A 4–60 MHz equalizer is also included to facilitate connexion to subsequent equipment.

Special Features

Reliability is an important design feature of transmission equipment, especially when a common path failure could result in 10,800 circuits being disconnected. For this reason, rack-mounted spares are provided for all active units which carry more than 900 circuits. This enables a faulty unit to be replaced as soon as possible and thus helps to reduce the circuit out-of-service time.

In addition, an amplifier specially designed for the 60 MHz line system has been utilised in the combining and distribution paths. The active elements of these amplifiers are completely encapsulated and mounted on a ceramic substrate and are believed to offer extremely high reliability. Overall negative-feedback is used to achieve the high gain-stability required.

Active modulator circuits are used which consist of four transistors in a double push-pull configuration, housed in a single package. These offer a number of technical advantages such as improved balance stability. It is also claimed that improved noise figures and better reliability are achieved.

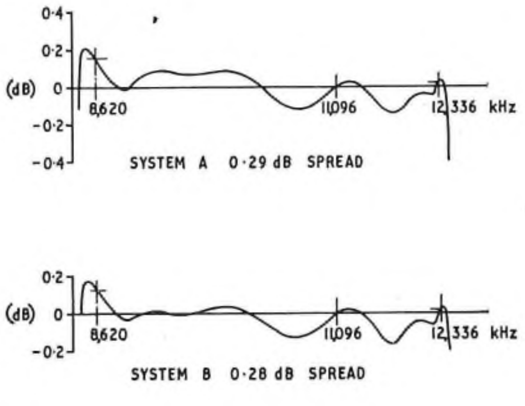


FIG. 7—Insertion gain/frequency response (equipment looped) No. 4 *BAND 3 IN*–No. 4 *BAND 3 OUT*

Carrier Supplies

The 60 MHz h.m.e. requires only one carrier frequency, 12,648 kHz, which is available from slightly modified existing 62-type equipment. However, the h.t.e. carrier supply system departs from conventional design. It was considered unwise for high levels of carrier supplies of frequencies up to 68,200 kHz to be distributed throughout the station. The probability of interference was considered to be too high to risk, and the central generator concept, although retained in essence, has been modified to provide three comparatively-low-frequency primary carrier supplies—124 kHz, 440 kHz and 2,200 kHz. Separate carrier generators, working on the phase-locked oscillator principle, are located within the h.t.e and provide the eleven carriers required by the modulators and demodulators. They are similar to the oscillators which form part of the master generating equipment. Each of these eleven generators is dependent on only one of the primary carriers, and their outputs are substantially unaffected by all normal ranges of supply level.

As with the translating equipment used in other parts of the hierarchy, it is necessary to ensure that the carrier supplies are maintained within the specified limits and checks can be made on the master oscillator frequency against the standard 60 kHz reference supply. However, it is not practicable to transmit 60 kHz over a 60 MHz line system, and the standard reference is directly converted by multiplication to 4,200 kHz for transmission purposes. The phase-locked oscillator principle is also used for this circuitry.

At the distant end, the incoming 4,200 kHz signal is extracted by the h.t.e. and can be down-converted to provide a reference for the master generating equipment. This procedure is used whenever a local reference is not available, or a second source is required for security reasons.

SYSTEM MONITORING FACILITIES

The system monitor represents a significant departure from existing B.P.O. policy. It has become normal practice to provide a line-system pilot to give an indication of total system failure. This is quite distinct from the individual band pilots, and is normally inserted by the line-terminating equipment. However, it does not protect the wideband portions of the translating equipment.

Hypergroup Pilot Supervision Equipment

No separate pilot is provided between the 60 MHz h.t.e. terminals. Since each band is provided with its own hypergroup pilot introduced by the supergroup translating equipment (s.t.e.), an effective system monitor is provided by a centralised scanning-system which monitors each pilot in turn. The *BAND 1* pilot is 1,552 kHz which becomes 11,096 kHz in *BAND 3*.

A scanning control unit (see Fig. 6) has access to a static switch located in each of the demodulators and scans each pilot in turn at intervals of about one second. If the incoming pilot level deviates beyond the preset high or low limits, an alarm is given automatically. In addition, the scanner unit checks the existence of the locally-generated calibration signals (high, low and nominal levels for each 1,552 kHz and 11,096 kHz pilots). If a failure occurs, the scanner unit continues, even though an alarm condition exists, until it is switched to the locate mode. A small lamp, one of which is associated with each pilot, then lights and identifies the failure. The alarm can be silenced by a simple mechanical operation, i.e. withdrawing and inserting in the reverse direction a small peg housed alongside the alarm lamp. When the scanning procedure is resumed in the alarm-silenced condition, a further alarm occurs when the fault condition is cleared. In addition, the automatic procedure can be inhibited and the scanner can be stepped manually to ease fault location.

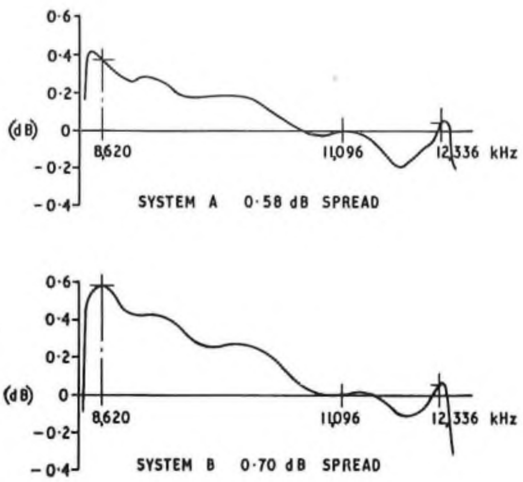


FIG. 8—Insertion gain/frequency response (equipment looped) No. 10 *BAND 3 IN*–No. 10 *BAND 3 OUT*

By logical interpretation of the fault conditions it is possible to locate the faulty apparatus without difficulty. For example, if failure of all the pilots occurs simultaneously, a common-path fault is assumed. Hence, it was considered unnecessary to provide a separate pilot between the h.t.e. terminals.

Measuring Unit

In addition, a measuring unit is provided as part of each h.t.e. (see Fig. 6). This unit is provided for maintenance and fault-location purposes only. It is not accurate enough for system alignment, but enables quick checks to be made in the event of a failure. In this way a fault can be located comparatively quickly and the correct remedial action taken.

The unit can measure power supply voltages and currents, pilot levels and carrier supplies. The power-supply measurements are simply made by the rotation of a switch. Signal measurements are made with the aid of a test cord which is plugged into the relevant test point. The frequency response of the unit enables wideband measurements to be made at all accessible points provided on the equipment.

FIELD TRIAL

One main object of the field trial at Marlborough is to enable a full set of electrical and mechanical tests to be carried out on the coaxial line system. However, it was considered that the extra benefit that could be gained from the installation of the line system and its associated translating equipment down to 4 MHz basic hypergroups fully justified a field trial of the combination. This is a departure from normal practice because the B.P.O. has hitherto approved translating and frequency-generating equipment as a result of the inspection of prototype equipment at the manufacturers' premises.

In choosing the field-trial equipment configuration of the translating equipment every effort was made to ensure that many combinations of equipment would be possible. The multiplex equipment layout is designed so that it can be split easily into two hypothetical, but essentially separate, terminals. Each terminal consists of one h.t.e., two h.m.e.s and their associated master frequency-generating equipment.

In addition to technical performance, the operational and serviceability aspects of the equipment are being studied. This is particularly important as there have been several major changes in design concepts. Some minor modifications may be made to parts of the mechanical design to improve certain operational aspects.

Test Results

The results of the electrical tests performed so far have given the designers confidence in the performance of the equipment. Some of these test results are shown in Table 1. Only the major performance parameters have been shown.

TABLE 1
Test Results

Test	Result
Insertion gain/ frequency response	Two typical responses are shown in Figs. 7 and 8. These have been measured with the equipment looped at the 60 MHz point, and include the cabling to the *BAND 3* distribution frame.
Basic noise	The worst measurement made on a looped system for a *BAND 3–BAND 3* connexion was −78·5 dBm0p.
White noise	A *BAND 3–BAND 3* connexion with the equipment looped at the 60 MHz point gave a worst result of −77·7 dBm0p.
Crosstalk (far end)	The worst transmit-receive crosstalk figure was −97 dB. The majority of measurements gave figures better than −110 dB.
Crosstalk (near end)	Most measurements were better than −100 dB. The worst figure was −92 dB.
Intermodulation	The intermodulation products were too low to measure directly and special test methods had to be adopted. The results all point to figures of better than −120 dBm0 for two-tone products.
Overload	The overload measurements indicate that the translating equipment has an overload margin well in excess of the design figure.

CONCLUSIONS

This article has dealt briefly with the development of a B.P.O. 60 MHz translating equipment. It has covered only the broader aspects of the design and the principles behind the more important decisions. Some measured equipment performance parameters have been given which are the result of the field trial at Marlborough. As this article has been written at a comparatively early stage in the trial, the multiplex equipment and line system have not yet been operated in conjunction with one another for any appreciable length of time. However, the results of the electrical tests so far carried out suggest that the performance of the complete system will be entirely satisfactory.

References

[1] HUGHES, L. E., and WALKER, D. C. The 60 MHz F.D.M. Transmission System: Carrier Frequency Generating Equipment. (In this issue, p. 150.)

[2] HALL, B., and BUFFIN, J. D. The 60 MHz F.D.M. Transmission System: The Line System. (In this issue, p. 135.)

[3] BLACKHALL, R. W. E. F.D.M. Multiplex Equipment. *P.O.E.E.J.*, Vol. 66, p. 38, Apr. 1973.

The 60 MHz F.D.M. Transmission System: Carrier Frequency Generating Equipment

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U.D.C. 621.395.452: 621.373

A new design of carrier frequency-generating equipment is described, with better frequency stability than existing types and giving the extra frequencies required for the translating equipment for the 60 MHz f.d.m. transmission system. It is intended primarily for use in 60 MHz system stations, but is also suitable for more general application.

INTRODUCTION

This article describes the carrier frequency-generating equipment of the 60 MHz f.d.m. transmission system. The terminal equipment used to translate the basic hypergroups (4 MHz) into the line frequency spectrum is described in another article.[1]

The primary stage of translation in the hypergroup modulating equipment (h.m.e.) requires many 12,648 kHz supplies and these are provided by a special single-frequency version of a standard generator for 8,432 kHz and 12,648 kHz. This is driven by a 124 kHz master frequency and has conventional working/standby change-over facilities; it provides 16 outlets at a level of +15 dBm in 75 ohms. As it has no new features it is not considered further here.

In order to avoid the station distribution of high-frequency carriers, the hypergroup translating equipment (h.t.e.) includes the generators for the carrier supplies required for the final translations. However, supplies of 124 kHz, 440 kHz and 2,200 kHz are required to drive the translating equipment generators, and the latter two frequencies are a new requirement for frequency-generating equipment. Also, for 60 MHz systems, the carrier supplies must have a frequency stability five times better than that required for existing 12 MHz systems so as to maintain the same maximum overall channel-to-channel frequency shift limit of 2 Hz—the C.C.I.T.T.* recommend a stability of better than ±1 in 10^8. In addition, the frequency supplies must be extremely reliable in view of the high revenue-earning capacity of the systems which they serve. Thus, it was decided to specify a new carrier frequency-generating equipment for 60 MHz system stations. This was developed under the contract for the other terminal equipment, and two models were made for the field trial described in another article.[1]

GENERAL DESCRIPTION

This equipment[2] is a proprietary design. Fig. 1 shows a close-up of the master oscillators, generators and the test equipment. Fig. 2 illustrates the construction of a typical unit.

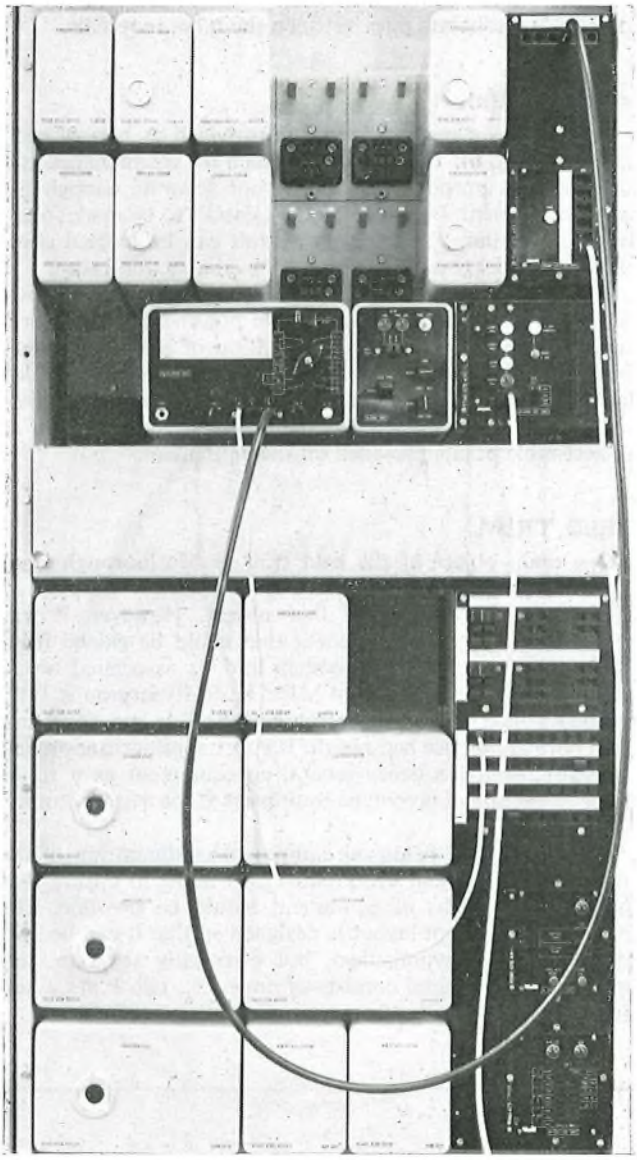

FIG. 1—Carrier frequency-generating equipment

[†] Telecommunications Development Department, Telecommunications Headquarters.

* C.C.I.T.T.—International Telegraph and Telephone Consultative Committee.

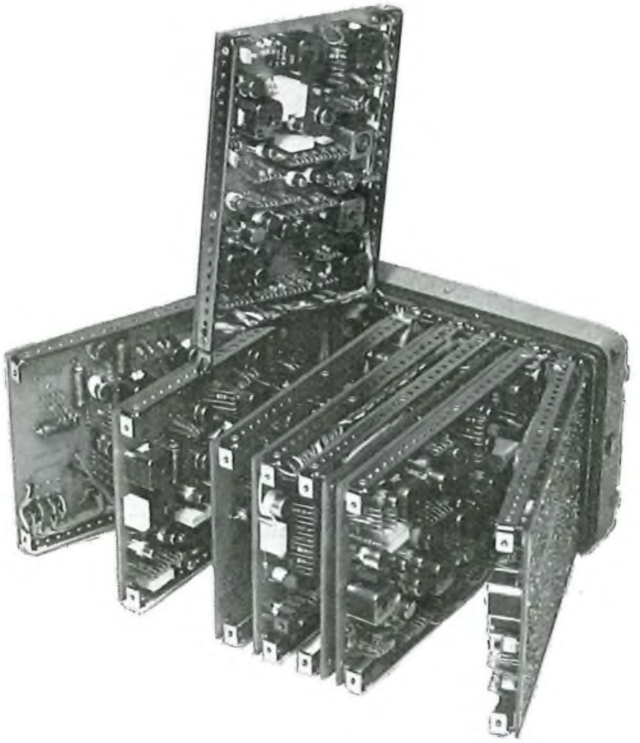

FIG. 2—The 60 kHz, 124 kHz, 440 kHz and 2,200 kHz generator unit

Although only frequencies of 124 kHz, 440 kHz and 2,200 kHz are essential for the 60 MHz system station translating equipment, the design has been made more universal and includes 4 kHz and 12 kHz supplies with levels compatible with existing equipments. 60 kHz is also generated for comparison with the national frequency standard, and 1,552 kHz and 11,096 kHz as calibration signals for the special hypergroup pilot supervisory equipment[1] on 60 MHz systems.

The principle of the generating equipment is illustrated in the block diagram shown in Fig. 3. To give the desired reliability, all generators are duplicated and arranged to give automatic working/standby change-over facilities. This is achieved by switches on each output (Fig. 3) controlled from level monitors via a logic circuit as illustrated for the master generator in Fig. 4. The working generators feed the distribution units giving outputs as shown in Table 1.

TABLE 1

Distribution Unit Outputs

Frequency (kHz)	Number of Outputs	Level (dBm)	Impedance (ohms)
4	20	− 6	600
12	20	− 6	75
60	1	0	140
124	40	− 6	75
440	20	0	75
1,552	4	−19	75
1,552	4	+ 4	75
2,200	20	0	75
11,096	4	−19	75
11,096	4	+ 4	75

The 4 kHz and 12 kHz generators and distribution units are optional as they are used with channel and group carrier-generating equipments[3] which may not be required at 60 MHz system stations. Some 124 kHz outlets could be used for supergroup and hypergroup carrier-generating equipments[3] for other than 60 MHz systems.[4] The −19 dBm, 1,552 kHz and 11,096 kHz outputs are used for 60 MHz system hypergroup pilot supervisory equipment, and if necessary, 8 outputs at this level can be obtained from each +4 dBm output by means of an optional distribution unit. The frequency-generating equipment can provide primary carrier supplies for up to twenty 60 MHz h.t.e.s having a total capacity of 216,000 telephone circuits, hence the need for extreme reliability particularly in any common path of the generating equipment.

The master oscillators are in triplicate because of the considerable time required for a replacement oscillator to warm-up to a stable-frequency condition. Two of the oscillators are connected to the working and standby generator chains which have automatic change-over facilities, and the third acts as a spare which can be manually switched in place of either of the other two by means of U-links (see Fig. 4). A new supervisory system has been developed in which a frequency comparison is made between the three oscillators to identify any one that drifts off frequency.

MASTER OSCILLATOR

The master oscillator is a fifth-overtone quartz-crystal-controlled oscillator[5] with an output frequency of 2·5 MHz. The crystal is housed in a temperature-controlled oven which is kept at approximately 61° C, the precise temperature being chosen for each individual crystal to correspond with that for zero slope in the frequency/temperature characteristic. The oven temperature is sensed by a platinum resistor situated in the crystal oven and forming one arm of a bridge in the feedback circuit of a 10 kHz oscillator. The oven-heater power supply is also derived from this 10 kHz oscillator and is thus controlled by the out-of-balance current from the bridge in such a direction as to restore balance and maintain the temperature constant to within about 0·015° C. Should a fault occur in the oven temperature-control circuit, the circuit arrangements ensure that the oven temperature does not exceed 75° C (approximately) in order to safeguard the oven and components in the oven from damage.

Frequency adjustments are normally made on a variable capacitor, but provision is made for further adjustment during the life of the equipment by means of padding capacitors. The movement of the variable capacitor is under the control of an electric motor which synchronizes the 60 kHz obtained from the master generator associated with the master oscillator requiring the frequency adjustment with the 60 kHz national frequency standard. This form of adjustment has been adopted because manual control would not be very practicable for the high accuracy of frequency required. It has the advantage of offering a choice between allowing the master oscillator to be free-running, and locking the master oscillator to the national frequency standard. However, it is intended that the master oscillators will be operated as free-running oscillators, and only periodically synchronized to the 60 kHz national frequency standard. The design also allows operation at master frequencies of 124 kHz, 300 kHz or 308 kHz if a suitable standard exists.

GENERATORS

The multiplication and division stages in the generators utilize a variety of circuit techniques. Besides the more conventional non-linear circuits, use is made of phase-locked oscillators and a novel synchronized oscillator circuit. However, the prime consideration in any design using an oscillator principle is that there should be no output other than when the system is locked at the correct frequency. The use of

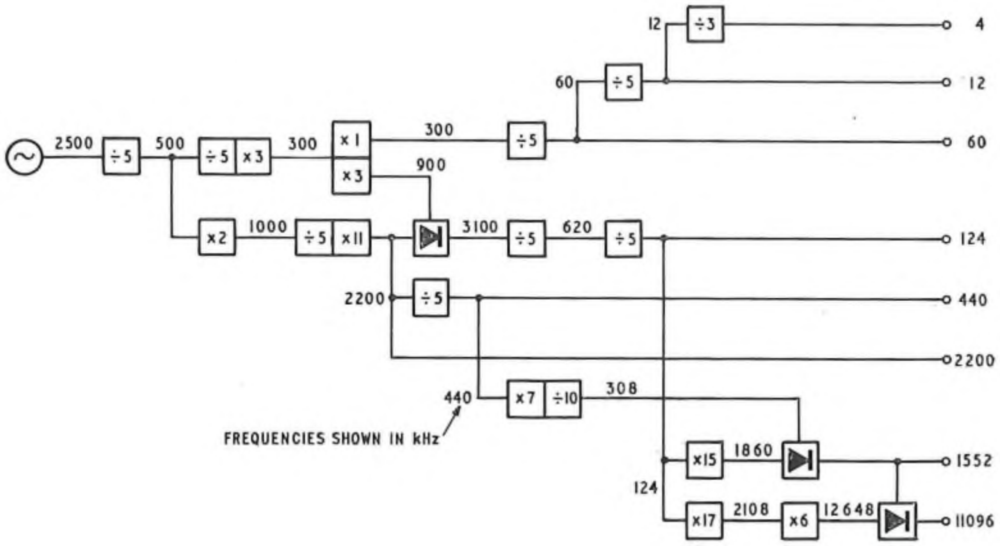

Fig. 3—Block diagram showing principles of frequency generation

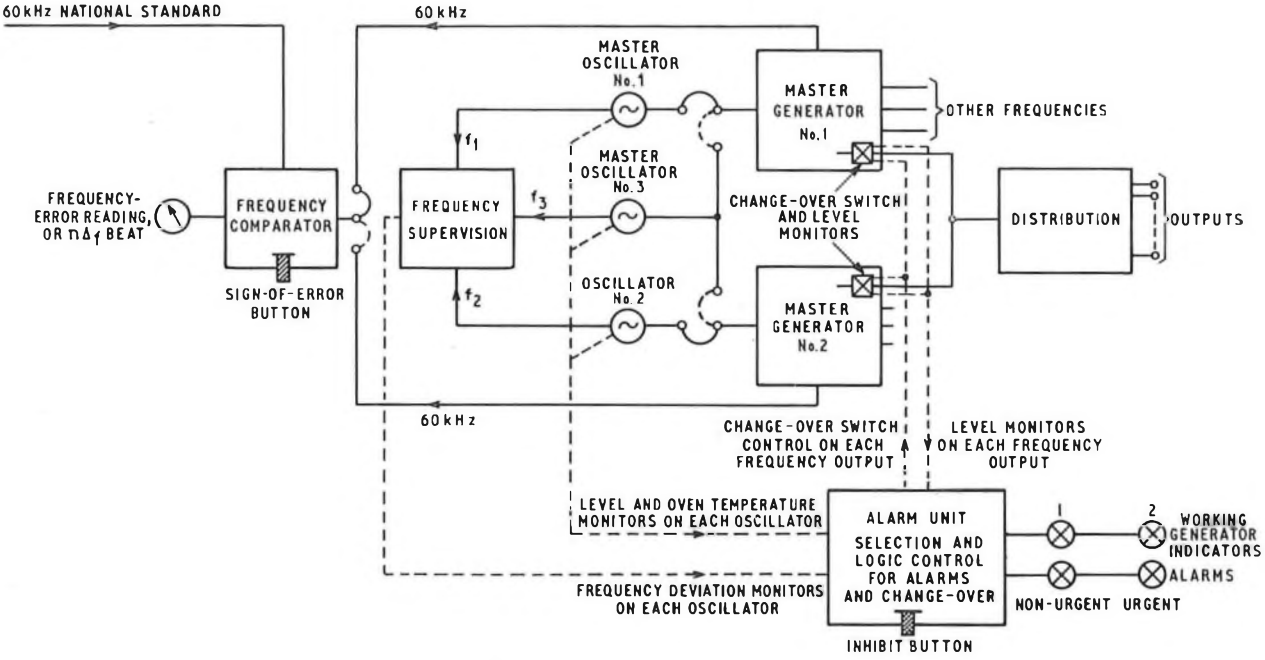

Fig. 4—Block diagram of frequency-generating equipment and supervisory arrangements

oscillator techniques provides filtration and offers considerable saving in conventional filters. Phase-locked oscillator techniques are also used in the carrier supply generators and the 60/4,200 kHz and 4,200/60 kHz frequency converters in the translating equipment.

Each set of generators is assembled as six units, the main unit, illustrated in Fig. 2, provides the 60 kHz, 124 kHz, 440 kHz and 2,200 kHz outputs and drives the other generator units to give the remaining output frequencies.

ALARMS AND CHANGE-OVER CIRCUIT

Should any master oscillator output level change by more than 1·5 dB, or the oven temperature by more than about 8°C, or the frequency difference between any pairs of oscillators exceed 1 in 10^8, then an alarm is given. This can be selected to be urgent or non-urgent by altering internal strapping on the alarm logic board shown in Fig. 4. However, a frequency change due to oven temperature change will normally raise the alarm long before the temperature alarm is given.

Level monitors on each output of the master generator, and all other generators associated with it, give an alarm and can initiate change-over. In the typical arrangement given in Fig. 4, the two generators are commoned via transistor switches which are under the control of the level monitors which operate at 1·5 dB drop in level. Monitors are also situated on the generator side of the switches, and the one in the standby unit operates a non-urgent alarm and prevents change-over should the level drop by more than 1·3 dB. To prevent possible undesirable change-over whilst units are exchanged, a manual facility is provided to inhibit change-over for a 90-second period.

The alarm logic board gives flexibility in choice of alarms and also enables change-over to be controlled by oscillator level or frequency changes as well as by the generator output-level changes. The maximum restoration time specified for a failed supply is 20 ms, and the interruption on all other supplies changed-over should be less than 2 ms. The longest restoration time measured was 3 ms in the 4 kHz supply, and on many supplies the change-over interruption was negligible.

TEST FACILITIES

A test meter is provided to check d.c. power supplies and to measure the output level from each oscillator, generator unit and test-point on each distribution unit. When normal, all levels read 0 dB on the meter. Also, a control unit is provided on the right-hand side of each sub-frame (see Fig. 1) which can be used in association with the alarm-location units to identify which set is working and to locate the faulty unit.

FREQUENCY MEASUREMENT AND ADJUSTMENT

The 60 kHz national frequency standard is provided to enable the frequency comparator (see Fig. 4) to measure the actual frequency from either the working or standby master generator 60 kHz supply to an accuracy of better than 1 in 10^9. The principle of the comparator is similar to some existing types, but is improved to obtain the higher degree of accuracy required. It virtually multiplies the frequency error by 1, 10, 100 or 1,000 so that the periodicity of the beat signal can be observed on the meter within a reasonable time—at ×1,000 an error of 1 in 10^9 gives a beat period of 16 seconds. Alternatively, an integrating circuit can be used to give a direct reading of error, full scale deflexion being 10 in 10^6, 10^7, 10^8 or 10^9, and throwing a key causes a meter kick, the direction of which indicates the sign of the error. This comparator can also be used with the oscillator synchronization circuit previously mentioned to speed up the process of automatically locking the oscillator frequency to the national standard. This facility is used for initial setting up, oscillator changing, or when frequency drift makes readjustment of frequency necessary. However, it is hoped that the reliability and stability will make the need for such adjustments infrequent.

The frequency comparator is designed to work with alternative frequency standards of 200 kHz and 300 kHz, should these be available (e.g. off-air standards). It can also be used to compare the frequencies of the two master generators at 60 kHz.

PERFORMANCE

The target requirement for master oscillator frequency stability was for a total variation of less than 4 in 10^9 over the ambient temperature range 10–40°C, and normal power-supply voltage variations. In addition, the drift rate should be less than 2 in 10^9 per month after 2 years. The first model varied by 2·5 in 10^9 over the temperature range 10–40°C, but the variation with power-supply voltage was negligible; most of the six field trial models were very similar. As the ageing characteristics on the field trial models have so far only been obtained for three months it is too early to confirm that the long-term stability requirement will be met, but one oscillator is already within the target and at present has a drift rate of 1·4 in 10^9 per month. Other oscillators are stabilizing much more slowly, and one has a small but noticeable daily cycle associated with temperature variations.

On switching on from a cold condition the oven should reach operating temperature (and extinguish the oven alarm) within about one hour, but the frequency will be outside limits for a much longer period and may take a few days to stabilize. However, when the oven alarm is extinguished, the oscillator can be synchronized rapidly to the national frequency standard, and held in synchronism until stabilized. In emergencies, such as if all three oscillators were cold, this method could be used, but a new spare oscillator would normally be allowed to stabilize before adjustment. This is an automatic adjustment, there being no manual control.

All generator output supplies met the specification requirements and the change-over facilities operated as intended. The field trial equipment has been in operation at Marlborough for over three months and so far has proved very satisfactory.

CONCLUSIONS

The carrier frequency-generating equipment described, although containing a number of new features, should prove to be satisfactory in 60 MHz system stations, but some minor changes may be necessary for production equipment. The field trial has enabled a thorough check to be made of performance in conjunction with other equipments. It is, however, too early to draw firm conclusions about the long-term drift rate of the master oscillators as tests over many months are necessary before an accurate assessment can be made.

Although primarily intended for the 60 MHz system stations the equipment is suitable for other applications, especially where there is a requirement for higher frequency stability than can be obtained from existing equipment, or where there is a need for the additional frequencies of 440 kHz and 2,200 kHz.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given by their colleagues both in the British Post Office and Industry.

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The 60 MHz F.D.M. Transmission System: Protection Switching Equipment

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U.D.C. 621.315.212.029.62: 621.395.5.004.15

The high level of availability demanded from a high-capacity transmission system calls for protection switching equipment. This article describes the main features of the equipment being developed for the 60 MHz f.d.m. transmission system where one standby line system is used to protect up to eight working systems.

INTRODUCTION

The British Post Office (B.P.O.) has not so far used automatic protection switching for coaxial line systems. Automatic point-to-point protection switching is commonly specified for radio systems to improve availability. The reliability target for the B.P.O. 60 MHz coaxial line system of a mean-time-between-failures (m.t.b.f.) of four years and availability of 99·99 per cent per 160 km—a considerable upgrading of coaxial line system requirements—is a current B.P.O. objective for which automatic protection switching is needed.

Under operating conditions, the line system is subject to working party interference, intermittent faults which may prove difficult to locate, surges, occasional operating mistakes and random failures.

Early failures during the settling-in period can also be expected to occur more frequently than the reliability target would suggest. Because some of these factors are outside the designers control, the design of the line system to meet the calculated m.t.b.f. objective may not, in itself, secure the availability objective throughout the working life of the system.

Fast switching to a spare transmission path is one method of reducing the out-of-service time caused by these largely unpredictable interruptions. A ratio of one spare transmission path for up to eight working systems is considered adequate to achieve the availability target of 99·99 per cent for the additional cost of one spare line system.

A changeover time of 10 ms was set as the target for a line up to 278 km in length. When not in use for protection, the standby system is connected to its own input and output ports and may be used for some classes of traffic. Its availability will be less than the other systems in the group because it will be seized when required to make good the failure of a working system. The performance requirements specified ensure that the switching equipment does not significantly worsen the overall transmission performance of the line systems being protected.

RELIABILITY REQUIREMENTS

The theoretical aspects of reliability, and the reliability of present day coaxial line systems, have been discussed in a previous article in the Journal.[1] It was shown that the availability of a group of systems is enhanced if a spare system and an ideal switching equipment is available. The reliability of this equipment is required to be greater than the line systems it is protecting and an order of improvement was suggested as a possible target. An availability objective of 99·999 per cent (5·3 minutes out-of-service time per year) is feasible if the equipment is installed in a staffed repeater-station and spares are to hand. However, a m.t.b.f. of eight years, i.e. twice that of each line system being protected, was specified as realistic for an equipment of this type, operating continuously for a period of some 25 years. Standard commercial components, suitably derated for stability and long life, have been used throughout for low cost and ease of replacement.

A simplified block diagram of a transmit/receive switching equipment is shown in Fig. 1. The transmission paths of one of the eight working systems and the standby are shown together with the associated logic and signalling paths for one direction of transmission.

Reliability requirements are eased by separating the transmission function from the control functions. Analysis yields two reliability structures. (Figs 2(*a*) and 2(*b*).) The first structure applies for static operating-conditions, when all systems are working normally.

The transmission path is kept simple and its failure rate is likely to be at least an order better than that of its associated 160 km line-system because of the very many more components and active devices required by the latter. A fast-acting bistable memory circuit is built into each changeover switch to maintain the switch state independently of any logic signals other than the signal to change state.

The reliability of the power units is critical. Three power units, each derated by 50 per cent, energize the switching rackside and a fourth, in reserve, is available via the customary switching diodes, (Fig. 3). Each power unit is allocated its own end-of-suite fuse. Power units required to operate continuously for 25 years do not require an input ON/OFF switch and this switch has been eliminated in the interests of reliability.

Power unit availability is enhanced by the additional diodes in each transmission unit which gives access to more than one power unit. Two power units may fail simultaneously without loss of traffic with this arrangement.

The reliability of the logic and monitoring functions appear in the structure when a working system fails and a switch is required (Fig. 2*b*). Additional elements are the backward signalling path and the standby line-system itself. Failure of any element in this structure, when a working system fails, results in failure to switch. The gainful use of the standby to improve availability relies on the small probability of the

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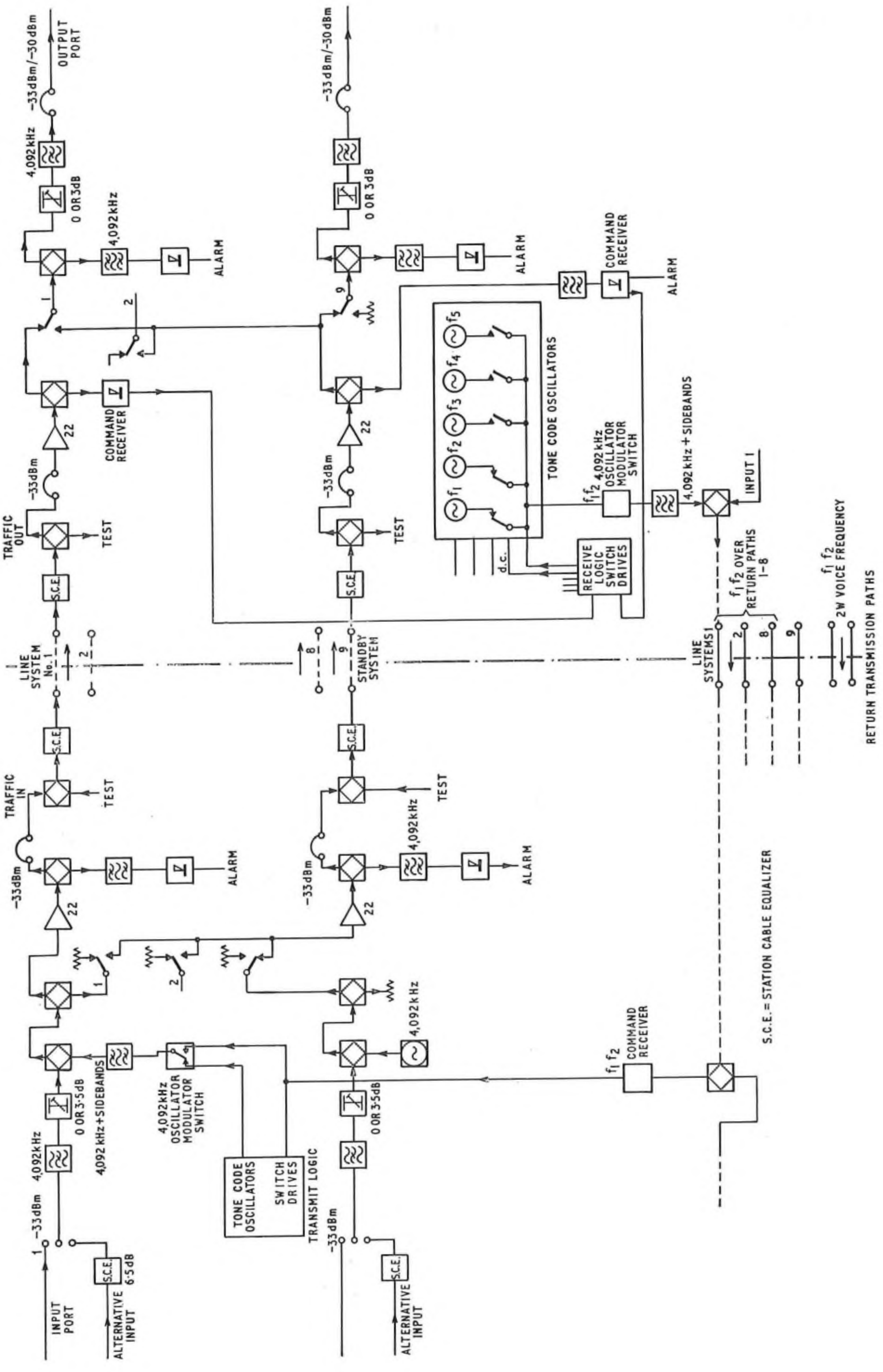
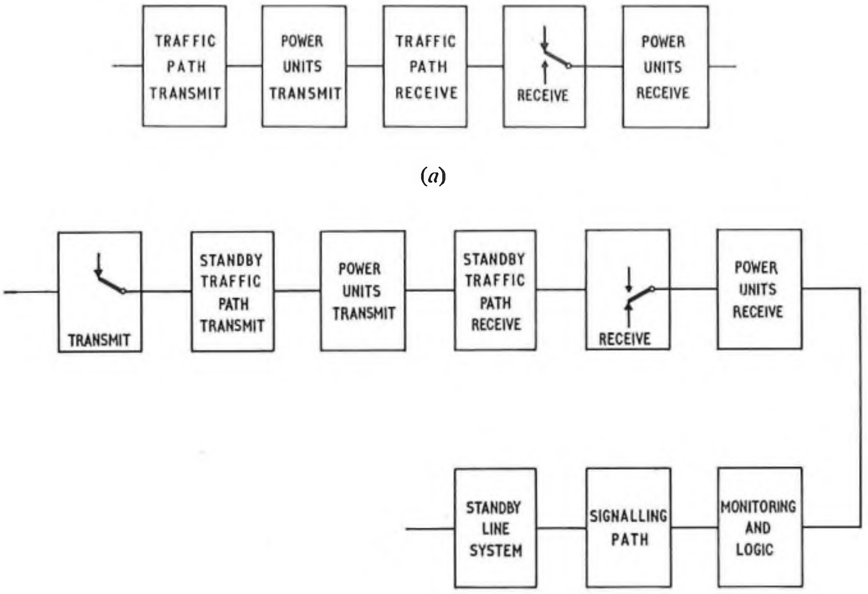


FIG. 1—A simplified block diagram of the switching equipment



(*a*)

(*b*)

FIG. 2—Reliability structures

simultaneous failure of a working system and any element in the structure.

The reliability of the signalling path is improved by transmitting the switching command signals simultaneously over the high frequency (h.f.) path of as many working systems as are available in the opposite direction of transmission. The signals are available for connexion to a 2-wire path, required for unidirectional working, or as a back-up signalling path over an alternative route if only one working system is available transmitting in the opposite direction of transmission.

Solid state switches are used for reliability and speed of operation. Positive intrinsic negative layer diodes (known as PIN diodes) are used in a conventional series-shunt-series switch arrangement.

The monitors and oscillators are simple devices using comparatively few components and, hence, a low failure-rate results. The logic makes extensive use of integrated-circuit devices, and has been subjected to many thousands of operations during development.

The continuity of the line systems is monitored by a 4,092 kHz pilot injected into each transmission path (see Fig. 1). The pilot also monitors the two amplifiers required by each traffic path through the equipment. A measure of self protection results: should either amplifier fail, continuity is maintained by switching to the standby transmission path and line system.

TRANSMISSION PATH

The equipment, designed for zero insertion loss, operates at a nominal channel test level of −33 dBm. Transmit equipment handling traffic to each of the nine line systems in one direction of transmission is mounted on the same rackside as the receive equipment for the return paths. One of two sources of traffic may be selected by the input coaxial U-link (see Fig. 1). The normal input is from the translating equipment; the alternative input is from another switching equipment. Any spurious output from the translating equipment which could affect the continuity pilot amplitude is prevented from entering the switching equipment by the 4,092 kHz pilot-stop-filter, which also confines the pilot to its own equipment. The incoming traffic passes via the continuity-pilot injection hydrid to the second hybrid where it divides. One output passes via a flat amplifier to the hybrid which feeds the *traffic-in* U-links of the line system and allows the continuity pilot level to be monitored via a narrow band-pass filter. The monitor gives high- and low-level alarms and has meter outputs so that a continuous record may be made of the pilot level transmitted to line. The other output of the hybrid is routed to a changeover switch which normally terminates in a resistive load. When a changeover to the standby is required, the switch operates to set up a parallel path over the standby line system. Simultaneously, another switch operates to isolate the standby system from its own input.

Traffic reaching the remote terminal of the line system passes over the *traffic-out* U-links into the receive equipment of the switching rack where it is amplified and equalized. A hybrid with a narrow band-pass filter on one output is used, together with a receiver, to measure the received level of the continuity pilot, while the second output of the hybrid is connected to a changeover switch. The receiver has high- and low-level alarm circuits coupled to both the alarm equipment and the switching logic. The switch selects either the worker or the standby line system as its source of traffic. A final hybrid with narrow band-pass filtering on one output allows the monitor to check the level of the continuity pilot after the switch. The second output of this hybrid is connected

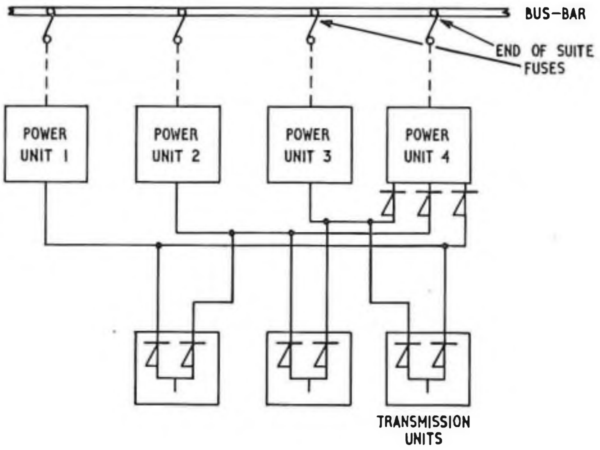


FIG. 3—Power unit switching arrangement

to the equipment output coaxial U-link via an optional attenuator and a band-stop filter tuned to reject the continuity pilot and its sidebands.

If two switching equipments (and line systems) are to be operated in tandem, the output of the first is cabled to the alternative input of the second equipment. The loss of 6·5 dB introduced by the station cabling equalizer (s.c.e.) is made good by strapping out the optional 3·5 dB and 3·0 dB attenuators.

SWITCHING AND CONTROL FEATURES

Ideal arrangements would permit the continuity pilot to monitor the entire traffic path from the input to the output (see Fig. 1). Practical engineering considerations, however, intervene. In this design a separate continuity pilot is generated and injected into each traffic path as near as possible to the input port. A change in level of the pilot exceeding the limit set for the system may be sensed by the monitor in the receive equipment in 2 ms, 1 or 2 seconds, as desired. This information is signalled to the receive logic, which, if more than one failure exists, decides in accordance with certain wired-in priorities which source of traffic to switch to the standby line system. The logic signals switching instructions to the transmit equipment at the distant terminal by modulating the continuity pilots of the return h.f. transmission paths with 2-out-of-5 v.f. tones. In Fig. 1 the two tones f_1 and f_2 instruct the transmit equipment to connect the standby system to its own input. Failure of a protected system results in a change to a different combination of tones. Each of the nine systems is identified by its own unique combination of two tones. Demodulation, tone detection and tone checking occur at the transmit terminal after which the changeover switches in the transmit equipment operate. The received-tone code is modulated onto the 4,092 kHz continuity pilot of the failed traffic path only, so that the source of traffic arriving over the standby may be identified. The logic operates the receive switches only when the code is verified, and the incoming pilot-level checked. Signalling and switching operations are completed in about 8 ms. Under normal operating conditions the reception of an unmodulated continuity pilot over the standby system indicates that it is connected to its own input and output ports and is available for use.

The logic may be strapped for automatic or manual restoration after a traffic path restores to normal. Manual restoration avoids the problem of frequent switching under marginal operating conditions. When strapped for manual control however, restoration will occur automatically if a line system having a higher priority than the first fails or if any second failure occurs after the first transmission path restores to normal, i.e. the standby is used to protect the second failure automatically.

Each direction of transmission is switched independently of the other. Two simultaneous failures, one in each direction of transmission, may thus occur without loss of traffic. This switching arrangment is also suitable for unidirectional working. A return signalling path independent of the coaxial pairs is required for unidirectional working. The velocity of propagation of this path is likely to be less than the h.f. path used previously and the switching time will increase accordingly.

SERVICE FACILITIES

Manual control over the switching functions is available via a control panel mounted at a convenient height on the rackside. The controls may be easily extended, if required, to a remote point in the repeater station. The controls work via the logic and do not override the safety features e.g. if a planned changeover to the standby is initiated, the switch is not completed if the standby is unfit for service. In this event, an incomplete switch alarm is given. The fast operating solid-state switches permit changeovers during normal hours and facilitate maintenance of the line systems. A planned changeover introduces a break in the transmission path equal to the transfer time of the switch of about 3 μs and is unlikely to be noticed by the majority of customers.

A simple manual override-control is available to set and lock all the receive changeover switches to their normal operating state. This action bypasses the logic and acts directly on the switches. It is provided to restore a traffic path to normal working should the logic fail.

Manual routine facilities are available to check the logic and the signalling path without interrupting a working traffic path. An inhibit key is operated and a manual signal given to route a selected traffic source over the standby. The appropriate two tones are signalled to the transmit equipment which sets up the parallel path, the logic checks the returned signal over the standby and the lamp indicating that the standby system is connected to its own input and output ports extinguishes i.e. the logic is used to check itself. Protected logic test points are provided for fault localization in situ using the rack mounted test meter.

Systems may be excluded from protection if desired. Lamp indication of this exclusion may be arranged at the remote point via a loop, available when the control is brought into use.

Access to the 60 MHz f.d.m. transmission system is provided via the test hybrids and associated s.c.e.s mounted on the switching rackside i.e. the nine systems may be tested from one location in the repeater station. The line systems engineering speakers are extended to the switching rackside and selective calling facilities are available.

ALARMS

The alarm unit is similar to that developed for the line system and a receiving attention facility is available. Failure of the static signalling conditions results in an invalid code alarm. The incomplete switch alarm checks active performance. A successful switch also gives rise to an alarm to indicate failure of a traffic path. Failure of a changeover switch or a 4,092 kHz oscillator does not result, however, in a switch and the stability of both is monitored and alarmed. The alarm arrangements may be used therefore to localize faulty units.

CONCLUSIONS

Automatic switching equipment permits prompt and efficient use of spare transmission capacity e.g. with this design one spare line system may be used to improve the availability of up to eight traffic paths. Check features have been incorporated which should safeguard the accidental loss of a large volume of traffic. The service facilities have been chosen to improve the maintainability of the switching equipment and the line systems being protected. Short term stability is improved by limiting the breaks in transmission caused by failures and interruptions, to some 10 ms if desired.

Automatic switching increases availability, minimizes the loss of revenue when a failure occurs and results in a marked improvement in service flexibility.

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The 60 MHz F.D.M. Transmission System: Cable Design and Manufacture

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U.D.C. 621.315.212

Development of new 2·6/9·5 mm coaxial cables is described. These are to be used, initially, for 60 MHz f.d.m. transmission systems but the possibility of their later use in the digital mode has been recognized. The types of 2·6/9·5 mm coaxial cable which have been installed in the network over the last 20 years are basically adequate for 60 MHz operation and for limited use with digital systems. A critical study has shown that their digital capability can be considerably enhanced by minor alterations to the manufacturing processes and close control of the mechanical aspects of production.

INTRODUCTION

The 2·6/9·5 mm coaxial cable* was first introduced into the British Post Office (B.P.O.) network in 1938. (The dimensions denote the outer diameter of the inner conductor and the inner diameter of the outer conductor, respectively.) The original coaxial structure has since been improved in successive steps as bandwidth requirements for system operation have widened, as new constructional materials have become available, and as techniques of manufacture have been progressively developed.

Electrical tests on 2·6/9·5 mm coaxial cables in current production for the B.P.O. showed that the requirements for a 60 MHz frequency-division multiplex (f.d.m.) transmission system could be met satisfactorily, but the performance of the cables above 60 MHz would limit their later exploitation for digital working. It was realized that the need for such exploitation would almost inevitably arise within the useful lifetime of any new cable installed for a 60 MHz system. For this reason, it was considered essential to investigate the possibility of improving the electrical performance of the 2·6/9·5 mm coaxial cable to enhance its potential for digital use and a transmission rate in the region of 800 Mbit/s has been suggested as a target. Such a figure might well be appropriate for a new cable dedicated to digital working at the outset but a lower rate could well be acceptable for the later conversion of an established 60 MHz f.d.m. route.

The 2·6/9·5 mm coaxial cables in current production (hitherto only required to operate up to 12 MHz) showed, at particular frequencies between 60 MHz and 500 MHz, the presence of reflexions of sufficient magnitude to hinder high-speed digital operation. The cause of these reflexions has been traced to very small but regularly-spaced dimensional irregularities in the coaxial structure which arose, primarily, during the process of stranding a number of individual coaxial pairs into a multi-pair cable. A critical review of the manufacturing techniques showed that relatively minor modifications to the machinery would suffice to achieve a substantial reduction in the amplitude of the reflexions and this, together with close control of material quality and dimensional tolerances, would allow for high-speed digital operation.

This article describes the cables which have been developed for the new 60 MHz f.d.m. transmission system and shows how the electrical performance has been improved to allow for their later exploitation in the digital mode.

FIG. 1—The 1935 design of 3·0/11·4 mm (0·450 in) coaxial cable

EVOLUTION OF THE 2·6/9·5 mm COAXIAL STRUCTURE

The 2·6/9·5 mm coaxial-cable structures in current use in the U.K. and elsewhere were developed progressively[1] from a design adopted for the first coaxial trunk cable in Great Britain which was installed between London and Birmingham during 1935 and 1936.[2,3] This was, in fact, a 3·0/11·4 mm coaxial structure (0·450 inch) having a solid copper inner conductor held centrally within an outer conductor of 12 interlocked copper tapes by a helical wrapping of esterified cotton cord, as shown in Fig. 1. In 1938, a new design was

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* Then known as the 0·375 inch or type 375 coaxial cable.

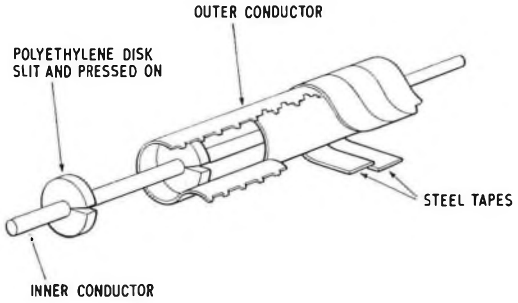


FIG. 2—The 1947 design of 2·6/9·5 mm coaxial pair (notched seam)

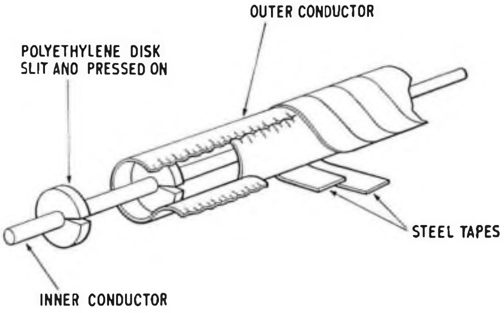


FIG. 3—The 1950 design of 2·6/9·5 mm coaxial pair (corrugated edge)

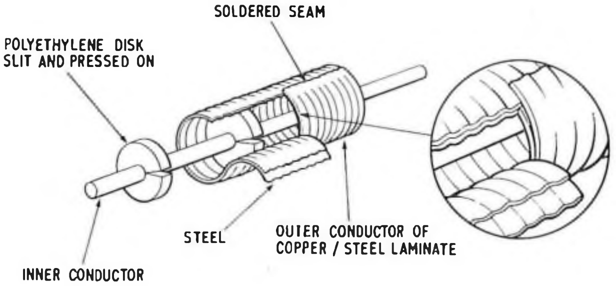


FIG. 4—The Cloax coaxial pair

introduced in which the inner diameter of the outer conductor was reduced to 9·5 mm (0·375 inch) and hard rubber disks, clipped on to the centre conductor at intervals, replaced the cotton cords.

In 1944, the use of interlocking tapes for the outer conductor was abandoned because they caused slight instability of its effective diameter. They were replaced by a flat copper strip formed into a tube as a continuous process during manufacture. The edges of the tape were notched with teeth using a flat punch so as to interlock as a longitudinal seam. This form of outer conductor was based on a Western Electric Company design for a 6·86 mm (0·270 inch) cable installed between Stevens Point and Minneapolis in 1940.[4] In 1947, polyethylene superseded hard rubber as the disk material to take advantage of its superior electrical qualities and, thus, reduce the dielectric-loss component of the attenuation. The 1947 design is shown in Fig. 2.

A restriction on the speed of manufacture is inherent in the use of a flat punch for cutting teeth on the edges and the use of a punch implies constant attention to the sharpness of its cutting edges. For these reasons some manufacturers have preferred to adopt the corrugated-edge design[5] which was introduced in 1950. In this design, shown in Fig. 3, the two edges of the outer conductor were butted together but corrugated in such a way as to avoid any tendency to overlap.

Recent Practice

During the last 20 years, production for the B.P.O. has included both the notched-seam and the corrugated-edge construction for the outer conductor. The notching technique has been improved by the replacement of the flat punch by a rotating cutter and the direct-moulding method of disk application has been introduced to a limited extent. Thus, both Fig. 2 and Fig. 3 are typical of recent U.K. production.

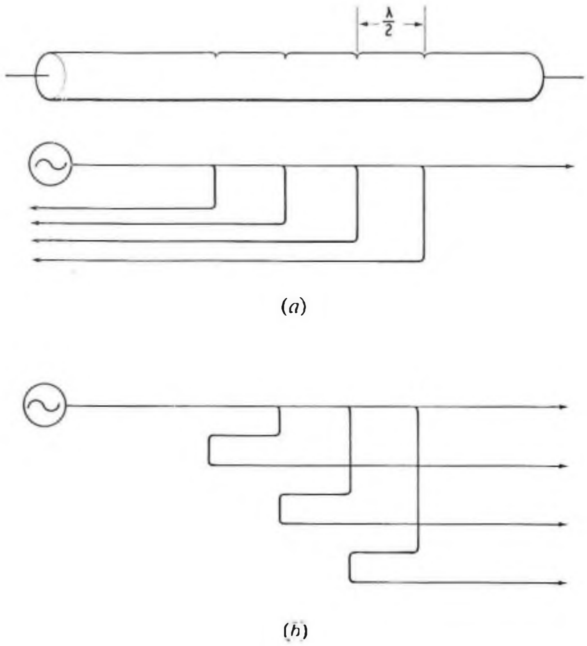
In recent years, the Cloax cable[6] illustrated in Fig. 4, has been developed in the U.S.A. The outer conductor is a laminate of copper and steel which is corrugated then formed into a tube. The copper edges butt together while the steel edges are overlapped and soldered. This construction uses less copper than the original design and corrugation of the outer conductor is claimed to provide a structure which is more resistant to crushing and more amenable to bending without permanent distortion than the plain tube. A similar design,[7,8] in which both copper and steel butt together and a separate lapping strip is soldered over the seam, has been introduced in Canada.

Development of the New Design

When the 2·6/9·5 mm coaxial cables in current production were first considered for a 60 MHz system, it was realized that the main impediment to their later exploitation in the digital mode was the occurrence of reflexions above 60 MHz. These reflexions, which were at harmonically-related frequencies, appeared to be based upon a fundamental somewhere between 150 and 250 MHz and it was recognized that their presence was attributable to the phenomenon of structural return loss[9] which is caused by regularly-spaced irregularities in the dimensions (and hence the impedance) of the coaxial structure.

A single imperfection, such as a distortion of the outer conductor of a coaxial pair, causes an impedance irregularity at a point and this causes part of the transmitted signal to be reflected back to the sending end. If there are a number of distortions spaced evenly along its length, as shown in Fig. 5 (*a*), reflexion occurs at each one and, at a particular frequency (where the spacing between distortions is equal to half the wavelength), all are in the same phase; their sum is, therefore, comparatively high in level relative to the transmitted signal and the pair tends to act as a band-stop filter. Thus, although such a coaxial pair may have an attenuation/frequency characteristic which is basically smooth, it exhibits an increase in attenuation at one frequency. This increase may be very small in amplitude for a single repeater section but, for a whole coaxial system, the cumulative effect could well be significant for f.d.m. working where one or more channels might be rendered ineffective. For digital operation, it is more important to consider the effect of multiple reflexions of the kind shown in Fig. 5(*b*), because these could cause unacceptable distortion of the received signals and give rise to intersymbol interference.

It was clear that the problem of developing a coaxial cable suitable for digital transmission was essentially a mechanical one which would involve a survey of the whole process of manufacture to identify the various parts which could give rise to structural return loss by building periodic dimensional irregularities into the coaxial structure. Examination of the input impedance/frequency characteristics of 2·6/9·5 mm coaxial cables in current production showed that the presence



(a) towards the sending end
(b) towards the distant end

FIG. 5—Reflexions from irregularities in a coaxial pair

of the deviations was directly related to the length of lay of the cable and, thus, their cause was immediately traceable to the stranding process. It was realized that other aspects of the manufacturing process, e.g. coaxial-pair fabrication, might have to be considered as well and that as each source of structural return loss was located and corrected, another, less noticeable, would come to the fore and assume importance.

The merits of the laminated and corrugated construction for the outer conductor of the American Cloax cable had been noted; the possibility of adopting a similar design for use in this country was considered, but rejected on economic grounds. For the comparatively small demand of the B.P.O. for 2·6/9·5 mm coaxial cable, the savings on copper would be very slight and would be more than offset by the cost of developing, constructing and installing new production machinery. Instead, it was considered preferable to use the existing plant, improve it where necessary, and exploit to the full the potential of the current British design of cable.

REVIEW OF CURRENT MANUFACTURING METHODS

Materials

The dimensional tolerance allowable for the inner conductor is too stringent to permit the use of a material as supplied commercially in the form of copper wire and, therefore, a sizing process is carried out in the cable factory. Fully-annealed high-conductivity copper wire, very slightly larger in diameter than that finally needed, is passed through a special die designed to yield a product which does not vary by more than one or two parts in a thousand from the required diameter. Stringent tolerances also apply to the copper strip used for the outer conductor.

Polyethylene for the disks is supplied in the form of strips with a close tolerance on their thickness. The disks punched from these strips are stored in air-tight cans pending use in the coaxial-pair fabrication machine. Where the disks are moulded directly on to the inner conductor, no such transfer of materials is necessary. For either method, the quality of the polyethylene is subject to very close control to ensure uniformity of the dielectric.

The helical steel tapes and lapping paper are of the normal high quality used in the manufacture of telecommunications cables but the precise dimensions are of little importance.

Coaxial-pair Fabrication

The following sequence of operations is involved in the fabrication of a coaxial pair:

(*a*) The polyethylene disks are applied to the inner conductor at intervals of 33 mm either by an applicator which clips the punched disks on to the conductor, or by a direct moulding process in which the disks are formed on the conductor itself.

(*b*) The flat copper strip for the outer conductor is corrugated (or notched) at the edges and then formed over the polyethylene disks.

(*c*) Two steel tapes are lapped over the outer conductor to provide electrical screening at low frequencies.

(*d*) Paper lappings are applied over the steel tapes.

The principle of the disk applicator is shown in Fig. 6. Each polyethylene disk is punched with a central hole slightly smaller than the diameter of the inner conductor. A magazine filled with punched disks feeds the applicator wheel which takes up one disk at a time and passes it down to the centre conductor which passes tangentially beneath it. As each disk passes round the wheel, it is slit radially by a fixed knife and opened out by a wedge-shaped part of the knife blade so as to clip over the centre conductor just before it leaves the applicator wheel. This design of disk applicator[10] was introduced for the 1947 design (the first to use polyethylene disks) and was a direct development of the earlier one[11] used for the hard-rubber disks of the 1938 design.

For the direct-moulding process, a number of split moulds mounted on caterpillar tracks are arranged to embrace the inner conductor. An extrusion device feeds each mould in turn as the inner conductor passes continuously through the machine. Fig. 7 shows a machine designed for this process. The extruder is to the right of the photograph and the inner conductor, with moulded disks attached, can be seen coming towards the cooler in the foreground. The polyethylene flash (later stripped off) is visible alongside.

After application of the polyethylene disks to the inner conductor, the corrugated (or notched) copper tape is formed round them, and the steel tapes and paper covering are added—all as a continuous process in a single enclosed machine. In general, the copper tape is corrugated (or notched) while in a horizontal plane and, thus, it is convenient to form the longitudinal seam at the top of the resulting tube. This is done in some designs of machine but, in others, the tape is rotated before forming so that the seam appears at the side, thus, coinciding with the neutral axis of bending round the haul-off capstan and storage drum. This arrangement is claimed to reduce the likelihood of tube distortion but, in view of the subsequent processes, this claim is of doubtful significance and, in practice, either arrangement of the longitudinal seam is acceptable.

Stranding

The elements of a laying-up machine for stranding a number of coaxial pairs into a multi-pair cable are shown in Fig. 8. The machine comprises a main rotating carriage carrying a number of drums, each on its own sub-carriage and filled with single coaxial pair. All the pairs are brought together in a closing die and all are pulled through the machine together by a haul-off capstan and passed to the storage drum. A multi-pair cable formed in this way consists of a helical arrangement of coaxial pairs in which the length of lay depends upon the relationship between the speed of the haul-

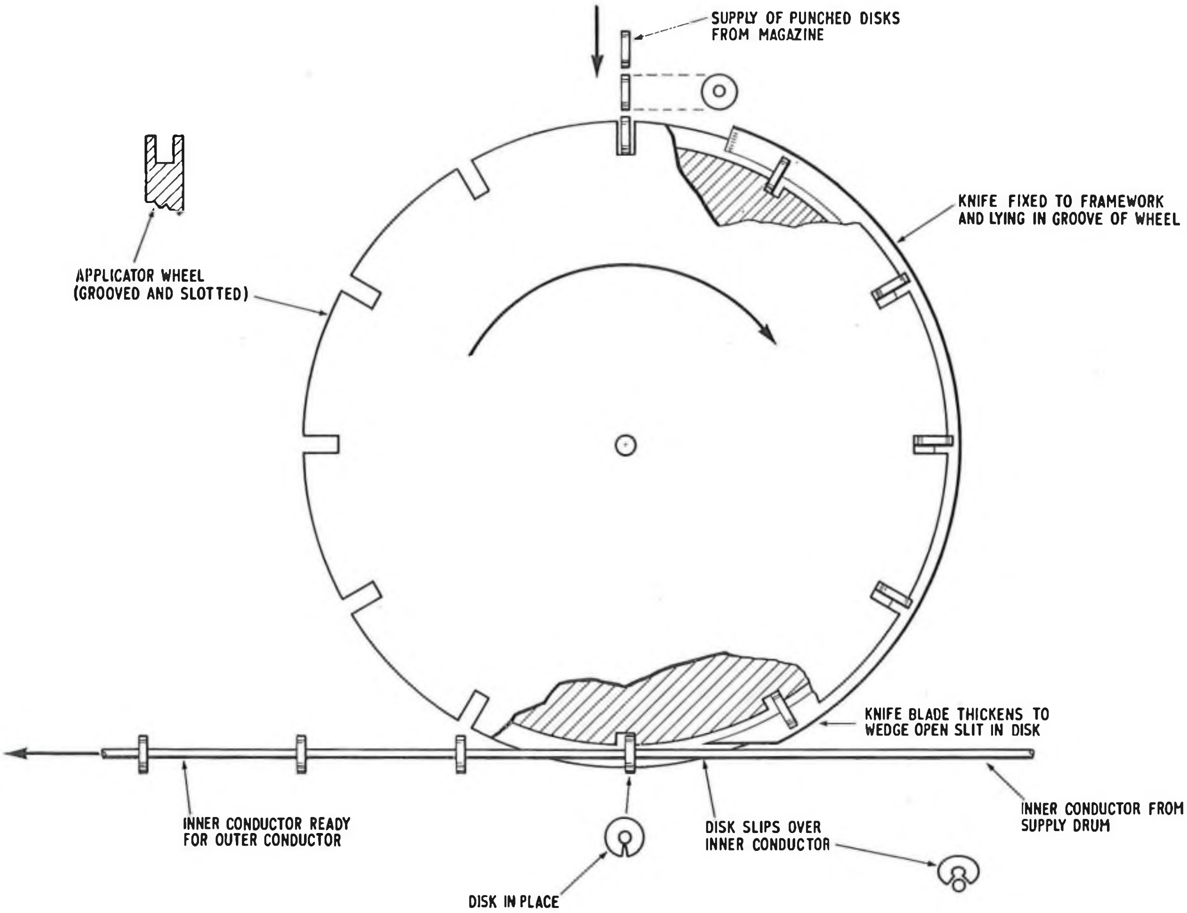


FIG. 6—Principle of the disk applicator

off capstan and the rate of rotation of the main carriage. The drums are geared so as to rotate counter to the main carriage and, thus, they remain in the same attitude as the stranding process proceeds.

There are several configurations of stranding machine in common use but they fall basically into two groups—those in which the axes of the sub-carriage are parallel to the main axis of the machine (type A) and those in which they are inclined (type B). These, together with variants, are shown in Fig. 9.

Rotational Bending

As each coaxial pair passes through the closing die, it is constrained to bend to take up its alignment in the laid-up cable core but, as each pair is rotating round the main axis of the machine (and thus round the axis of the closing die), the direction of the bend is continuously changing relative to the longitudinal seam in the outer conductor. Now a tube having a longitudinal seam of any kind is not uniformly resistant to bending in all directions. Furthermore, when bent and straightened again, the extent to which it regains its original shape depends on the direction of the bend relative to the longitudinal seam. It follows, therefore, that the curvature of the closing die must be large enough to allow the tubes to pass without residual distortion if periodic dimensional irregularities (and consequent regularly-spaced changes of impedance) are to be avoided. Experiments with single coaxial pairs showed conclusively that the curvature of the closing die had a marked effect on structural return loss.

Rotational bending is not confined entirely to the closing die as it may occur at any point in which the tubes change direction while passing through a rotating orifice. One such point is the hollow journal by which the front end of each

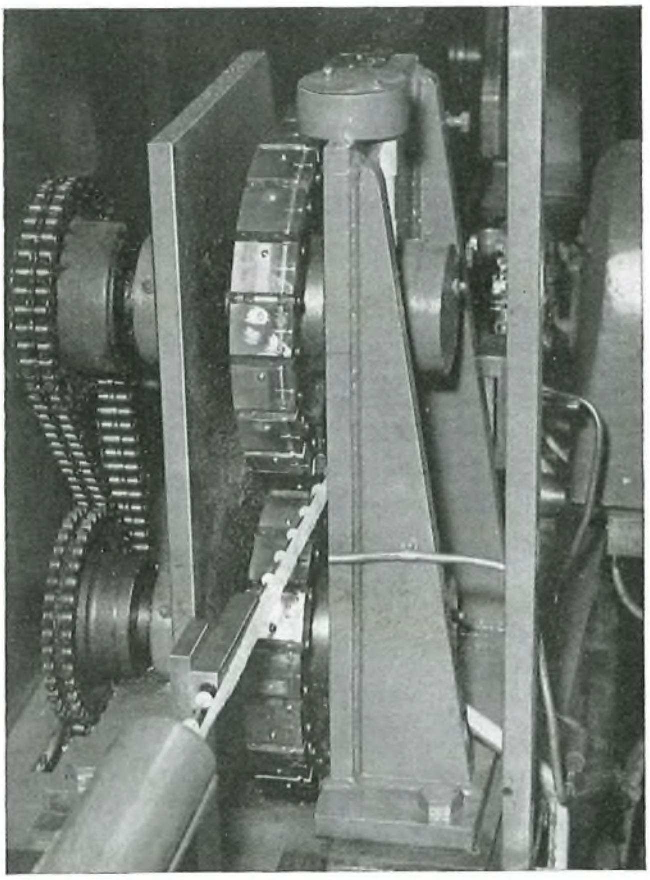


FIG. 7—Moulding machine for forming disks on inner conductor

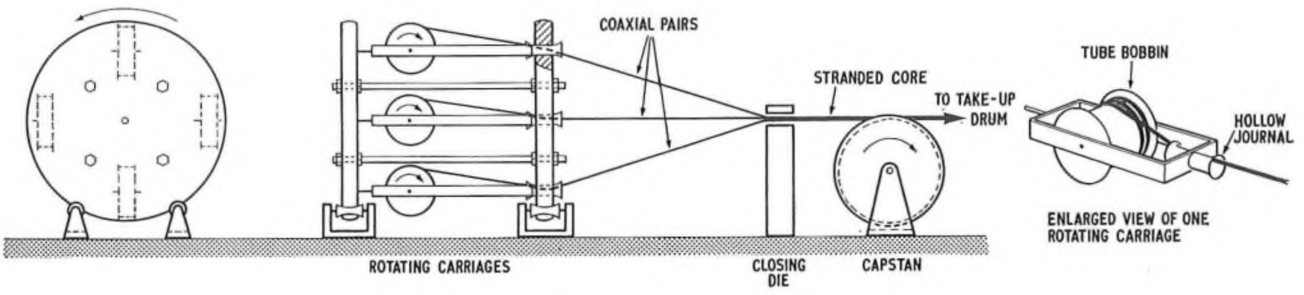


FIG. 8—Elements of stranding machine

sub-carriage is suspended. The effect is more marked in A type machines than in type B.

Cyclic Tension

Where the axes of the sub-carriage are inclined relative to the main axis of the stranding machine (as in type B), the rate of rotation of the individual drums must, perforce, vary cyclically as the main carriage rotates. This is apparent from Fig. 10 which shows that, for a rotation of 180° of the main carriage (lower transit to upper transit), any one drum must move forward through an angle θ in order to accommodate the new angular configuration within the main carriage. The stranding process is a continuous one and all pairs pass through the machine at a constant speed. Thus, the rotational speed of each drum varies cyclically during the stranding operation and the tension in each coaxial pair varies in consequence.

Such cyclic variation of tension might well cause periodic distortion of the coaxial structure but this has not been proved. The magnitude of the forces involved is small in relation to the strength of the coaxial pair and this suggests that their effect, if any, would be insignificant. Stranding is, in general, a fairly slow process; the speed of rotation of the main carriage is low and the cyclic variation in tension small. However, it is desirable that the hollow journal of each sub-carriage should be a fairly close fit over the coaxial pair which passes through it, thus avoiding any tendency for the pair to move about within it as the tension varies. Such movement could possibly cause slight but regularly-spaced indentations in the coaxial structure.

Capstan Pressure

During the stranding process, tension is transmitted to the individual pairs by the drive to the haul-off capstan around whose barrel the multi-pair cable core is passed several times. It is quite possible, therefore, that the consequent normal pressure between the core and the capstan could cause slight flattening of the outer conductor thus producing irregularities of impedance spaced apart by the length of the helical lay. For this reason, each multi-pair layer of the new design is cushioned with some kind of resilient material.

Residual Helix

In the completed multi-pair cable core, the helical-lay construction implies that each coaxial pair finally takes up a position in which it is slightly bent and the direction of the bend changes continuously along the length of the core. The radius of curvature can be calculated for any core diameter and lay length, and this figure can be used to indicate an appropriate curvature for the closing die or the exit from the hollow journals of the sub-carriages.

Passage of the multi-pair core around the haul-off capstan causes each coaxial pair to be bent and straightened again, and this process can, in itself, cause further distortion. In practice, the bending and straightening process occurs several times during the complete manufacturing operation before the cable is finally delivered to site, drawn off the drum and installed in a duct for use.

Layer Interaction

For a layered cable, such as the 18-pair 2·6/9·5 mm design, in which each layer has a different length of lay, slight indentation of the outer conductors occurs where pairs of one layer lie across pairs of the other. This effect, although slight, has been observed. It is similar to the problem of capstan pressure and it is minimized in the new design in the same way, i.e. by cushioning the layers.

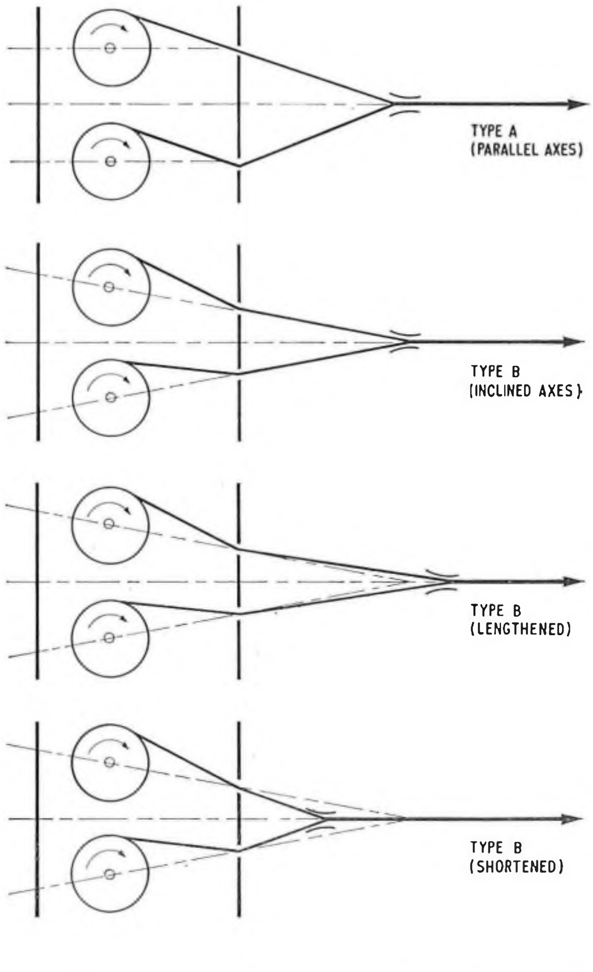


FIG. 9—Various configurations of cable-stranding machine

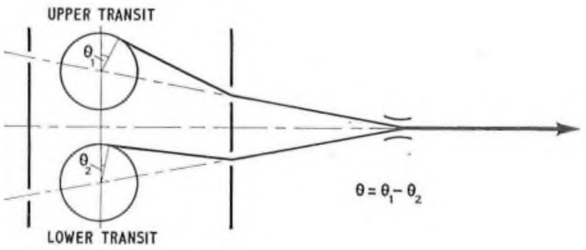


Fig. 10—Sketch to show basic source of cyclic tension

Choice of Coaxial-Pair Construction

It became apparent from the review of manufacturing techniques that minor improvements to the stranding machinery would reduce the likelihood of adding periodic irregularities to the coaxial structure during the stranding process. Nevertheless, it was realized that, so long as the helical arrangement of pairs was retained in a multi-pair cable, the ability of each coaxial pair to be bent in any direction and then to be straightened again without distortion would remain as a very important mechanical property of the coaxial structure. The main influencing feature was, clearly, the longitudinal seam in the outer conductor and, since the notched-seam version (Fig. 2) and the corrugated-edge version (Fig. 3) were fundamentally different in mechanical construction, there seemed no reason to suppose that they would react in the same way to bending and straightening. Accordingly, controlled tests were made on coaxial pairs with each type of longitudinal seam and the results showed the corrugated-edge construction to be better able to withstand such treatment than the notched-seam construction. It was evident that the notched seam tended to open slightly when bent and then failed to recover its original form completely when straightened again. In contrast, the butting edges of the corrugated edge merely slid relative to each other to accommodate the bending and straightening without noticeable distortion. For this reason, the corrugated-edge construction has been adopted for the new cable.

DESIGN OF THE NEW CABLE

Fig. 11 shows 18-pair 2·6/9·5 mm coaxial cables developed for initial use with 60 MHz f.d.m. system and later exploitation for digital working. The 18 coaxial pairs are arranged as an inner layer of six pairs and an outer layer of 12 pairs, both laid helically over a central paper core. To preserve the inherent flexibility of the cable structure, both are laid in the same direction although a different length of lay is used for each. Twelve 0·63 mm copper quads, which together occupy approximately the same space as one coaxial pair, are included in the outer layer. A cushion of resilient material covers each of the two layers and is held in place by a belting of paper. The whole is sheathed in lead, coated with bitumen, and protected by an extrusion of polyethylene overall. Each coaxial pair is of the corrugated-edge design and the polyethylene disks are attached to the inner conductor by one of the two methods already described.

A 6-pair version of the cable has been developed for simplifying the task of terminating, and for use in tunnels where access difficulties would restrict the use of the 18-pair size to short lengths. An 8-pair design is being developed for routes on which the 18-pair size would not be justified.

A solid-core (i.e. with solid-polyethylene dielectric) single-coaxial-pair interruption cable of rugged construction is under development and one version of it is shown in Fig. 12. Its electrical characteristics are substantially identical with those of the 2·6/9·5 mm coaxial cable up to 60 MHz.

Identification

Hitherto, it has been customary to identify every pair of a coaxial cable by printing numbers on the paper covering of each tube, but a different arrangement has been adopted for the new cables.

It is intended that faults should be repaired *in situ* but it is undesirable that power should be removed from the whole cable in the event of a fault on a single coaxial pair. A safe method of working has now been developed[12] by which it will be possible to effect a repair on a single damaged coaxial pair without interrupting service on the remainder. An essential feature of this method is positive identification of pairs by electrical means, and, in these circumstances, numbering of tubes is unnecessary; in fact, the presence of a line of figures on each might well cause confusion. However, it is essential to retain some means of identification for use during factory testing and the marker/reference system has been adopted. Thus, in each layer, one tube is printed with a red line as the marker and another with a blue line as the reference. For the inner layer, the marker and reference tubes are adjacent in the usual way but, for the outer layer, they flank the core of 0·63 mm quads. This arrangement allows the core of quads to be distinguished from the coaxial pairs.

Protection

The polyethylene oversheath is added, primarily, to give protection against corrosion while the underlying coating of bitumen provides a seal between the lead sheath and the polyethylene covering. Additionally, the polyethylene oversheath plays an important part in the cabling operation because it has a much lower coefficient of friction in a duct than has plain lead. The outer polyethylene protection is coloured so that the new cables can readily be distinguished from those already in the network.

Installation

The cable will be installed in ducts. To aid installation, all cables will be fitted with a specially-designed pulling eye and pressurized with dry air before despatch from the factory. Laboratory tests followed by field trials have shown that 500 m lengths can be drawn in without difficulty or hazard to the cable provided a suitable lubricant (e.g. liquid paraffin) is used.[13] It is possible, therefore, to have only two joints in a repeater section of 1,500 m. Study of the trial results showed that lengths of 750 m could, in fact, be drawn in but this aspect has not been pursued because the consequent saving of joints would not compensate for the extra cost of the very large and heavy drums and drum-handling equipment which would be needed.

Jointing

By close control of the manufacturing process, it is possible to reduce impedance variations between individual coaxial pairs to a minimum and, thus, the need for selection on the basis of impedance matching at joints is obviated. This, together with the absence of a numbering scheme, allows each coaxial pair in one length to be jointed directly to the opposite one in the next length* thus simplifying the jointing layout and allowing the diameter of the jointing sleeve to be smaller than it otherwise would be.

As the method of jointing[14] does not depend upon a colour code or numbering system, there is no need for any re-drumming of cables in the factory to allow for a particular direction of pull during the drawing-in process to ensure proper correspondence between the two ends.

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* This is termed a *straight-across* joint in contrast to a *straight* joint in which the colour coding or numbering is preserved. It is not to be confused with a *random* joint in which pairs are jointed without reference to identification or position.

(a) (b)

FIG. 11—18-pair 2·6/9·5 mm coaxial cables of the new design

Electrical Performance

The specified electrical characteristics recognize the following basic requirements of the 2·6/9·5 mm coaxial cable:

(*a*) a satisfactory performance for the new 60 MHz f.d.m. transmission system,

(*b*) a performance in the range 60–500 MHz suitable for later exploitation in the digital mode at an acceptable rate, and

(*c*) a performance up to 12 MHz equivalent to that of existing cables so that the new design can be used for maintenance in the present network.

Attenuation

Each coaxial pair is designed to conform to the following expression for attenuation at 10°C:

$$\alpha = 0{\cdot}013 + 2{\cdot}305\sqrt{f} + 0{\cdot}003f \quad \ldots\ldots \ (1)$$

where α is the attenuation in dB/1,000 m (coaxial-pair length)* and f is the frequency in MHz. In expression (1), the root frequency term is dominant and is a function of the copper loss which is mainly attributable to skin effect. The frequency term is a function of the dielectric loss contributed by the polyethylene disks.

It is not possible in a production length of multi-pair cable for the coaxial pairs to conform exactly to this expression and Fig. 13 shows the practical limits allowed at 10°C for divergences provided that the spread of attenuation is restricted. This spread is controlled so that, within any layer, the difference between any two coaxial pairs must not be more than 0·5 per cent of the mean attenuation of the cable at all frequencies in the range 4–64 MHz and 1 per cent at all frequencies in the range 64–500 MHz.

The temperature coefficient of attenuation is expected to be 0·0019/°C of the 10°C value.

End Impedance

Each coaxial pair is designed to conform to the following expression for impedance:

$$Z = 74{\cdot}4\left[1 + \frac{0{\cdot}0123\,(1 - j)}{\sqrt{f}}\right] \quad \ldots\ldots \ (2)$$

where Z is the impedance in ohms and f is the frequency in MHz. This expression implies a non-reactive value of 74·4 ohms at infinite frequency. In practice, a tolerance of ±0·4 ohms is allowed.

Uniformity of Impedance

Peaks in the return loss/frequency characteristic, due to the small but regularly-spaced impedance irregularities arising in manufacture, must not exceed 35 dB relative to the smooth mean impedance/frequency characteristic up to 60 MHz. Between 60 MHz and 500 MHz, 20 dB is allowed but there is an additional restriction on the mean power returned in any 10 MHz band.

High-Voltage Test

Every coaxial pair is required to withstand a potential between the inner and outer conductor of 4 kV d.c. applied gradually and maintained for one minute. Furthermore, to allow for operation of the power-feeding system with the outer conductors of all the coaxial pairs insulated from earth, each is required to withstand a potential of 2·8 kV d.c. relative to the remainder, the 0·63 mm quads, and the lead sheath. As before, the testing voltage is to be applied gradually and maintained for one minute.

TRIAL CABLES

Marlborough

In 1972, a 6·75 km route length of 18-pair 2·6/9·5 mm coaxial cable was installed at Marlborough, Wiltshire, to provide facilities for a trial of the repeaters and terminal equipment designed for the new 60 MHz f.d.m. transmission system.[15] The coaxial pairs of this cable were of the notched-seam type. The cable construction differed from the later design shown in Fig. 11 in that each of the 0·63 mm quads was placed in one of the interstices between the outer layer of coaxial pairs and the sheath. This earlier design has already been noted.[16]

Manufacture, installation, jointing and testing of this cable allowed the value of various newly-developed techniques to be assessed in the field. As a result, a new method of duct-lubrication was shown to be practicable, a new jointing method was proved for field use, and the need for improved mobile testing facilities was recognized.[17]

Marlow

In 1973, a 6 km route length of the new 18-pair 2·6/9·5 mm coaxial cable (Fig. 11) was installed at Marlow, Buckinghamshire, to asses the value of the new cable design when installed in conditions typical of those expected for projected 2·6/9·5 mm routes. It gave an opportunity to commence pilot

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* The take-up factor $\left(\frac{\text{coaxial-pair length}}{\text{sheath length}}\right)$ is not to exceed 1·012.

FIG. 12—Interruption cable

production and to consolidate the new installation[13] and testing[18] techniques developed as a result of experience gained at Marlborough. It will be used as a test bed for experiments on pressurization methods and fault location techniques, and may, possibly, be incorporated into the new trunk network, as could the Marlborough cable.

CONCLUSIONS

In recent years, two versions of the original 2·6/9·5 mm coaxial-pair structure have been manufactured in the U.K. Both are suitable for 60 MHz f.d.m. transmission systems and either could be used in the digital mode. A critical review of the coaxial-pair design and the whole process of manufacturing a multi-pair cable has shown that the extent of this digital use could be enhanced considerably by slight modification to the cable design and minor improvements in the manufacturing processes. These modifications and improvements have been made and one of the two versions of the 2·6/9·5 mm coaxial structure currently available has been chosen for general production for the new cables intended for 60 MHz f.d.m. working. As a result, these cables will be suitable for later conversion to digital operation at an acceptable transmission rate should this ever be required. The electrical performance for f.d.m. systems of less than 60 MHz bandwidth remains unaltered and, thus, the new cable can be used for the maintenance replacement of any 2·6/9·5 mm coaxial cable already in service.

Acknowledgement

The whole of the cable development described in this article has involved close collaboration with the British cable makers, and their assistance is gratefully acknowledged.

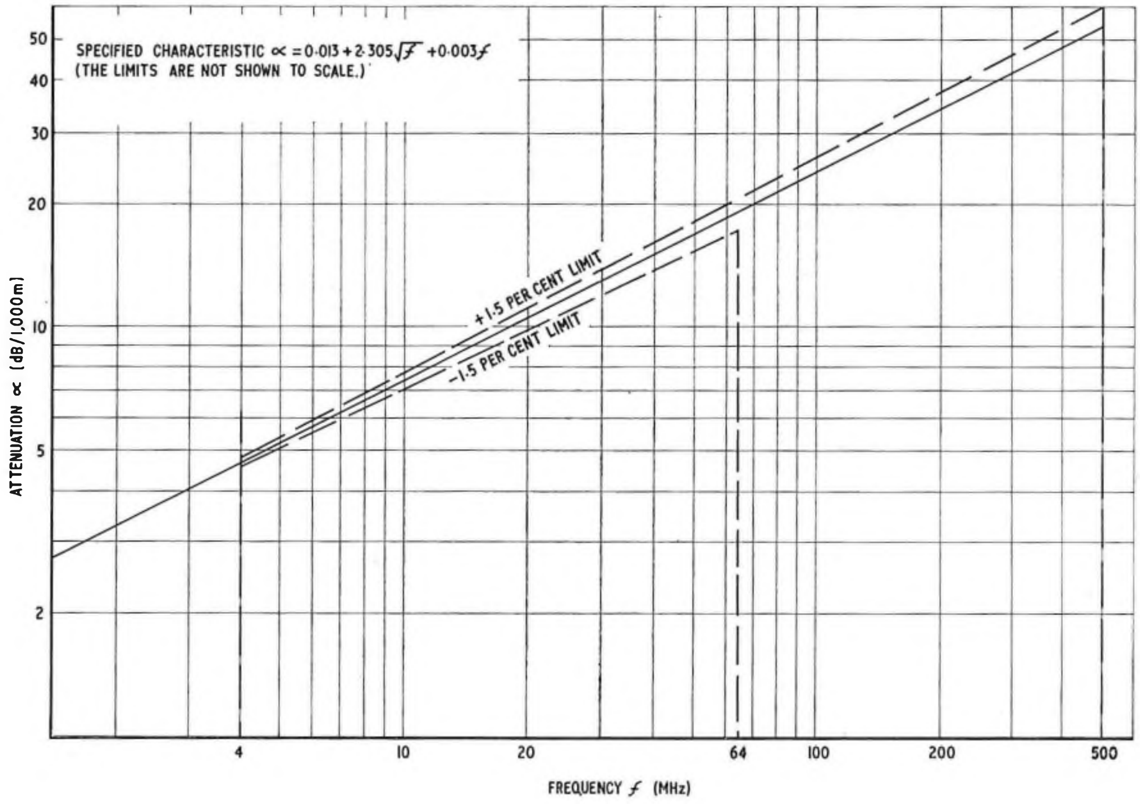

FIG. 13—Specified attenuation/frequency characteristic

Their advice on the manufacturing aspects of the cable has been particularly valuable. The authors are indebted to Telephone Cables Limited and Pirelli General Cable Works Lomited for the photographs reproduced as Fig. 11. Telephone Cables Limited also contributed Fig. 7.

Thanks are due to the authors' colleagues in the Research Department of the B.P.O. for their assistance in making many of the electrical tests involved in the assessment of the various designs of cable.

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Book Reviews

"The Atlantic Telegraph." W. H. Russell (New Impression). David & Charles Reprints. vi + 117 pp. 26 ill. £3·50.

"If the labours of Men of science could ever create any material revolution, direct or indirect, in our condition, and in the impressions which we habitually receive, the Poet . . . will be ready to follow in the steps of the Men of science, not only in those general indirect effects, but he will be at his side, carrying sensations into the midst of the objects of science themselves." Generally speaking, alas, the men of science and their achievements have failed to elicit the poetic response that Wordsworth so confidently predicted. The poet obstinately continues to be preoccupied with emotional matters of a more personal kind, leaving science and technology to the exclusive attention of the professional journalist.

Dr. W. H. Russell (later Sir William Howard Russell, LL.D.) was probably one of the earliest to practise in this role, being appointed *Times* correspondent on board the *Great Eastern* in 1865 when the Atlantic Telegraph Company made a further attempt to lay a submarine cable between Ireland and Newfoundland. Russell's despatches from the ship appeared in *The Times* under the title "Diary of the Cable," and were described as "one of the most complete chronicles of its kind which has ever appeared in a public journal." In *History of Wonderful Inventions* by John Timbs, 1868, Robert Dudley, artist and contributor to the *Illustrated London News* also accompanied the expedition. Russell's Diary was subsequently published as a "handsome folio with truly artistic illustrations," the latter being lithographs of Dudley's drawings.

The present volume is apparently a facsimile reprint of Russell's book, and hence, bibliographically speaking, cannot be regarded as another edition as its designation implies. A publishers' note about the author and his original publications would have been helpful to readers in the 1970's. The Diary of the 1865 venture is preceded by the familiar story, in an abbreviated form, of the earlier attempts to link the Old and New Worlds by telegraph, and it ends in 1866 before this aim had been successfully realized.

The value of works of this kind lies in their importance to the historian as records by eye-witnesses of great events: their reproduction makes them more easily available to students in a wide range of disciplines at a reasonable cost. The general reader is however likely to find the period flavour of the prose, not to mention the type-face, unattractive.

D. A. J.

"Modern Data Communication." William P. Davenport. Pitman Publishing. 200 pp. 114 ill. £2·75.

The subtitle of this book is "Concepts, Language and Media" and the preface states that it is written "to explain the theories and concepts of data transmission to the operators and managers of information systems and students of information handling. An attempt has been made to reduce intricate theories to clear and understandable terms without losing the essence of their meanings." The attempt has failed and, frankly, the reviewer is unable to recommend this book as a reliable source of information.

The first three chapters define data source, data sink and transmission medium and briefly explain binary notation and bits and bauds. Storage codes for paper tape, punched cards and magnetic tape are given fairly detailed treatment and start/stop transmission is briefly mentioned (7.42 elements per character). There is little scope for going wrong in such material but nevertheless there are some errors.

The next three chapters concern transmission and abound in disputable statements. For instance, on the first page alternating currents are explained and "either half of the cycle is called a baud". Three pages later "There are three types of distortion that a channel may impart to a signal: delay distortion, attenuation distortion and jitter". Jitter is revealed to be telegraph distortion measured as a percentage of two signal elements duration instead of the normal one. Later on, in the modulation chapter, concerning frequency-modulated (f.m.) modems we find that "an f.m. signal is said to be fully modulated when it has reached ± 75 kHz from the carrier frequency". Phase-modulated modems are described in terms of absolute rather than differential phase and the diagrams are not consistent with one another. The above examples are only a small selection of the peculiar snippets of information which can be found in these chapters.

The final chapters mention the transmission channels and services offered by the U.S. common carriers, give a muddling description of switching systems and methods, and an extraordinarily terse mention of data sets (modems).

The author concentrates almost entirely on American data transmission and American terms are used throughout. The language is authoritative and plausible and between the errors some clear and simple descriptions occur. Therein lies the danger for the non-expert. The treatment is far too shallow to contribute anything of significance to the knowledge of the expert.

R. H. T.

The 60 MHz F.D.M. Transmission System: Housings for Dependent Repeaters

N. E. FLETCHER†

U.D.C. 621.395.4.029.62:621.315.212:621.395.724

New repeater housings have been designed to accommodate the repeaters required for the 60 MHz f.d.m. transmission system. Two designs are described, one of which differs radically from established B.P.O. practice. The considerations which led to their adoption are discussed.

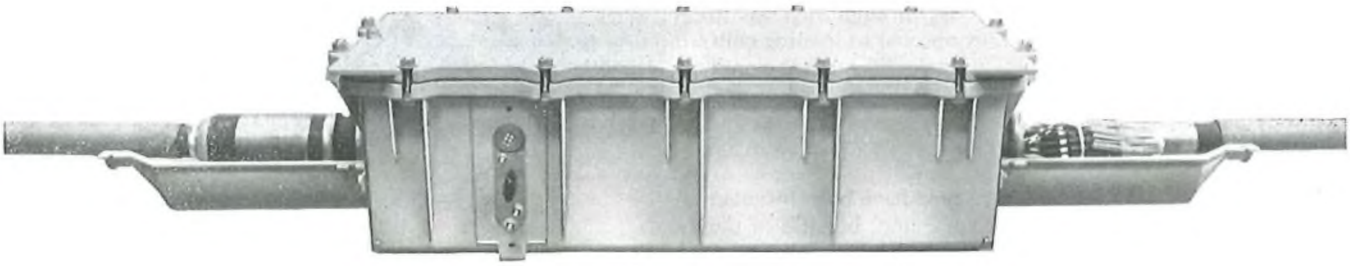

FIG. 1—The rectangular repeater case

BACKGROUND

For the new 60 MHz f.d.m. transmission system, use of 8-pair and 18-pair 2·6/9·5 mm coaxial cable is envisaged and dependent repeaters will be required at 1·5 km intervals between power-feeding stations. The basic requirements for the repeater housing, therefore, were that it should be capable of containing 18 line amplifiers and terminating the cables.

Initially, it was thought that 60 MHz working would not permit the use of flexible connexions to the amplifiers and an attempt was made to design a repeater housing in which the coaxial pairs terminated directly on the amplifiers. This proved extremely difficult since the housing had to be suitable for installation in a manhole or for burying directly in the ground. It led naturally to the concept of making the repeater housing large enough for a man to work inside it, thus rendering the manhole superfluous. This type of housing came to be known as a silo because the prototype was, in fact, a modified grain silo. The title has persisted, despite attempts to change it, and is still used for current designs.

DEVELOPMENT

As the new system evolved, it became obvious that the amplifier would be considerably smaller than at first thought and that suitable flexible connexions would be permissible between the coaxial pairs and the amplifiers. As a result of this, a rectangular repeater case was evolved containing two rows of nine amplifiers with cable terminations between them. An alternative design was produced, consisting of a circular base-unit fitted with two entry glands for the cables and a central column supporting vertically-mounted amplifiers. The amplifiers were enclosed in a circular "top hat"-shaped cover bolted on to the circular base unit. A rectangular case was also developed in which the amplifiers were arranged in three rows of six. This gave a more compact case than the previous design but required an extension cover at each end to cater for the cable terminations. This case also had the advantage that it was cast in an aluminium alloy and was, therefore, much lighter and easier to handle than the earlier design. During this period, work on the silo continued. The smaller amplifier and flexible connexions reduced the space requirement considerably, but it was decided that, as a man was required to work inside the structure, its original dimensions should not be reduced.

THE 18-COAXIAL-PAIR REPEATER CASE

Fig. 1 shows the repeater case finally adopted: it is 1,350 mm long, 576 mm wide and 500 mm deep; it is cast in a silicon-aluminium alloy and is coated externally with nylon to reduce the risk of corrosion. It incorporates a number of interesting features differing from current designs. The lid, which is retained by 14 stainless-steel bolts, seals on to a double rubber gasket. By pressurizing the annulus between the two seals, it is possible to check the lid seal for leaks before the case is pressurized. The case can be pressurized from the cable by means of an air-switch mounted

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on the side of the case. The switch permits the cables on either side to be connected to the case or isolated from it. Schrader valves are provided adjacent to the switch so that pressure checks can be made on the case and the cables without opening the case. In normal circumstances, the case and the cables are coupled together and an air-tight cover is fitted over the switch and Schrader valves. This cover has an internal projection which ensures that the switch is left in the correct position when the cover is in place. Inside the case, a mounting rack is provided to carry the 18 amplifiers. These are connected by flexible coaxial cables to the cable-termination units at either end of the case. These units provide the cable air-seal and sealed leads-through for the coaxial pairs and the 0·63 mm quads provided in the cable for supervisory purposes. The units have gunmetal tubes extending through the end walls of the case and through these pass extensions of the flexible cables, as shown in Fig. 2. The joint to the main cable is made outside the case, the flexible cable being jointed to the coaxial pairs using a specially-designed joint.[1] A lead sleeve covers the joints and is plumbed to the cable sheath and to the gunmetal tube. A split coupling mounted on either end of the case provides mechanical protection for each joint and also permits the use of a filling compound to protect the lead sheath and jointing sleeve against corrosion.

The 0·63 mm audio quads also pass through air seals in the cable-terminating unit and are connected to loading coils and a U-link panel which enables any selected speaker circuit to be extended to a socket adjacent to the air switch and Schrader valves. A pressure contactor is mounted on the U-link panel and connected to an audio pair to monitor the case pressure.

Three repeater cases of the above type have been installed on the field-trial route at Marlborough[2] and, because of the possible corrosion risk associated with aluminium, have been provided with two magnesium anodes as additional protection.

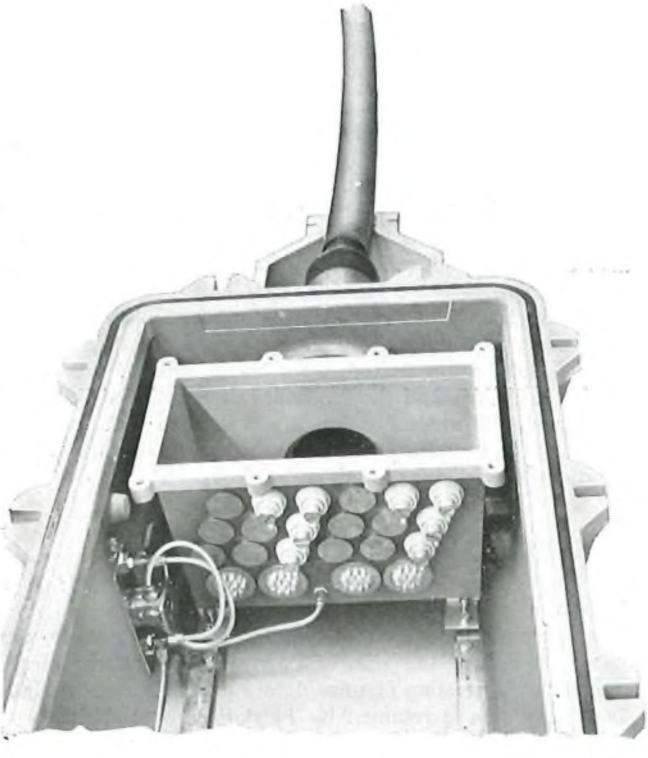

FIG. 2—Lead-through arrangements in the cable-terminating unit

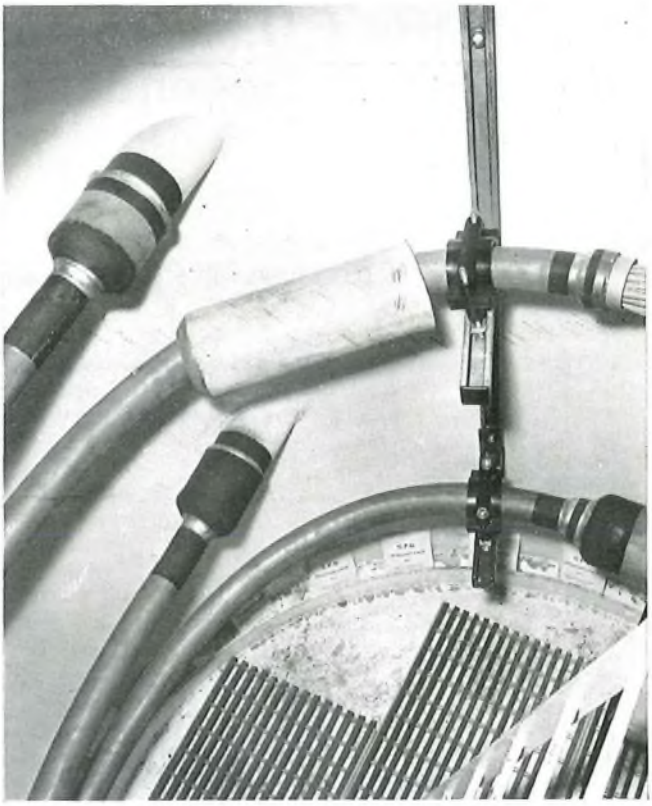

FIG. 3—Cable arrangement in the silo

THE SILO BURIED REPEATER STATION

The internal diameter of the silo is 1,800 mm and the height 2,100 mm. The cables enter through steel ducts welded tangentially into the wall. This allows the cables to be positioned close to the inside wall as shown in Fig. 3. The layout of the amplifiers and cable-terminating units is similar to that of the rectangular case so that the parts are interchangeable. The cables are connected to the cable-terminating units by a lead sleeve enclosing the coaxial-to-flexible joint. A standard air-pressure panel is provided above the amplifier rack and is connected to the air-boxes so that cable pressure can be monitored and cables isolated as required by means of a three-way valve mounted on the panel.

Entry to the station is through a short steel shaft in the roof and a pipe is provided to carry services to ground level. These include a pressure-test pipe for monitoring the cable pressure, a power cable and two small-diameter pipes for carrying out gas tests before the silo is opened. The power cable serves three bulkhead lights and a power socket fitted inside the silo. It is not intended to provide mains electricity however. If it is convenient to bring a 110-volt portable generator to the site, it can be connected to the power input socket beside the entry shaft.

The first silos designed were provided with a manhole cover fitted with 24 studs and nuts, and sealed with a flat rubber gasket. This design required considerable time for opening and reclosing, and alternative methods of sealing the entrance were investigated. Two designs are currently being tested. The first is a hinged lid closed by four bolts and a double gasket, and the second is a hinged lid with a self-sealing device contained within it. Release of the lid in the latter design is effected by the use of a double handle and the seal is broken as the lid is raised.

The silo is protected externally with zinc spray and an

FIG. 4—The silo buried repeater station

epoxy paint and then wrapped with a tape impregnated with petroleum jelly as a corrosion inhibitor. Fig. 4 shows a silo awaiting installation. When installed, four magnesium anodes are provided to further reduce the corrosion hazard. Repeater housings of this type may find particular use in wet situations where they offer a considerable advantage over the normal manhole installations.

At an early stage in the design of the silo repeater station, it was realized that the concept was a radical departure from current British Post Office practices, and the ability of the silo to provide the right conditions for the successful operation of equipment would have to be proved. It was, therefore, decided that a silo would be installed at a test site and instrumented to determine the changes in environment resulting from normal operating conditions. The installation of this unit has now been completed and tests are under way.

Facilities have been provided to measure and record the following:

(*a*) temperature inside the silo,
(*b*) temperature outside the silo at ground level,
(*c*) relative humidity of the air within the silo,
(*d*) relative humidity of the external atmosphere,
(*e*) oxygen content of the air within the silo, and
(*f*) carbon monoxide and carbon dioxide content of the air within the silo.

A program of tests has been agreed to determine the effects of men working, and equipment operating, on the atmosphere inside the unit. The results will indicate whether the silo concept can be used in the network generally.

CONCLUSIONS

This article has described development work executed primarily for the 60 MHz f.d.m. transmission system. However, a number of new design features have been evolved which will, no doubt, find application on other standard line systems.

ACKNOWLEDGEMENTS

The author wishes to thank his colleagues in the British Post Office and industry, whose efforts have led to these developments.

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The 60 MHz F.D.M. Transmission System: Cable Jointing

D. W. STENSON, B.SC.(ENG.), and W. G. F. SLAUGHTER†

U.D.C. 621.315.212.4: 621.315.687.1

A new type of brazed joint has been developed which meets the exacting mechanical and electrical requirements of the 18-pair coaxial cable to be used for the 60 MHz f.d.m. transmission system. The philosophy behind the new joint design is given together with a description of the jointing sequence and the situations in which the joint is used.

INTRODUCTION

The history of coaxial-pair joint design parallels the development of the cable in reflecting the progressive increase in bandwidth exploited. An equally important aspect is the mechanical performance of the joint. The earlier joint designs adequately met the electrical standards required by the then current systems but long-term stress conditions, mainly due to cable creepage, imposed forces on the joint that could lead to mechanical failure. These joints used soft-soldered inner and outer-conductor ferrules, and in every case failure was traced to solder fractures. These mechanical problems were solved by the introduction in 1960 of the brazed form of joint. This was designed originally for the 1·2/4·4 mm coaxial-pair cable and was subsequently extended to the 2·6/9·5 mm coaxial-pair cable. With the proposed design of a 60 MHz f.d.m. system, and the possibility of future digital exploitation, the design of coaxial-pair joint was examined critically and found to give a satisfactory electrical performance. However, a major problem area was the design of a satisfactory joint for the proposed new two-layer 18-pair coaxial cable. Other requirements for the new system that conditioned the joint design are as follows.

(*a*) Electrical performance needed to be such that the joint had little restriction on the further exploitation of the cable.

(*b*) The mechanical performance needed to be adequate for field conditions. This is generally based on past experience that the strength of the joint in the coaxial pair should be not less than about 80 per cent of the parent conductors.

(*c*) The complete joint needed to have a long-term high integrity.

(*d*) The coaxial-pair joint needed to be adaptable for on-site local repair of a damaged cable.

The development of an 18-pair coaxial cable joint to meet these design requirements and the factors that have led to the design are described. A description is also given of a joint between the normal underground coaxial pair and a solid-dielectric flexible coaxial cable at the repeater housing.

THE NEW 2.6/9.5 mm COAXIAL-PAIR JOINT

From earlier work carried out on 18-pair coaxial cables it was clear that the standards of skill and expertise demanded of the jointers was such that there were doubts about the quality that could be achieved in a complete 60 MHz cable system. A new approach to coaxial-pair jointing was therefore considered necessary.

The decision to use only electrical means to identify the coaxial pairs in the cable between terminations eases the jointing problems[1]. It allows the coaxial pairs on one cable end to be jointed to the coaxial pairs appearing directly opposite on the other cable end. The pairs are identified only at the cable terminations. Since pairs can be jointed straight across, movement of the tubes is kept to a minimum and the joint can be designed with the minimum working space around individual tubes. In this way the overall diameter of the 18-pair joint is kept to a minimum.

The new design of joint combines existing and specially-developed methods. As shown in Fig. 1, the inner conductor is butt-brazed, whilst a ferrule is used to join the outer conductor. To avoid the tedious and difficult task of unwinding and rewinding the steel tapes around the copper outer-conductor the former are removed over the area of the joint during the initial preparation of the coaxial-pair ends. The necessary screening of the joint is provided by a steel ferrule which is held in place with a heat-shrinkable polyolefine sleeve on completion of the joint. (Certain features of this joint are the subject of a British Post Office (B.P.O.) patent).

Jointing Sequence

The salient points of the jointing sequence are given below, and illustrated in Fig. 1.

A steel tube and a polyolefine sleeve are passed over one of the coaxial pairs to be jointed. The paper lapping tapes, steel tapes and the outer conductor of the other pair are then removed to expose the inner conductor. One polyethylene disk is removed from inside the coaxial pair by passing a heated wire between the two conductors. The protruding end of the inner conductor is then cut to size with the aid of a special jig and the coaxial-pair end is temporarily sealed with a wooden plug. The other pair is prepared in a similar manner.

The temporary wooden plugs are removed and the pairs aligned so that the inner conductors just meet. Each inner

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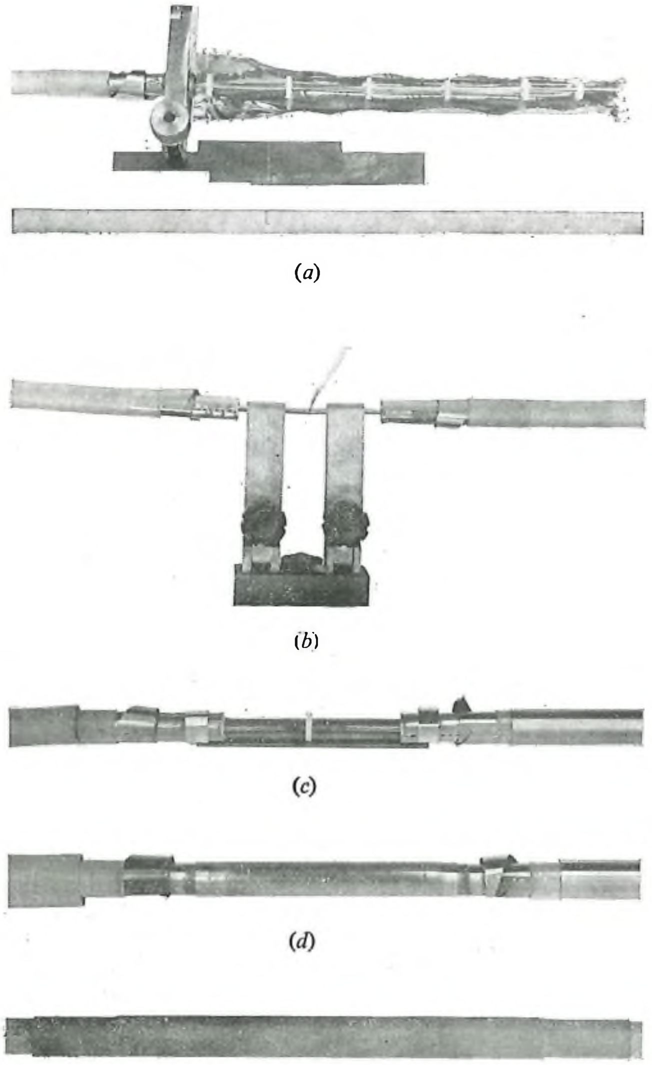
† Operational Programming Department, Telecommunications Headquarters.



(a) Preparation of the outer conductor
(b) Brazing the inner conductor
(c) Partially-assembled outer conductor prior to brazing
(d) Completed outer-conductor
(e) Completed joint.

FIG. 1—The 2·6/9·5 mm coaxial-pair joint

conductor is then gripped firmly in the tongs of a brazing unit. A thin strip of silver solder is trapped between the inner conductor ends, and a low a.c. voltage is applied to the tongs, causing the junction to heat and thus braze the conductors together. Three polytetrafluroethylene (p.t.f.e.) disks are then placed in appropriate positions over the inner conductor.

A specially-shaped two-piece copper ferrule is placed over the jointing gap so that the slightly-enlarged ends rest over the ends of the outer conductor. The ferrule has an internal diameter which is the same as that of the cable pair. Rings of silver solder are placed between the outer conductor and the ferrule ends, and the ferrule is electrically brazed in a similar manner but using shaped carbon tongs.

The steel sleeve is slid over the joint which is then insulated by heat-shrinking the polyolefine sleeve with a hot-air blower. The audio pairs are jointed in the traditional way, and the completed 18-pair joint is enclosed in a 90 mm × 760 mm lead sleeve which is then wrapped, together with the exposed lead sheath, with protective tape.

The time taken for the complete joint is about 26 hours, compared with the 72 hours needed for all-brazed joints of earlier design.

To assist the jointer in avoiding errors such as the omission of p.t.f.e. disks, and to ensure that the parts are available in a clean condition when required, the components for the completion of one coaxial-pair joint are supplied in a packaged form. The jointer, therefore, unpacks only sufficient parts for one coaxial-pair joint at a time, and this gives him some check on the parts as the joint is completed. The completed 18-pair joint is shown in Fig. 2.

Electrical Characteristics

The electrical variability of the earlier all-brazed joint is almost completely eliminated in the new design. Changes in the impedance of the cable across the joint due to the use of p.t.f.e. disks, with their slightly higher dielectric constant than that of polyethylene, is partly offset by suitable spacing of the disks. Also, the internal diameter of the outer conductor is maintained constant across the joint. During the design of the joint considerable use was made of the time domain reflectometer (t.d.r.) which gives a very convenient and ready indication of changes in electrical characteristics of the joint with the mechanical changes that are made. A typical t.d.r. trace for the new joint is given in Fig. 3 for pulses with rise times of 5 nanoseconds and 150 picoseconds which are approximately equivalent to 60 MHz and 2·3 GHz. With the slower rise-time pulse, the joint is almost indiscernable from other irregularities in the cable, and even with the faster rise-time the reflexion peaks shown are equivalent to a return loss which is always greater than about 38 dB. Thus, the electrical performance is well within the standards required. Joints made in this way by various jointers have been tested and found to give consistent results of this order.

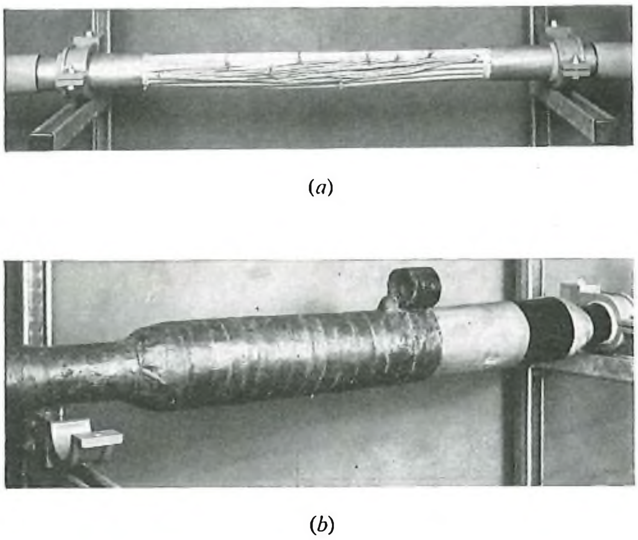
Some joints have been constructed with a number of possible jointer errors or omissions and also subjected to tests. Such faults were found to be almost undetectable, except for one where grossly-excessive heat was applied to the outer-conductor during brazing, causing some melting of the polyethylene disks adjacent to the joint. Such a joint, in fact, only fails the high-voltage test between inner and outer conductor, whilst the other faults only become electrically detectable after long periods of vibration.

BURIED JOINTS

Because of the need to carry out *in situ* repairs, where practicable, rather than length replacement, some joints will be buried directly in the ground. There are two aspects which could affect the initial quality of the joint and its subsequent mechanical integrity. Firstly, it is essential that the two cable ends are supported firmly in relation to one another whilst the coaxial pairs are jointed. Secondly, since the joint must of necessity be made above the trench bottom, there is a risk of subsidence in the backfill material below the joint once the hole has been filled in. To meet both these problems, the cable is supported both initially and permanently in the trench by steel sections driven firmly into the ground on each side of the joint. Adjustable horizontal tie-bars are then fixed across the trench to give full support to the cable. On completion, the protected joint is enclosed in a glass-fibre-reinforced plastic coupling which also encloses, at its ends, the exposed ends of duct. The coupling rests on the steel supports and is filled with a cold-setting bituminous compound to give additional mechanical and corrosion protection, before the excavation is backfilled.

JOINTS IN MANHOLES

In manholes, the joint is supported on adjustable cable supports. This form of support permits adjustment both horizontally and vertically to avoid setting the cable. Moulded



(a) Jointing complete
(b) Completed joint with protective tape

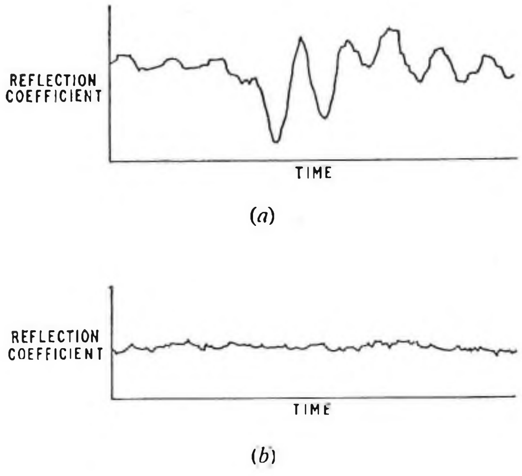
FIG. 2—The completed joint of an 18-pair 2·6/9·5 mm coaxial cable

plastic cable clamps which fit to these bearers have been designed to permit rotation through two planes, thus ensuring that the cable can be clamped firmly and without risk of distortion and damage. The clamp is illustrated in Fig. 4.

JOINTING TO REPEATER HOUSINGS

Entry and exit cables are jointed on site to the repeater housings. 18 solid-dielectric flexible coaxial leads and 24 plastic-insulated audio pairs are led out through gunmetal pipes fitted at each end of the case.[2] During manufacture, the ends of the flexible leads are prepared with a crimped ferrule applied to the outer-conductor of the flexible cable and a ferrule soldered to the inner conductor. Numbered collets are also fitted and the prepared leads are sealed into the gunmetal tube by a lead cap.

The cable coaxial-pairs are identified by tapping through from the previous repeater housing to ensure correct appearance at the amplifier in each case.



(a) 150 picosecond
(b) 5 nanosecond

FIG. 3—Time domain reflectometer traces

The on-site jointing sequence is then as follows.

The 2·6/9·5 mm cable pairs are prepared by removing the outer conductor and inserting a p.t.f.e. disk over the inner conductor. A prepared tinned-brass ferrule, threaded at one end, is passed over the cable pair together with the heat-shrinkable polyolefine sleeve. The inner conductor is soft-soldered to the centre ferrule of the flexible cable. The tinned-brass ferrule is passed over the inner conductor and screwed onto a nut attached behind the flexible cable outer-conductor ferrule and then soft-soldered to the outer conductor of the coaxial pair. The joint is then insulated with a heat-shrinkable polyolefine sleeve. When all pairs are jointed, a lead sleeve is plumbed between lead cable-sheath and the gunmetal pipe of the repeater case. A protective coupling is fitted over the joint and filled with a cold-setting bituminous compound. The joint is illustrated in Fig. 5.

The use of the crimped connexion for the outer-conductor braids of the flexible cable avoids softening of the solid dielectric which results if soldering is attempted. Experience shows that such softening allows small displacements of the inner conductor, with a consequent affect upon the electrical characteristics of the joint. The p.t.f.e. spacer on the flexible cable inner-conductor reduces the risk of similar trouble when soldering the inner-conductor ferrule, although the heat applied is considerably less than that required for the braids. The electrical performance of this joint is adequate for 60 MHz systems, however, its performance is almost entirely limited by the impedance tolerance of the flexible cable.

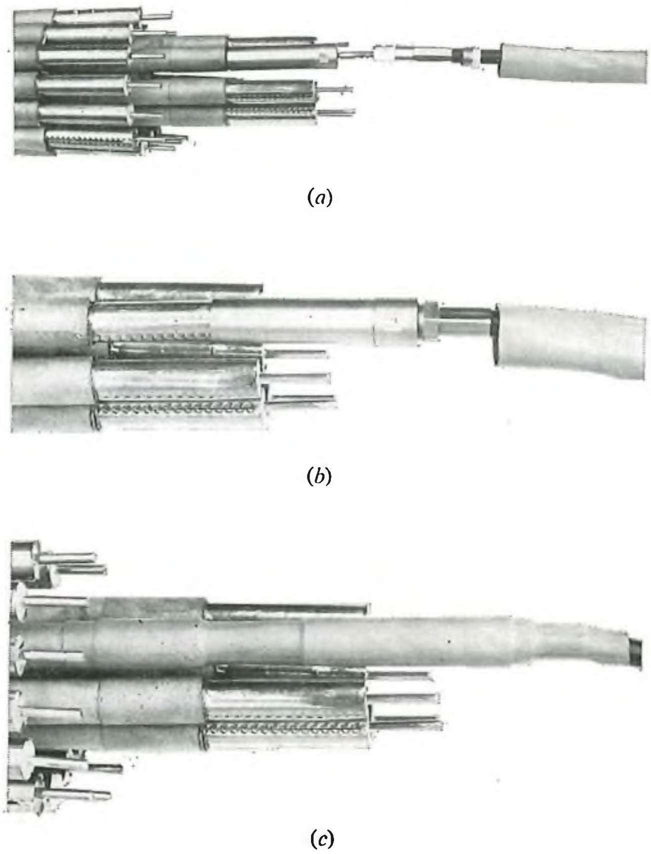
IN SITU REPAIRS

As mentioned earlier, a technique of *in situ* repair of the cable has been developed for maintenance. The repair method depends on the nature of the cable fault and the prevailing site conditions. However, certain techniques have been developed to enable maintenance staff to restore quickly, and to maintain service on, as many systems in the cable as possible until permanent repairs are complete. The safety procedures and safe-working facilities provided by the power-supply system permit the jointer to work on cables carrying working systems.[3,4] A basic principle is that the coaxial pair on which he is actually working at any time shall be isolated at the adjacent repeater points.

Where a cable length has been damaged, temporary restoration of service can be given with either standard cable or a special interruption single coaxial-pair cable. Similarly, where damage is localized or even restricted to one coaxial pair, it may be necessary to piece-out temporarily with short lengths of flexible cable. Use is made of a prepared plug-ended length of flexible cable mating with a socket end that can be quickly soldered to the prepared coaxial cable-pair.

The use of these flexible cables for patching permits access to a faulty coaxial pair which is awkwardly placed for

FIG. 4—Cable clamp



(*a*) Inner conductor jointed
(*b*) Outer-conductor ferrule in position
(*c*) Completed coaxial-pair joint

FIG. 5—Flexible cable to 2·6/9·5 mm coaxial-pair joint

the jointer. In such cases, restoration of the coaxial pairs requires a small amount of slack, even with the new ferrule-type brazed joint. Although, exceptionally, it may be necessary to piece-in a short length of coaxial pair, a repair joint has been designed which is longer, but otherwise similar to the new ferrule joint.

The use of patching cable and the repair type of coaxial-pair joint requires only a small working space, thus enabling the jointer to carry out a repair on a tight cable with minimum disturbance of adjacent undamaged coaxial pairs.

CONCLUSIONS

The new design of coaxial-pair joint is both mechanically sound and electrically consistent. The tedious features common to many of the earlier joint designs have been removed or at least reduced. Thus, the jointer is able to produce coaxial-pair joints that are more consistent. Cable joints should therefore have a higher integrity than before, and an electrical performance which promises to permit the exploitation of the cable beyond the present 60 MHz.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues within the B.P.O. and industry whose joint efforts have contributed to these developments.

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Book Reviews

"Wave Transmission." vii + 107 pp. 61 ill. £1. "Antennas." vii + 99 pp. 56 ill. £1. F. R. Connor, Ph.D., M.Sc., B.Sc.(Eng.)Hons., A.C.G.I., M.I.E.E., M.I.E.R.E., M.Inst.P. Edward Arnold.

There are six books in this series, namely, Vol. 1—Signals, Vol. 2—Networks, Vol. 3—Wave Transmission, Vol. 4—Antennas, Vol. 5—Modulation and Vol. 6—Noise. Volumes 1 and 2 were reviewed in *P.O.E.E.J.*, Vol. 66, p. 9, Apr. 1973, Volumes 5 and 6 are in the course of preparation and Volumes 3 and 4 are reviewed below.

In writing this series, the author's intention is to prepare texts on introductory topics in electronics and telecommunication mainly for students who are studying for L.U. examinations, degrees of the C.N.A.A., examinations of the C.E.I. and for other qualifications such as H.N.C. and H.N.D.

VOL. 3—WAVE TRANSMISSION

The main topics dealt with in this book are—analysis of lines, refleions on lines, field phenomena, waveguide theory and microwave techniques. There are also appendices dealing with—vector analysis, boundary conditions and cavity resonators. Included in the book are 14 worked examples and 15 problems with the numerical answers provided at the end of the book. In addition, there is a list of references for further reading on transmission.

The only important omission is the use of the Compensation Theorem for solving certain types of transmission problems on mismatched lines, lossy or loss-less.

Generally, the book could be recommended to students studying for the professional examinations previously mentioned, and those taking the City and Guilds Advanced Line Transmission examination.

VOL. 4—ANTENNAS

The main topics dealt with in this book are—elementary antennas, vertical and horizontal antennas, antenna arrays, microwave antennas and electromagnetic waves. There are also appendices dealing with—effective aperture, radiation field, loop antenna, half-wave dipole electron collisions and earth's field. Included in the book are 15 worked examples and 12 problems with the numerical answers provided at the end of the book. As with the previous volumes, a list of references for further reading is provided.

As is to be expected this book is rather more specialized than any of the previous volumes in the series, and will only be of use to those whose course of study requires a good knowledge of aerials at a fairly advanced level. It could, therefore, only be recommended to students studying for professional examinations, and those taking the radio subjects of the City and Guilds Telecommunication Supplementary syllabus.

J. F.

The 60 MHz F.D.M. Transmission System: Cable Testing

L. H. STILL, W. J. B. STEPHENS and R. C. H. BUNDY†

U.D.C. 621.315.212: 621.317.34: 621.394. 029.63

Testing equipment and testing techniques developed for the assessment of the new 2·6/9·5 mm coaxial cable are described. Although the cable is to be used initially for 60 MHz f.d.m. transmission systems, the feasibility of its later use for high-speed digital systems has necessitated the extension of the testing frequency range. Close control and definition of cable parameters is required and this has resulted in the further development of existing measuring techniques and the development of methods new to trunk coaxial-cable testing.

INTRODUCTION

As the cable developed for the 60 MHz f.d.m. transmission system is likely to be exploited later for high-speed digital systems, the cable performance requirements have been specified up to 500 MHz. There is very little commerical test equipment readily available for cable testing in the region of 500 MHz and much of the testing equipment required has had to be specially designed and constructed.

This article describes the test equipment and testing techniques which have been developed to allow the electrical performance of the new 2·6/9·5 mm coaxial cable to be assessed in relation to the requirements specified for its initial use for the 60 MHz f.d.m. transmission system and for later digital exploitation. These requirements are outlined in another article.[1] Test equipment of the kind described requires controlled conditions of temperature and humidity for its performance to be consistent and accurate. Some of the equipment developed is required in a mobile form for field testing, and standard test-vans adapted for this purpose are also described in another article.[2]

TESTING PHILOSOPHY

Measurement of the specified electrical performance of the new 2·6/9·5 mm coaxial cable calls for high-calibre test equipment which is costly to provide, operate and maintain.

Although comprehensive checks of all aspects of cable performance are essential during the development stage, it is probable that the same scale of testing during production would lead to a significant and unjustifiable increase in the total cost. Close control of the various manufacturing processes for the new cable will undoubtedly lead to a very consistent product and thus allow less rigorous procedures to be adopted in the various factories. It is expected that full assessment of the comprehensive tests carried out on pilot production cables recently installed at Marlow will enable an appropriate scale of factory and field tests to be specified when full production commences.

CABLE MEASUREMENTS

Attenuation

The manufacturing specification requires the coaxial-pair attenuation α at 10° C to conform to the following expression:

$$\alpha = 0{\cdot}013 + 2{\cdot}305\sqrt{f} + 0{\cdot}003f,$$

where α is the attenuation in dB/1,000 m and f is the frequency in MHz. Figures calculated from this expression, together with the appropriate specification limits, are shown in Table 1.

TABLE 1

Attenuation/Frequency Characteristics

Frequency (MHz)	4	16	64	256	484
Attenuation (dB/1,000 m)	4·635	9·281	18·645	37·661	52·175
Allowable limits (dB)	±0·07	±0·14	±0·28	+0·56	+0·78

For a 500 m length of cable the limits are: ±0·07 dB at 16 MHz, ±0·14 dB at 64 MHz and +0·39 dB at 484 MHz.

To make confident measurements within these tolerances requires measuring equipment having an uncertainty of measurement one order better, i.e. 0·007 dB at 16 MHz and 0·04 dB at 484 MHz. Uncertainties of measurement achieved by laboratories approved by the British Calibration Service[3] over the cable specification frequency and attenuation ranges are typically 0·02–0·4 dB. Therefore, current measurement technology has had to be extended in order to measure the specified performance of the new cable.

The comparison method of measurement has been used for many years for the assessment of coaxial cables and has already been described.[4] However, more sophisticated equipment is needed to cater for the increased frequency range and closer tolerances demanded for the new cable. Some suitable equipment is available commercially and

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in addition at British Post Office (B.P.O.) design is now in production.[5]

A block diagram of the comparison-type attenuation measuring equipment used for the cable measurements is shown in Fig. 1. The accuracy is dependent upon the integrity of the calibrated attenuators but is independent of the long-term stability of the oscillator and detector. The effect of the test leads is eliminated by making measurements with the leads coupled together and using the resulting readings as references.

Fig. 2 shows typical results for the 18-pair 2·6/9·5 mm coaxial cable laid at Marlborough for the 60 MHz system field trial. All pairs are within the specified attenuation limits.

A further attenuation requirement of the specification is the limit on the spread of attenuation between any two coaxial pairs within the same layer. To check this requirement, an attenuation difference measurement is made with one coaxial pair connected in the reference path and every other coaxial pair connected in turn in the measure path. Fig. 3 shows typical results from the Marlborough cable. Again, all pairs are within the specified limits.

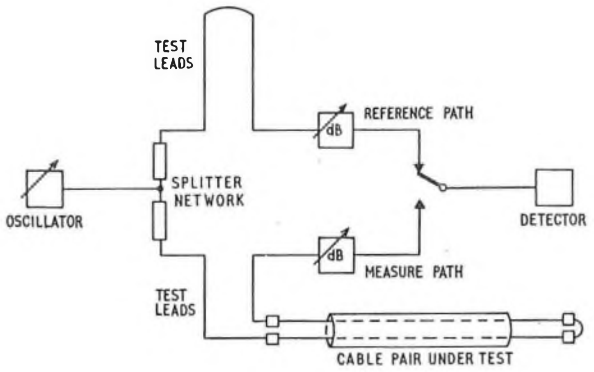


FIG. 1—Block diagram for looped-pair attenuation measurements

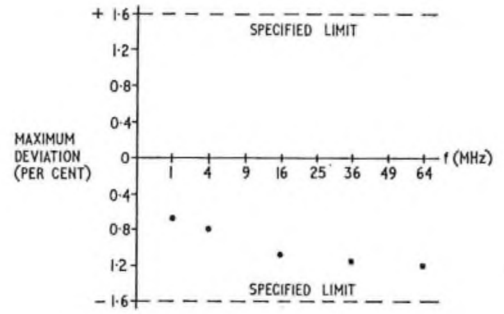


FIG. 2—Maximum attenuation deviation of any coaxial pair from the specified attenuation

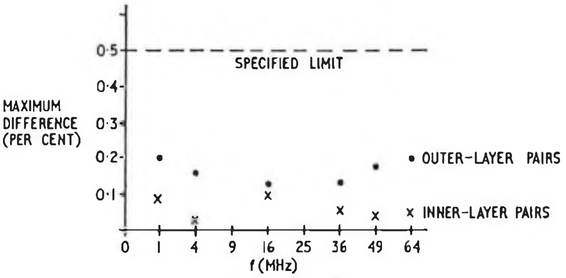


FIG. 3—Maximum difference in attenuation between any two coaxial pairs in the same layer.

Length Estimation

Coaxial-pair length is estimated from a measurement of delay using the Meyer test.[6,7] A block diagram of the equipment is shown in Fig. 4. It consists of a bridge, the reference arm of which has a virtually constant phase-delay characteristic. The measure arm (including the coaxial pair under test) has a phase-delay characteristic which is a function of frequency. As the oscillator frequency is advanced from zero, the signals in the two arms of the bridge are summed in the delta network, nulls being detected at frequencies where the signals are in anti-phase, i.e. at intervals of 2π radians. The bridge is balanced by alternately adjusting the frequency of the oscillator and equalizing the attenuation in the reference and measure paths. The nulls are counted from zero frequency and given a number N. Delay is then calculated using the formula:

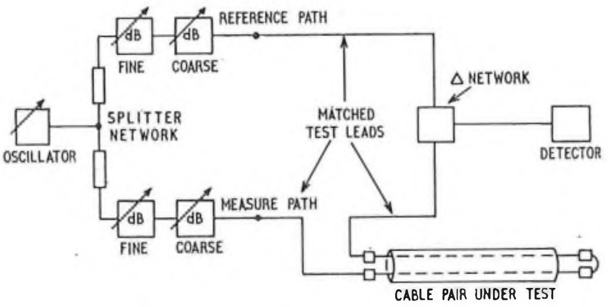


FIG. 4—Block diagram of Meyer test

$$\tau = \frac{2N - 1}{2f},$$

where τ is the delay in μs and f is the frequency in MHz.

The length of coaxial pair under test is then determined using the standard delay figure for 2·6/9·5 mm coaxial cable (3·4511 μs/1,000 m at 30 MHz).

Pulse-Echo Test

The pulse-echo technique has been in use for many years in the testing of coaxial cables for impedance irregularities. Various methods have been described elsewhere.[8,9,10,11,12] For the 60 MHz system it was realised that a 10 ns raised-cosine pulse would suffice, but for checks of performance at 500 MHz a 2 ns pulse would be necessary. Fig. 5 shows the basic block diagram of a pulse-echo test set. Fig. 6 shows a typical trace.

A time-domain reflectometer (t.d.r.) is more suitable for assessing irregularities which are very close to the testing-end because of the greater resolution which can be achieved. It

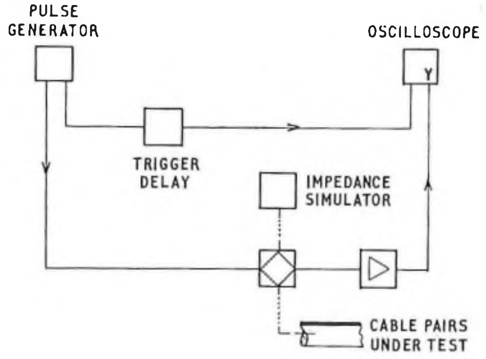


FIG. 5—Block diagram of pulse-echo equipment

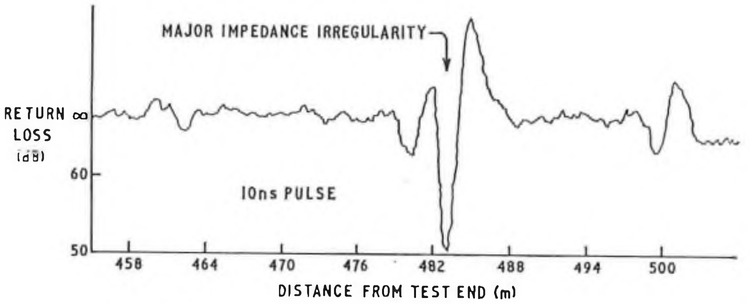


FIG. 6—Pulse-echo trace of 2·6/9·5 mm coaxial pair showing major impedance irregularity

is, thus, extremely useful for checking the quality of tail-cable joints in the repeater housing. A block diagram is shown in Fig. 7. A typical trace of a tail-cable joint is shown in Fig. 8.

End Impedance

The end impedance of a coaxial pair is measured with the pulse-echo test set shown in Fig. 5. It is necessary to balance the cable-impedance simulator against the cable end under test, the simulator itself having been previously calibrated against a standard network or a length of cable.

Each coaxial pair is designed to conform to the following expression:

$$Z = 74\cdot4\left[1 + \frac{0\cdot0123(1 - j)}{\sqrt{f}}\right],$$

where Z is the impedance in ohms and f is the frequency in MHz. The impedance of each coaxial pair at infinite frequency is required to be within the range 74·4 ±0·4 ohms.

It is extremely difficult to define the construction of a variable simulator network to match the cable impedance over the whole frequency range, but sufficient accuracy can be achieved to determine the relative impedance of coaxial pairs and thereby allow the consistency of the manufacturing process to be assessed.

To overcome the difficulties associated with the cable simulator, a method employing a standard t.d.r. has been developed[13] in which the cable impedance can be compared, using a bridge, with a d.c. calibrated resistor having a good high-frequency performance. A block diagram of such an

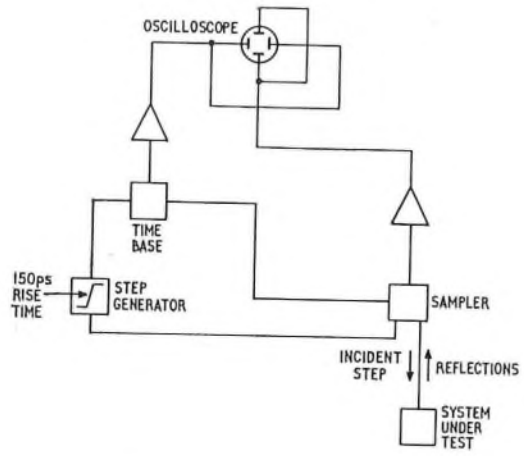
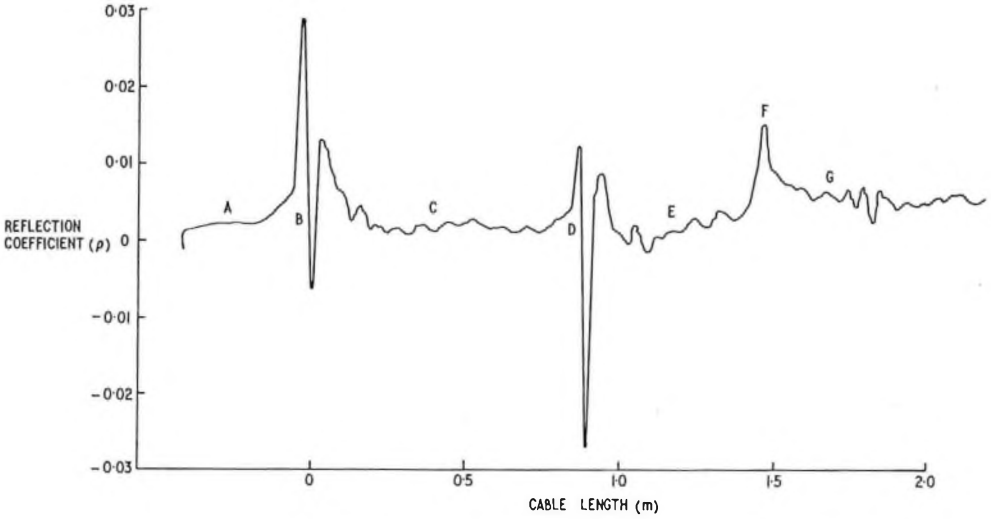


FIG. 7—Block diagram of time-domain reflectometer



A—12 m test lead
B—connectors
C,E—flexible coaxial tail cable
D—air seal
F—joint
G—coaxial pair

FIG. 8—Time domain reflexion trace of main cable to tail cable assembly of a 60 MHz system repeater housing

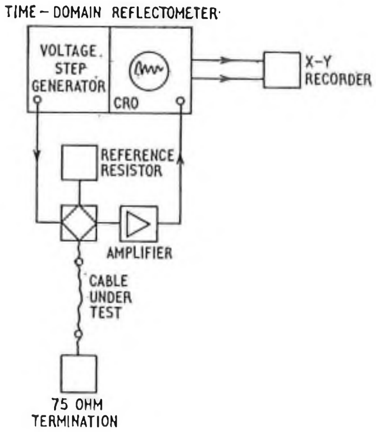


FIG. 9—Block diagram of equipment for end-impedance measurement using the raised-step method.

equipment is shown in Fig. 9. The resultant impedance characteristic is recorded on a pre-calibrated chart using an X–Y plotter. Fig. 10 shows an example of a typical recording.

Uniformity of Impedance

It is important to assess the effect of the regularly-spaced impedance irregularities which can occur during the manufacturing process. The probable cause of these irregularities and their possible effect on the cable performance are considered in another article.[1]

Sweep-Frequency Return Loss

One method of assessing the uniformity of impedance of a coaxial pair is to use a sweep-frequency return-loss technique. The basic arrangement of a suitable testing apparatus is shown in Fig. 11. The measured impedance of the cable is compared with a standard 75-ohm reference resistor. A typical trace is shown in Fig. 12. It would be preferable to use a variable cable-impedance simulator network for this test rather than a 75-ohm resistor, but as has already been noted, the problem of constructing such a simulator to cover the whole frequency range is almost insurmountable.

Return Loss by Carrier-Wave Burst

Another method[14,15] of assessing uniformity of impedance involves a technique in which bursts of carrier wave are applied to the cable under test and the reflected signal detected and recorded. By suitable timing of the bursts and adjustment of the detector it is possible to assess the reflexions from any particular portion of the cable. In this way the effect of a test lead, a tail cable or a connector can be eliminated from the results. A typical recording is shown in Fig. 13.

Returned Power in Band

Return-loss measurements are insufficient for judging the performance of coaxial pairs for digital transmission. Ideally, an assessment of unwanted signals reaching the distant end after multiple reflexion (forward echo) is required, but this presents measurement difficulties. As a compromise, the ratio of returned mean power to the power sent in a defined frequency band is measured by processing the signals from the carrier-burst return-loss equipment. The returned power is integrated over 10 MHz bands to give the mean power returned in each band. Various methods have been described.[16]

Crosstalk

Crosstalk measuring techniques have been described elsewhere.[17] For the new cables a capability for measuring crosstalk attenuation up to 160 dB and up to 500 MHz is required.

High-Voltage Test

High-voltage tests are made on cable lengths in the factory, and on repeater sections in the field, to ensure freedom from incipient breakdown in service. Standard testing techniques are used.

D.C. Resistance

It is necessary to measure in the factory the d.c. resistance of the inner conductors with an uncertainty not worse than 0·1 per cent at a stable temperature. These figures can then be used for assessment of the temperature of the cable when laid. The accuracy of this assessment thus depends largely upon the precision with which the temperature of the cable in the factory can be estimated.

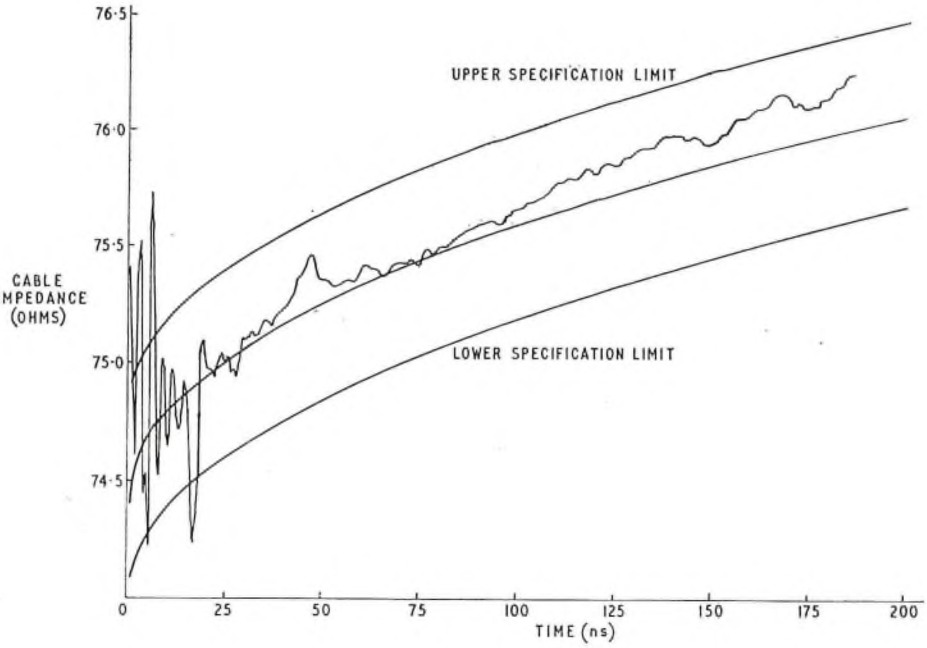


FIG. 10—End-impedance trace of 2·6/9·5 mm coaxial pair (measured using the raised-step method)

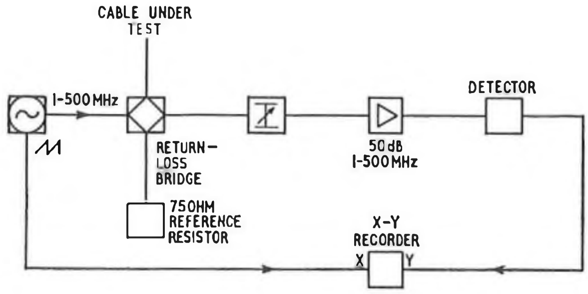


FIG. 11—Block diagram of equipment for conventional sweep-frequency return-loss measurement.

Insulation Resistance

The minimum requirement for all coaxial pairs is 25,000 Mohms between inner and outer conductors and 120 Mohms between outer conductor and the lead sheath. Both figures are for a 1,000-metre length.

For the 0·63 mm quads in the cable, the insulation resistance between any one conductor and the remainder (earthed) is required to be better than 10,000 Mohms on drum and 6,000 Mohms when laid and jointed (again, for a 1,000-metre length). The quads are otherwise generally required to be in accordance with a standard 24-pair P.C.Q.T. cable.

CONCLUSIONS

The electrical tests required for the 2·6/9·5 mm coaxial cables designed for the new 60 MHz f.d.m. transmission system have been described and an indication of the nature of the testing techniques has been given. While the development of new techniques has been necessary, it has been possible to adapt many of the old-established methods to suit the very stringent requirements of the new cables. It is essential that the scale of production testing should be fixed at a suitable level, and as cable production progresses and experience is gained, an economic scale of testing will become increasingly evident.

ACKNOWLEDGEMENTS

The development of test equipment and the evolution of the testing methods described has been carried out in conjunction with the authors' colleagues in the B.P.O. Research Department. Their assistance is gratefully acknowledged as is that of the British cable makers who have given their full cooperation.

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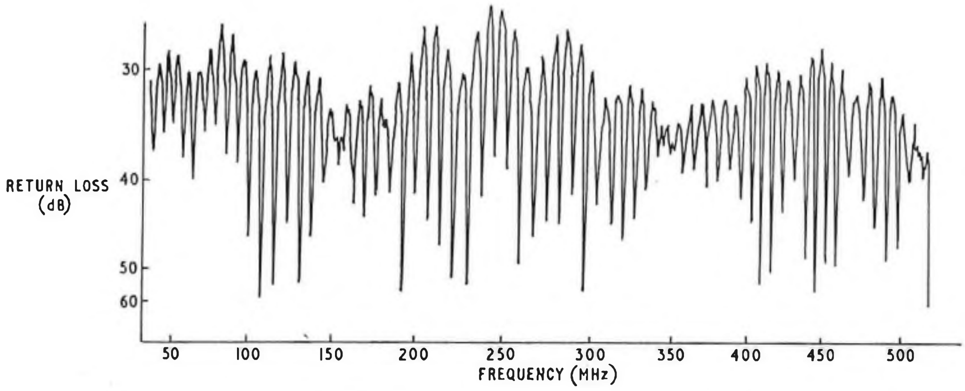
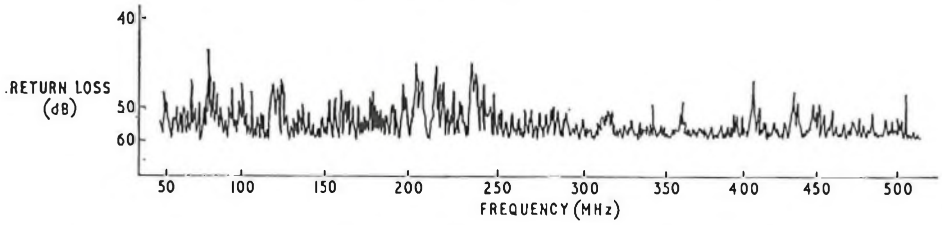


A major impedance irregularity (1·5 m from the test end) is indicated by the cylic frequency roll

FIG. 12—Conventional sweep-frequency return-loss trace



The major impedance irregularity shown by the sweep-frequency return-loss trace is eliminated

FIG. 13—Carrier-wave-burst trace

The 60 MHz F.D.M. Transmission System: Cable Test Vans

E. V. T. PERRINS, B.E.M.†

U.D.C. 621.317.361: 621.394.44.029.62: 621.317.2–182.3

The introduction of precision high-frequency test equipment for field testing of coaxial cables has created a need for a new design of test van. The design and construction of such vans for initial use with the 60 MHz f.d.m. transmission system is described.

INTRODUCTION

The proposed installation of 2·6/9·5 mm coaxial cables for initial use with 60 MHz frequency division multiplex (f.d.m.) transmission systems and possible later exploitation for digital working has demanded the use of mobile precision testing equipment. This has posed new problems for the field-test engineer. The need for test gear, suitable for high-precision measurements, to satisfy the system requirements implies the use of equipment designed for use in a laboratory environment, and the need for high-frequency operation involves the permanent assembly of a number of individual items of equipment rather than temporary connexion of several portable pieces of apparatus.

New test vehicles have been designed and constructed so as to provide an appropriate environment for both the equipment and the testing personnel.

DESCRIPTION OF THE VEHICLES

Experience with a standard British Post Office test van during installation of the 18-pair 2·6/9·5 mm coaxial cable for the field trial at Marlborough, showed the need for considerable improvement to the internal layout in order that high-frequency tests could be conducted efficiently and with confidence. Considerable difficulties arose in operating laboratory-type equipment within the environment of a standard test-van and the need for some degree of temperature control became apparent.

The new layout, shown in Fig. 1, was designed to make proper provision for rack-mounted equipment and to give adequate working space for the testing personnel. Space was allotted for an air-conditioning unit and storage capacity allowed for spare equipment and test leads. The need for a teletype and modem for direct computer access for rapid calculation of test result was recognized.

To accommodate all the equipment required for testing the new 2·6/9·5 mm coaxial cable, two separate test

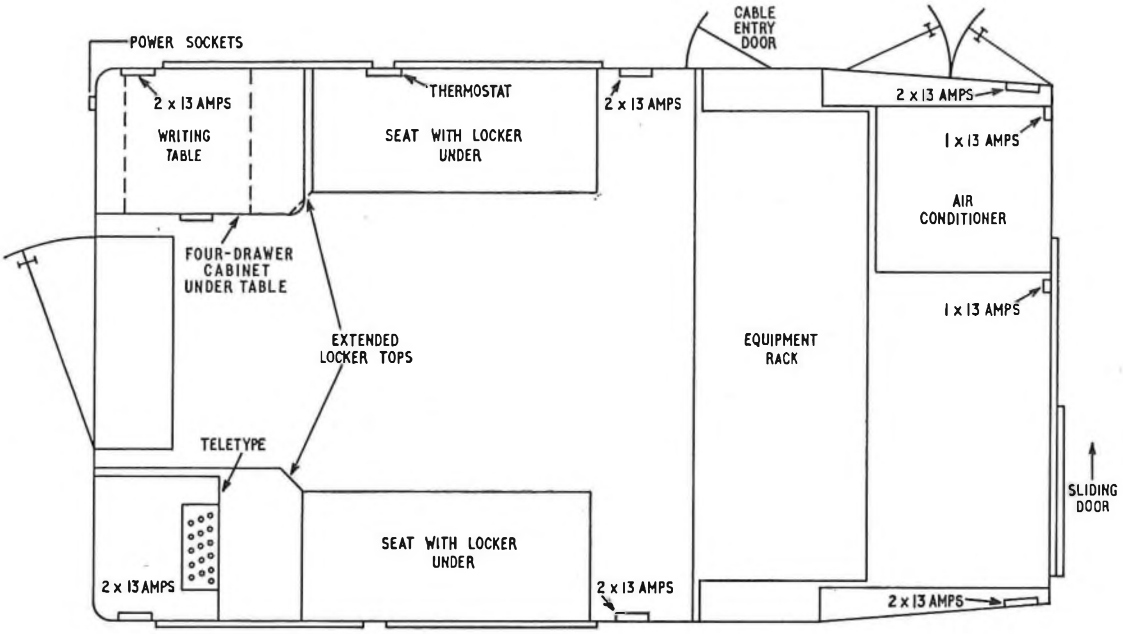


FIG. 1—Interior layout of the test-van, after modification

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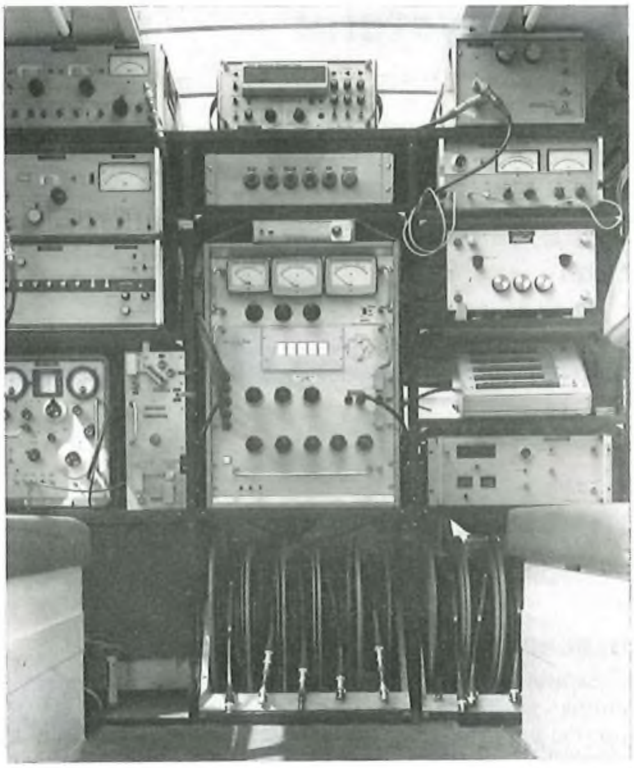

Fig. 2—Rack of equipment for transmission-measurement vehicle (before fitting auxiliary roof)

vans are needed, each having the same basic layout but differing in detail. Two standard vans have been stripped of all interior fittings and equipped with completely new custom-built functional items to suit the new arrangements. The equipment racks are constructed so that they can easily be converted to take modified layouts and changes of equipment. The main framework, constructed of 25·4 mm square steel section, is divided vertically into three equal divisions, each 500 mm wide. In one vehicle, the rack is equipped with vertically-adjustable shelves, and the other vehicle is similarly equipped, except that six of the shelves are fitted with ball-bearing sliders enabling the equipment to be pulled into a forward position. The equipment is secured to the shelves by rubber straps and prevented from sliding by small wooden blocks. Fig. 2 shows the arrangement for the transmission-measurement vehicle and Fig. 3 shows that for the pulse-echo and sweep-frequency return-loss measurement vehicle.

Fig. 3—Rack of equipment in vehicle (before fitting auxiliary roof) for pulse-echo and sweep-frequency return-loss testing

Temperature Control

Preliminary calculations showed the need for approximately 2kW of heating to maintain a temperature of 20°C inside the van when the outside temperature was 0°C. During hot weather, a cooling capacity of 3·1 kW would be required to maintain the internal temperature of the van at 15°C when the external temperature was 30°C. Standard commerical air-conditioning units are installed in the spaces previously occupied by the front near-side lockers. The units chosen have a heating capacity of 2·5 kW and a cooling capacity of 3·5 kW, the dimensions being such that the units can be installed through the locker doors without disturbing any of the interior fittings in the vans. These units use a non-toxic refrigerant and thermal cut-outs protect the units from overheating.

It has been necessary to duct some of the conditioned air to the upper part of the van bodies, thereby removing the tendency for the air to stagnate in layers of differing temperatures.

To overcome the solar gain (greenhouse effect) of the translucent fibre-glass roofs, auxiliary outer roofs made of alumimium-alloy sheets have been provided. These alloy roofs are painted matt black on the underside, the reflecting outside surface being the natural polished alloy protected by clear varnish. The auxiliary roofs are separated from the original roofs by wooden spacers.

Comparative measurements of the internal air temperature of an air-conditioned van and a standard van were made

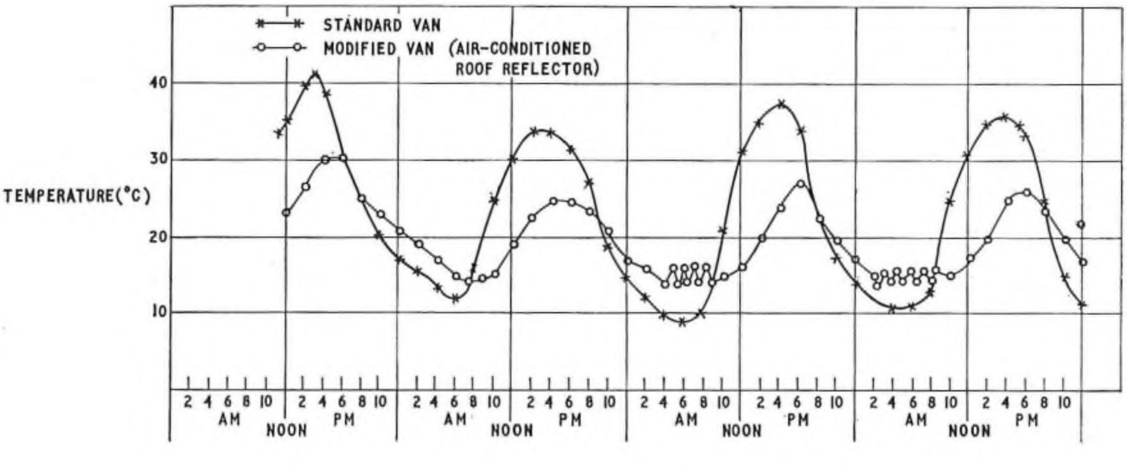

Fig. 4—Comparison of climatic conditions inside a modified van and a standard van

FIG. 5—New van complete with trailer generator

using thermographs. Fig. 4 shows how the temperature fluctuations were restricted by the air-conditioning units for a typical period in summer. This degree of control has proved to be adequate for both equipment and personnel and, although humidity control is not provided, the air temperature is sufficiently high to prevent reaching the dew point and consequently no condensation problems arise.

Power Supply

In each van, the test equipment requires a 2 kW supply at 230 volts 50 Hz and the air conditioner requires a supply of 3·5 kW capacity. Separate power supplies are needed so that the test equipment is isolated from the transients arising from load switching in the air conditioner. Two similar 3·5 kVA petrol generator sets are mounted on a single trailer to meet these requirements.

Ring mains, with outlets at strategic points (as indicated in Fig. 1) and protected by earth-leakage trip units are installed in each of the vans to power the equipment. Two 50-watt fluorescent lights are also energized from this supply. Part of the existing low-voltage lighting is retained for emergency use. Fig. 5 shows the external appearance of one of the new vans complete with trailer generator.

TESTS ON THE CONVERTED VEHICLES

After conversion, each of the vans was subjected to a series of tests to determine whether the equipment would be affected by vibration and also to prove the strength of the fittings under adverse conditions. For a road test, the vehicles were driven over rough surfaces and unmade roads at speeds higher than would normally be used in practice. Emergency stops were made and the equipment inspected for movement. None of the equipment moved or sustained damage due to the vibration. The electrical performance of the equipment was unimpaired by these tests.

FIG. 6—External view of trailer caravan showing air conditioner intake

FURTHER DEVELOPMENT

In the early planning stages it became apparent that some parts of the new 2·6/9·5 mm coaxial cable routes might well be difficult of access by a test van and for this reason a new unit is being developed. This is basically a commerical trailer caravan with inside dimensions 3·56 m × 2·13 m × 2·06 m fitted with lifting eyes to allow placement by crane if necessary. It has the additional merit of housing all the test equipment in a single vehicle rather than in two separate ones. Fig. 6 shows the exterior view of the partly finished prototype unit.

CONCLUSIONS

Two standard test vans have been converted to suit the housing of equipment for precision high-frequency testing of cables. They have proved reliable in service, and acceptable to the testing personnel. The new layouts of equipment and temperature-control arrangements have both contributed to an improvement in working conditions.

The 60 MHz F.D.M. Transmission System: A Loss-and-Gain Measuring Set

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U.D.C. 621.317.361:621.315.212.029.62

The advent of higher-frequency inland and submarine coaxial systems has led to a need for an accurate high-frequency loss-and-gain measuring set. An equipment developed by the British Post Office (B.P.O.) Research Department and now in limited commercial production for general B.P.O. use is described. Both the Research Department models and the commercial prototypes have been used extensively on the initial 60 MHz coaxial cable feasibility studies and the later field trials.

INTRODUCTION

The two fundamental parameters in a coaxial cable system are the loss of the cable sections and the gain of the associated amplifying elements. Consequently, the need to measure loss and gain arises frequently during the development, manufacture and installation of such systems. Measurement of loss or gain also arises in many other fields, and requirements for precision, dynamic range and frequency spectrum vary widely.

In the past, many equipments for loss and gain measurement have been produced and this has sometimes led to difficulty in relating results from different sources, obviously undesirable where the final objective is to match the gain of a repeater against the loss of a cable section.

With the progressive increase in system bandwidths, testing requirements have become more onerous; measuring sets having greater precision over wider frequency ranges are needed and ideally these should be simple and quick to operate.

Following the development, some years ago, in the British Post Office (B.P.O.) Research Department of a wide range loss-and-gain measuring set, designed for submarine and inland coaxial system applications,[1] (Fig. 1), this was made the basis of a standard B.P.O. set and there was sufficient demand to arrange for limited commercial production.

Target specification requirements were formulated as a result of consultation with prospective users and on the basis of the known performance of the B.P.O. prototype. These are summarized in the table.

A development contract was placed for the production of two commercial prototypes, (Fig. 2), and these have now been in the field between one and two years.

Both the B.P.O. models and the commercial prototype equipments have proved successful and have been in continual use for some time on submarine and inland coaxial cable system applications, including the initial 60 MHz feasibility studies and the later field trials.[2]

FIG. 1—B.P.O. Loss-and-Gain measuring Equipment (B.P.O. model)

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TABLE
Target Specification

Frequency range	0–1 GHz (with limited extension to 2 GHz)
Uncertainty	0·02 dB up to 100 MHz, over a dynamic range of 60 dB 0·2 dB from 100 to 500 MHz, over a dynamic range of 60 dB 0·5 dB from 500 MHz to 1 GHz, over a dynamic range of 60 dB
Uncertainty of difference measurement	0·002 dB up to 60 MHz, over a dynamic range of 50 dB
Resolution	0·001 dB over a dynamic range of 60 dB
Maximum dynamic range	160 dB (1 dB uncertainty)

METHOD OF TEST

Before development of the equipment started, a choice had to be made between direct substitution, where the unit under test (u.u.t) is compared with a measuring standard at the test frequency, and indirect substitution,[3, 4, 5] where the measuring standard operates at an intermediate frequency (i.f.) or at a low frequency. A detailed discussion of the relative merits is outside the scope of this article but the choice depends largely on the frequency range to be covered.

Where wide frequency ranges, well up into the microwave region, are required, and for most computer-controlled applications, the indirect substitution technique is more appropriate.

When considering equipments for manual operation over ranges where variable standards of sufficient accuracy can be obtained, the direct substitution technique, sometimes known as radio frequency (r.f.) substitution, offers advantages of greater simplicity and reduced time to make measurements and has been selected for the present application.

There are two basic direct substitution test methods available, simple series-substitution where the u.u.t. is in series with the measuring attenuator, and parallel substitution, where they are in opposite paths. Although either of these methods may be used in the equipment, a combination of the two techniques, referred to as series-substitution comparison, is chosen for most purposes.

This method has many advantages, including the less stringent demands it makes on long-term level-stability compared with simple series-substitution. Also, it does not suffer from the disadvantage of wide variation in receive levels associated with parallel substitution.

The method is illustrated in simplified form in Fig. 3. The variable attenuator is adjusted until the indicated output levels of the MEASURE and REFERENCE paths are the same; firstly with the u.u.t. in circuit (leads plus unknown run), and secondly with the u.u.t. out of circuit (leads run).

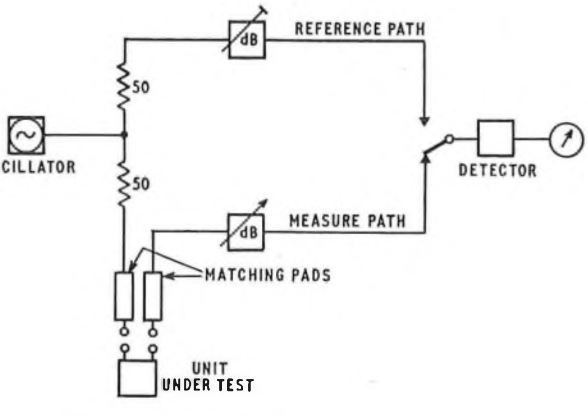

FIG. 3—Series-substitution comparison technique

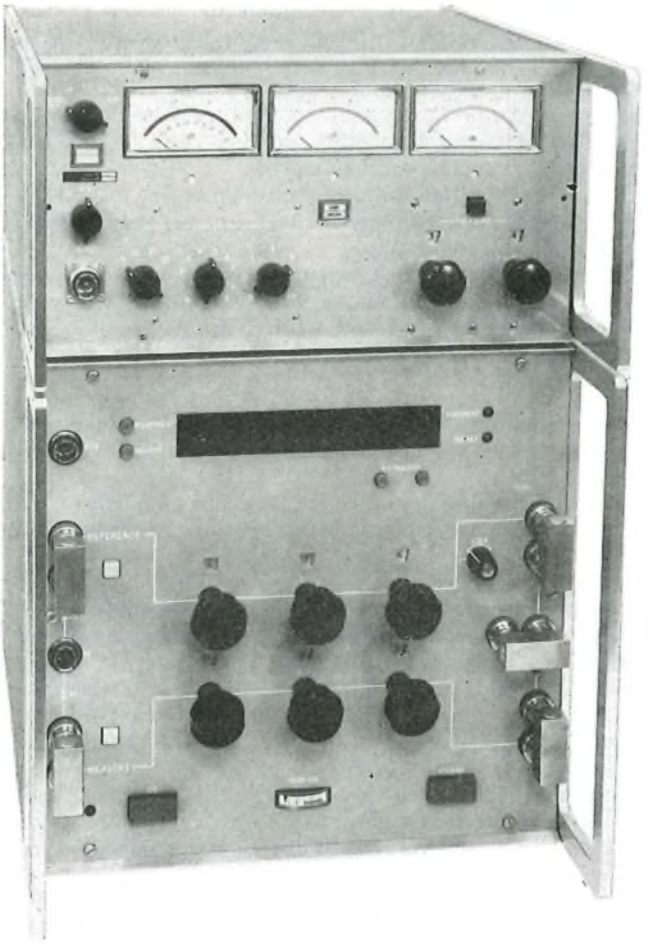

FIG. 2—B.P.O. Loss-and-gain measuring equipment (commercial prototype)

The loss or gain of the u.u.t. is then given by the difference in attenuator readings for the two balance conditions.

OUTLINE DESCRIPTION OF THE SYSTEM

Fig. 4 shows a typical lay-out of the system. The basic units are:

(*a*) A signal source comprising an oscillator, or frequency synthesizer, covering the required frequency range and capable of providing adequate signal level. For precise work the oscillator must have good amplitude and frequency stability, pure waveform and negligible spurious radiation. A frequency counter is also required sometimes.

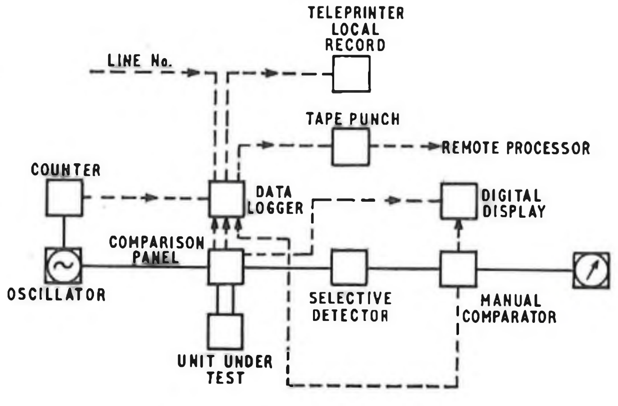

FIG. 4—Loss-and-gain measuring set

(*b*) A comparison panel, containing the necessary high-frequency components for direct-substitution measurements,

(*c*) A selective detector having the required frequency range and sensitivity and providing either a d.c. or an i.f. output signal. For precision applications the detector should have good amplitude and frequency stability and should provide adequate discrimination against spurious signals.

(*d*) A level-comparator unit which processes the output signal from the selective detector and provides the necessary visual display of the results.

(*e*) Automatic electronic data-processing (e.d.p) facilities for use where a large number of measurements are to be made. Suitable binary-coded-decimal (b.c.d) facilities are provided in the comparison panel and in the level comparator for this purpose.

The oscillator, frequency counter, and detector units used are all standard commercial items and are not discussed further.

Referring to Fig. 5, the r.f. test signal is applied to the comparison panel where it is divided between the measure and reference channels by means of a series resistive splitting-network, which effectively provides a precise 50-ohm source impedence for each channel irrespective of the output impedance of the oscillator.[6] Facilities are provided in the measure and reference channels for setting up a variety of direct substitution tests, but the method shown in Fig 3, where the u.u.t. is connected into the measure channel, is used for most purposes. Signal levels at the output of the two channels are compared by means of a coaxial switch and passed via a terminating amplifier to the selective detector. The output signal from the detector, either at i.f. or d.c. is applied to the input circuit of the level comparator of the loss-and-gain set. Depending on whether i.f. or d.c. operation is selected, the signal is passed either through a high-linearity rectifying circuit, or directly to a buffer amplifier, after which the signal is again divided between the measure and reference channels by means of a second resistive splitting network. The purpose of this second division of the test signal, now at d.c., between measure and reference channels is two-fold,

(*a*) to provide a means for correcting known errors in the r.f. attenuators, and

(*b*) to provide finer attenuation steps than can be achieved using the r.f. attenuators.

Correction of errors in the r.f. attenuators is achieved by switching-in appropriate correction resistors in the d.c. circuitry of the level comparator; ganged switching being provided for this purpose. From the correction networks, the d.c. test signal passes to incremental attenuators having steps of 0·01 dB and 0·001 dB, which provide interpolation between the 0·1 dB steps of the r.f. attenuators. The outputs of the two d.c. channels are compared by means of a mercury-wetted relay, which operates synchronously with the coaxial switch in the comparison panel and the resulting test signal is fed to the level and expanded-scale meter circuits.

The Comparison Panel

The comparison panel, which is the lower unit shown in Figs. 1 and 2, contains the necessary components for r.f. substitution measurements.

Referring to Fig. 6, both measure and reference paths contain three resistive attenuators variable in 10, 1 and 0·1 dB steps respectively. The u.u.t. is normally connected between ports E and F or G and H, i.e., in series with the measure attenuator. Measurements are made by balancing the measure channel against a fixed pre-set reference setting. The coaxial switch, used for comparing the output levels from the two channels, may be operated either manually, by a push button on the front panel, or automatically, by electronic circuitry in the level comparator.

Attenuators

The attenuators use modified commercial turret assemblies containing non-spiralled metal-film resistors mounted in cylindrical cavities. Considerable experimental work on contact materials coupled with extensive life testing was undertaken to obtain a constant low-resistance contact and, thus, ensure good repeatability of measurements and long life.

Extension spindles, fitted to the attenuators, operate switch wafers connected in the d.c. circuitry of the comparator. The additional switching functions so provided are:

(*a*) decimal outputs for digital indicators etc.,

(*b*) binary-coded-decimal outputs for data processing applications, and

(*c*) selection of d.c. correction networks to compensate for errors in the attenuators.

Thirty-six degree switch indexing is used in preference to standard 30° indexing as it is more compatible with the digital circuitry and, by obviating the need for end stops, permits direct progression from nine to zero, with consequent reduction of balancing time and attenuator wear.

Selected fixed resistors, which are fitted in the d.c. circuitry of the comparator after calibration of the attenuators, are used to correct for small errors in the attenuators.[7]

Coaxial Switch

In addition to meeting stringent return-loss and spurious-coupling requirements the coaxial switch must provide constant low contact-resistance coupled with long life under continuous high-speed operating conditions. The only element adequately fulfilling the latter requirements is the mercury-wetted reed relay. This has a quoted life expectancy of a least 10^9 operations, with contact resistance variations

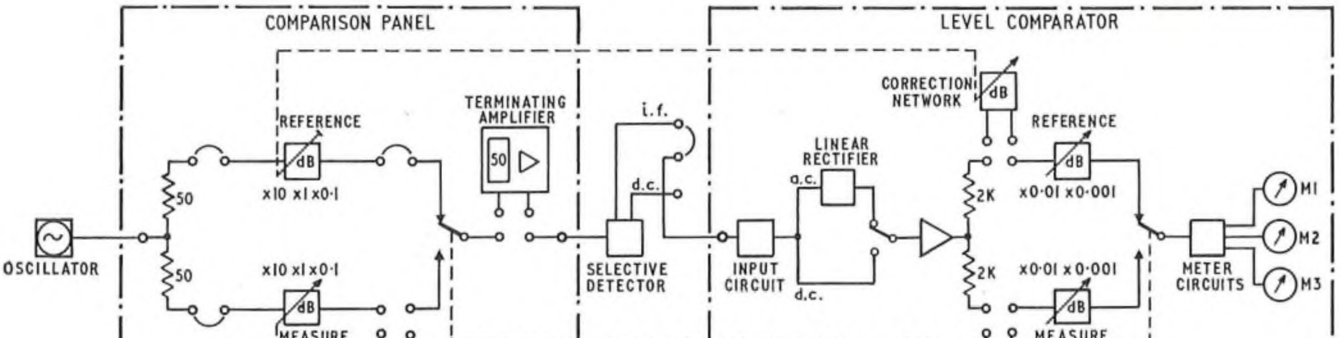

FIG. 5—Layout of measuring equipment

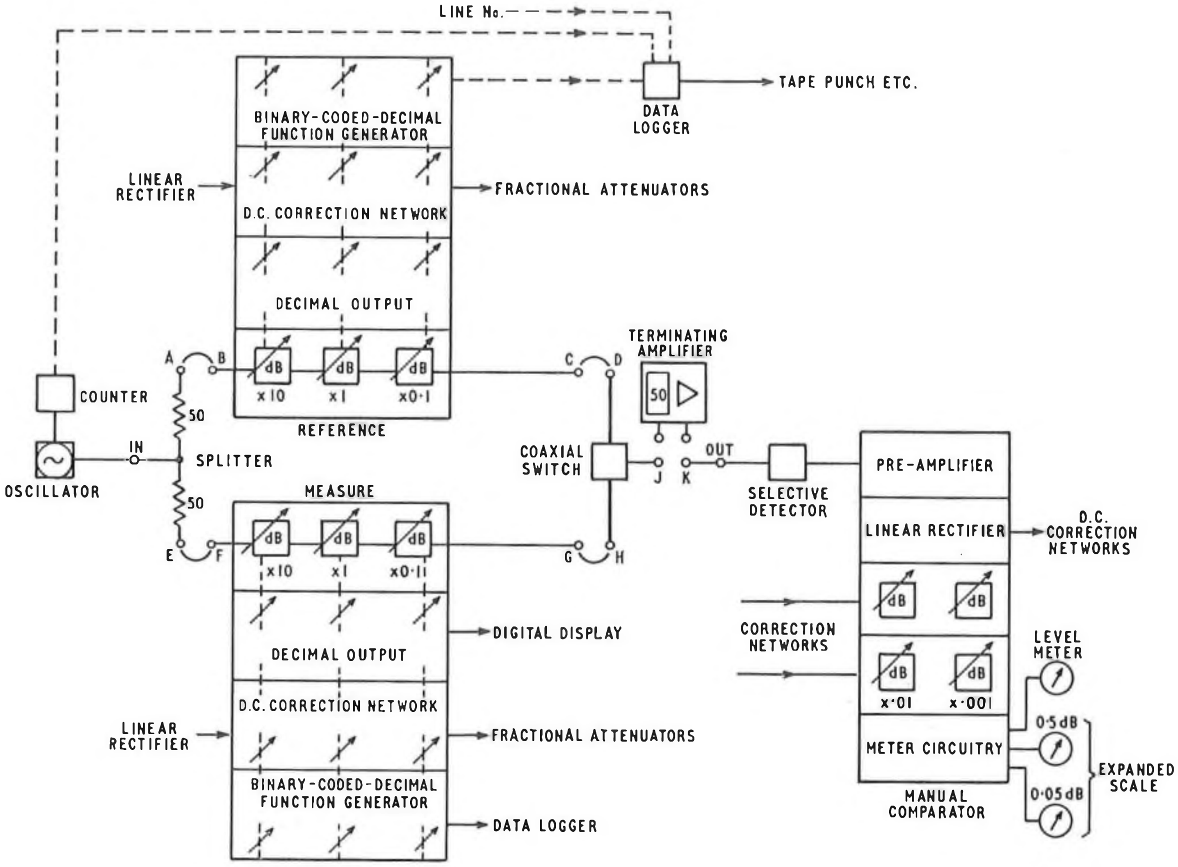

FIG. 6—Loss-and-gain measuring set (functional diagram)

less than 2 milliohms. Unfortunately, such relays have not been designed for high-frequency applications and the purpose of the present design is to obtain the necessary r.f. performance using available relays.

Connexion to the Unit Under Test

The design impedance of the comparison panel is 50 ohms and connexion to external circuits is via 50-ohm coaxial sockets on the front panel.

In the design, emphasis has been placed on the achievement of a high return-loss at each port with negligible spurious internal couplings. For precise work, these factors should not be significantly degraded in the inter-connexion between the panel and the u.u.t. Ideally, rigid 50-ohm airlines should be used, but in many practical situations flexible test leads are necessary, in which case precision double or triple braided cables need to be used. The return loss of such cables is rarely in excess of 30 dB and errors due to mismatch are reduced by the use of additional masking between the test leads and the u.u.t. For measurements on networks of impedance other than 50 ohms, the use of precision matching pads fulfils both the matching and masking functions. A range of 10dB matching pads has been designed for general use on submarine and inland coaxial systems. Over normal system frequency ranges these should yield return losses of the order of 50 dB.

Identical layouts have been used for the reference and measure channels and, as a result, they have closely matching frequency responses. In certain cases, it is advantageous to duplicate the test lead and matching-pad arrangements in both channels. With sufficient care it is possible, for most applications, to obviate the need for the usual calibration run for the leads.

Ancillary Units

A number of ancillary units have been designed for use with the comparison panel. These comprise:

(*a*) Plug-in terminating amplifiers to provide a precise 50-ohm termination to the equipment when connected to a selective detector which may have only a nominal impedance.

(*b*) A combining network used for the measurement of phase and group-delay by means of the Meyer method.[8]

(*c*) A plug-in unit to enable crosstalk loss of 160 dB to be measured in accordance with present coaxial-cable specification requirements.

General

Interconnexion between individual r.f. units in the comparison panel is by means of precision 14 mm coaxial airlines. Particular attention has been given to the elimination of spurious coupling within the comparison panel; heavy screening being used throughout.

A five-digit display is provided, with facilities for extinguishing either of the two least significant digits where not required.

An optional locking facility is provided to lock the reference attenuators at any chosen setting.

The comparison panel is temperature controlled, normally at 37·5°C (100°F), the temperature being sensed by a thermistor fitted in the attenuator assembly and indicated by a calibrated edge-meter on the face of the comparison panel. In the event of failure of the main controlling thermostat, a second series thermostat, operating at a higher temperature, takes over the control function and brings up an OVERHEAT alarm.

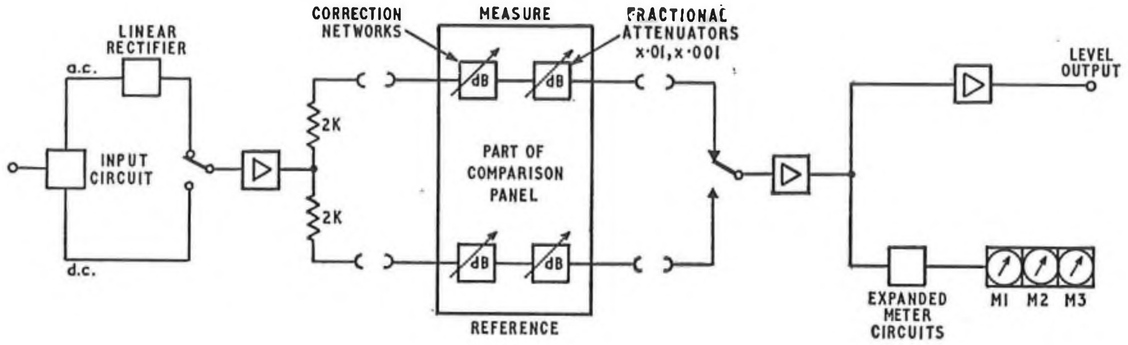

FIG. 7—Manual comparator

Level Comparator

The level comparator, which is the top unit in Figs. 1 and 2, processes the output signal from the selective detector to provide the final visual display.

The input circuitry (Fig. 7) accepts an i.f. signal from the selective detector in the range 1–100 kHz, or alternatively, a positive or negative d.c. signal. Where only higher frequency i.f. signals are available, it is necessary to provide additional frequency changing.

Operating levels are set by calibrated gain controls and i.f. to d.c. conversion is achieved by means of a high-linearity rectifying circuit.

The attenuator correction networks, sited in the comparison panel, are connected by flexible interconnecting leads. Also, in this part of the circuit, are the fine incremental step attenuators which provide interpolation between the smallest steps on the r.f. attenuators. To reduce switching complexity, only one resistor is switched in each d.c. attenuator network, sufficient loss being provided in the networks to maintain the resulting mismatch errors below 0·0001 dB.

Varying degrees of resolution between 0·001 and 1 dB are provided by the three level meters; the main meter M1 being calibrated between –20 and +3dB, the expanded scale (suppressed-zero) meters M2 and M3 between −0·5 and +0·5 dB and −0·05 and +0·05 dB respectively.

A buffered output is available for use with external sweep displays, XY recorders etc.

Alternating to Direct Current Conversion

Since there will normally be small differences between the r.f reference and measure levels at each balance point, it is essential that all processes in the a.c. to d.c. conversion are linear over the dynamic ranges involved. Care must be taken to ensure that all modulators and amplifiers in the chain are operated over linear portions of their characteristics. Rectification circuits in commercial selective detectors are unlikely to be sufficiently linear for precise applications, thus, an i.f. output should be used in conjunction with the high linearity a.c. to d.c. converter in the level comparator, wherever possible.

Corrected/Uncorrected Operation

The attenuator correction circuits have been provided for users not having access to a computer. However, where the equipment is used in conjunction with a computer it may be preferred to store the attenuator corrections and apply them as part of the computer program. To allow for either mode of operation, the attenuator correction networks can be strapped in or out of circuit by the insertion of a shorting plug in the appropriate socket. Selection of either mode is indicated by an illuminated legend on the front panel.

Circuit and Constructional Details

The components are mounted on double-sided plated-through fibre-glass printed-wiring boards, readily accessible for maintenance. Standard integrated circuits are used, together with a small percentage of discrete components. Switch contacts are duplicated, wherever possible, and switches are mounted inside dust covers to improve reliability.

AUTOMATIC ELECTRONIC DATA PROCESSING (E.D.P.)

Where large numbers of measurements are to be made, the use of e.d.p. facilities results in large savings in time and effort. Human error associated with manual logging and calculation is also removed.

A typical e.d.p. arrangement is as follows:

(*a*) a line-number generator for identifying each measured result,

(*b*) a data logger (or serializer) for accepting the b.c.d. outputs from the line-number generator, the frequency counter (or synthesizer), the comparison panel, the level comparator and other devices that may be involved in the measurement, such as temperature sensing devices, digital clock, or π point counters,

(*c*) a teleprinter, operating from the serializer, to provide a local printed record of the test results and a punched paper-tape for subsequent processing by a computer, and

(*d*) a graph plotter operating from the remote computer terminal.

A specification for a data logger for use with the loss-and-gain measuring system has been prepared and a number of commercial versions provided. The equipment serializes 32 of 44 × 4 wire b.c.d. characters and presents them at 10 characters/s in USASCII[9] code to a teleprinter. The data logger can be operated by local or remote command signals.

FURTHER DEVELOPMENT

In the development of the present loss-and-gain set, an effort has been made to reduce complexity of operation and time required to make a measurement. Typically, measurements to 0·001 dB resolution take several seconds, which compares favourably with indirect substitution equipments where the time per measurement may be of the order of minutes.

A semi-automatic level comparator sometimes known as a time-shared comparator has been developed by the B.P.O. and makes further significant reductions in the time and expertise required to make a measurement. The semi-automatic comparator has been produced in a fully compatible form and in an identical cabinet with that of the existing commercial manual level comparator already described, and the comparison panel may be used with either version.

Both digital and analogue display facilities are provided. The former are normally preferred for measurements at set frequencies, while the latter are more useful, for example, in investigating peaks and troughs in the frequency response of the u.u.t.

Using the semi-automatic comparator, it is only necessary to obtain a balance to within ± 0·99 dB, the remaining unbalance being measured digitally. The range of unbalance measured corresponds to the dynamic range of the integrator; when this is out of range the digital display is extinguished.

To make a measurement, the attenuators are adjusted to give a within range condition and the RECORD button pressed. This results in:

(*a*) integration of the unbalance signal for a pre-selected time period,
(*b*) combination of the processed unbalance signal in digital form with the b.c.d. outputs of the measure and reference attenuators,
(*c*) display of the net loss or gain result with appropriate sign,
(*d*) transmission of b.c.d. outputs to peripheral equipments, and
(*e*) generation of a FREQUENCY ADVANCE signal for use with programmable synthesizers.

The switching and integrate periods are locked to the mains frequency in order to eliminate errors due to spurious mains frequency components that may be superimposed on the measure signal during certain types of measurement. A choice of three switching speeds, corresponding to one, ten and a hundred mains periods is offered. This permits the measuring time to be optimized according to the dynamic range of the measurement, i.e. the signal-to-noise ratio of the received test signal. For most purposes, the fastest speed can be used and this results in virtually instantaneous operation of the meters.

The analogue display is similar to that of the manual comparator except that the expanded-scale meters, M2 and M3, indicate level difference between channels instead of absolute level.

Buffered outputs are provided for level and level difference for application to sweep or remote displays.

CONCLUSION

Considerable experience has been obtained from extensive laboratory and field use of the prototype equipments, amounting to six years continuous use for the first B.P.O. set and two years for the first commercial prototype.

During this time, numerous measurements have been made in connexion with such projects as the CANTAT 2 and TAT 6 submarine systems and 60 MHz f.d.m., 120 Mbit/s and higher speed digital systems. The equipment has proved extremely reliable in such diverse environments as laboratories, cable factories, field test-vans and cable ships. Crosschecks made at national standards level and with precision equipments developed by Bell Laboratories indicate that the target specifications have been adequately realised.

Where the equipment has been used in conjunction with a computer, the uncertainty of measurement has been very considerably improved by storage of attenuator frequency corrections in the computer program. As the equipment has a very high degree of repeatability, the uncertainty of measurements then corresponds closely with that of the original national standards calibration source. In this way, the accuracy of the equipment up to 1 GHz has been made to correspond with that of the best available indirect-substitution equipments, whilst retaining the advantages of speed and simplicity of the direct-substitution equipments.

Compared with earlier equipments, a reduction of measuring time of about 90 per cent has been achieved and in a side-by-side comparison on submarine cable tests there was little difference in time taken to complete a frequency run between the B.P.O. set and two computer-controlled equipments.

ACKNOWLEDGEMENTS

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The 60 MHz F.D.M. Transmission System: Civil Engineering Requirements for the Cable Route

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U.D.C. 621.315.232: 621.315.212: 621.394.44.029.62

For the 60 MHz f.d.m. transmission system, the duct and cable must be routed so as to minimize the risk of accidental damage. The ducts and associated civil engineering works, which are described, are planned to give the protection required.

INTRODUCTION

One of the essential requirements of a high-integrity communication route, such as the 60 MHz coaxial-cable system, is that once installed it should be free from interference of any kind. Duct and cable laid in footpaths and roads, although protected from many hazards, are still very vulnerable to damage.

The conditions for placing duct in the ground for local, junction and trunk-network cables are, basically, governed by the mechanical strength of the type of duct used, the width and depth of excavation, whether there is sufficient room, and the need to keep costs to a minimum. The British Post Office (B.P.O.) does not have exclusive rights to lay duct in footpaths and roads, and has to share the available space with other statutory undertakers;* in addition, there are drainage and sewerage networks, and other miscellaneous services.

The activities of statutory undertakers, installing new plant and maintaining existing plant, and local and highway authorities undertaking roadworks etc., continually put B.P.O. plant at risk. It therefore becomes necessary to consider new minimum standards of construction and the use of different routes to ensure the security of the coaxial cables used on the 60 MHz project, and the plant for other high-capacity/high-integrity routes.

NEW STANDARDS

An initial consideration was to continue to use the existing routes of roads (and the footpaths alongside them) but place B.P.O. plant at a greater depth. Evidence of damage to B.P.O. duct and cable in the past has shown that the majority of damage occurs in the first 0·9 m from the surface. Therefore, it was decided that the minimum depth at which the duct should be laid was 1·2 m although it was realized that damage, on a much reduced scale, can still occur at this depth and the process of laying the duct at extra depth is more costly.

Complementary to laying the duct at the increased depth, consideration was given to making the routes for the 60 MHz system a *dedicated* route i.e. a route on which the duct and associated jointing chambers would be laid separately from local, junction and trunk cable routes and remain for the exclusive use of coaxial cables for the 60 MHz system. The main objection to this proposal was that the B.P.O. would be occupying yet more space in already-congested footpaths and roads. Nevertheless, this concept has been adopted.

NEW ROUTES

Alternatives to footpaths and roads have not been seriously considered for duct routes in the past, primarily because of wayleave difficulty. The desire, however, to find a route uncluttered with other undertakers' plant and reasonably free from interference or damage resulted in the B.P.O. giving thought to other routes such as canal towpaths, railways and across country.

There still exists in the United Kingdom an extensive canal network, but, preliminary surveys showed that the canals are far from straight and that a number of ductlaying problems were likely to arise at locks, basins, bridges and intersections. Although not insurmountable, these would need solving and could be costly. In addition, the gas and electricity authorities have already taken the opportunity of laying their plant in the canal towpaths and its presence could present problems at a number of locations.

Motorways, which probably offer the best path for trunk cables, are excluded from B.P.O. use by the Highways Act of 1971.

Railway routes have been surveyed and some could have application for 60 MHz cable purposes. The main advantages of a railway route are that it can afford a direct path with the minimum of deviations, either vertically or horizontally, for the duct. Furthermore, only one wayleave has to be negotiated and there should be less risk of interference or damage to B.P.O. plant. One disadvantage would be the need to adopt a strictly-controlled safety code of practice for staff working in the railway environment.

DUCT

At the present time, the B.P.O. uses p.v.c. duct, having internal diameters of 51 mm, 89 mm and 102 mm, and earthenware duct, which has an internal diameter of 92 mm; all are intended for use by cables in various diameters up to 72 mm. The 18-pair 2·6/9·5 mm coaxial cable for the 60 MHz system will be the largest cable in use, and can have a maximum diameter of 78 mm. This, together with the maintenance requirement of sufficient space within the duct to use thin nylon rods with a "sniffer",[1] to detect leaks of air from the

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† Operational Programming Department, Telecommunications Headquarters.

* Statutory undertakers—a term embracing all those bodies empowered to provide public services in excavations on highways; it includes water, gas and electricty services as well as the B.P.O.

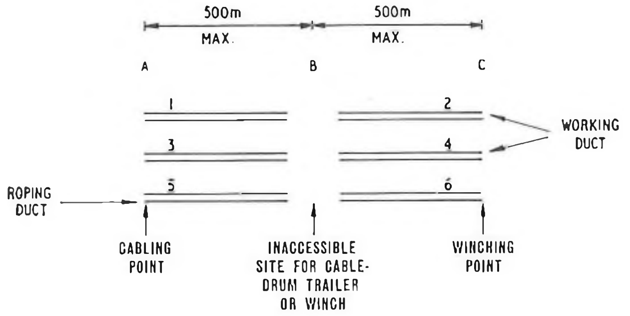

FIG. 1—Arrangements for cabling through an inaccessible amplifier point or jointing point

cable sheath, has resulted in the need for a duct with a larger internal diameter.

The minimum acceptable internal diameter to accommodate the cable and the sniffer, which is approximately 19 mm in diameter, is 102 mm. Existing p.v.c. duct of 102 mm internal diameter has a wall thickness of 3·4 mm and, at the varying depths the duct will be laid on the 60 MHz project, would not be strong enough to withstand earth pressures and traffic loads without distortion or damage. The duct chosen for 60 MHz routes is standard 102 mm Class C p.v.c. water pipe which has, in fact, an internal diameter of 105 mm. Its wall thickness is 4·5 mm and it is manufactured in lengths of 3 m and 6 m. Jointing is by means of spigot and socket; the 6 m length has a 102 mm socket formed at one end and, for reasons outlined later, the 3 m length has sockets formed at both ends.

The natural minimum bending radius of a 6 m length of 102 mm p.v.c. duct is approximately 14 m which does not easily permit small deviations in the line of route when obstructions are encountered. Therefore, 102 mm pre-formed p.v.c. bends, approximately 1·2 m in length and 5·1 m radius, have been introduced.

Where there is a risk of damage, e.g. because of the need to reduce the depth of cover, the p.v.c. duct will be replaced by 102 mm internal-diameter mild-steel duct.

The 102 mm mild-steel duct in current use is internally coated with bitumen compound and externally clad in high-density polyethylene. The coefficient of friction of the internal lining to polyethylene-sheathed cables is almost twice that of p.v.c. duct; the introduction of steel duct into sections of the route containing p.v.c. duct would, therefore, increase the cabling tensions and could result in a reduction of the cabling lengths and, possibly, require additional manholes and joints. It therefore became apparent that there was a need for a steel duct with an improved internal coating which gave a coefficient of friction comparable to p.v.c. duct.

Following discussions with manufacturers, a new lining of epoxy red-oxide paint has been successfully tested and introduced; it has a coefficient of friction to polyethylene-sheathed cables almost the same as that of p.v.c. duct and has improved protective qualities over the existing bitumen lining. The cost of the new steel duct is approximately 18 per cent greater than the bitumen-coated steel duct but this increase is less than the cost of any alternative method necessary to obtain maximum cabling lengths.

Normal practices, as outlined in standard specifications, are employed for jointing and laying of both p.v.c. and steel duct. Where it is necessary to joint p.v.c. duct to steel duct a satisfactory joint is made when the spigot of steel duct is jointed to the socket of p.v.c. duct; a lapping of p.v.c. tape is required, however, on the spigot of p.v.c. duct when jointed to the socket of steel duct. A final lapping of p.v.c. tape with a 50 per cent overlap is placed on each p.v.c.–steel duct joint.

One requirement for the 60 MHz system duct route is that all jointing chambers and duct should be, as far as possible, free from water; therefore, all duct entering jointing chambers will be sealed. Due to the high pre-manufacturing costs of an injection moulding for a caulking gland for the 102 mm p.v.c. duct, it has been decided to use caulking disks and compound. This arrangement requires that all duct shall terminate in jointing-chamber walls with a socket; a disk is placed inside and against the shoulder of the socket, the socket is then tightly packed and slightly overfilled with a compound, and a second disk forced home in the socket until recessed approximately 10 mm. A draw-rope will be left in every bore and secured to the back caulking disk. To provide a satisfactory seal between the duct and the concrete of the jointing chamber wall, the outside of the p.v.c. duct socket is coated with a solvent compound, rolled in sand and cast in the wall of the jointing chamber during construction.

The requirement that all duct should terminate with a socket in all jointing chambers necessitates either a double-socketed length of duct or a connecting sleeve for every duct section. In addition, there is the need for 1·5 m lengths of p.v.c. duct for laying duct in tunnel headings, negotiating difficult sections or where only short sections of trench may be open at a time. To meet these requirements, 5 per cent of all duct manufactured will be in 3 m lengths with a socket formed at both ends; one of these cut in half gives two 1·5 m single-socketed lengths.

DUCTLAYING

Duct routes for 60 MHz purposes will normally consist of two duct ways. However, where it would be impossible to provide an overground route for interruption cables (such as road crossings) to maintain service whilst cable faults are cleared, additional duct ways will be provided for maintenance purposes. The maintenance duct will, usually, be laid from jointing chamber to jointing chamber but sometimes it will only be laid for the affected section and then both ends of the duct will be terminated with a socket, sealed with caulking disks and compound, and marked on the surface. To assist the maintenance engineer in identifying the correct working duct and cable, when repairs are necessary, the duct will be two colours, light grey and black.

Surveys undertaken to date have shown that there are a number of locations where there will be difficulty in getting the cable-drum trailer and/or the cable winch to the site of an amplifier point (a.p.) or jointing point (j.p.). A way of overcoming this problem is to provide an additional duct (or make use of any maintenence duct) for roping purposes between the inaccessible a.p./j.p. and the j.p./a.p. on each side (Fig. 1 refers). This arrangement enables the cable drum and the cabling winch to be set up at points A and C respectively and to cable through point B. The procedure is:

(*a*) Pull in the first length BC—ducts 1 and 2 used.
(*b*) Pull in the first length AB—ducts 1 and 4 used.
(*c*) Pull in the second length BC—ducts 3 and 4 used.
(*d*) Pull in the second length AB—ducts 3 and 6 used.

Duct 5 is provided in case the cable drum and cabling winch positions are reversed.

The 1·2 m depth of excavation for duct-laying results in a wider trench than would be required for a lesser depth and, to give the maintenance engineer easier access to the duct and cable for repairs, the ducts will be laid with the maximum separation afforded by the trench. Each separate duct formation in the trench will be maintained in its appropriate colour throughout the whole route.

A British Standard Institution sub-committee has for some time been discussing methods of identifying buried plant and the responsible undertaker; the agreement so far is that embossed or engraved lettering would be used on p.v.c. duct and buried plastic-sheathed cables. In addition, colours may be used as added identification; the colour agreed for B.P.O. plant is green and it has been decided that a

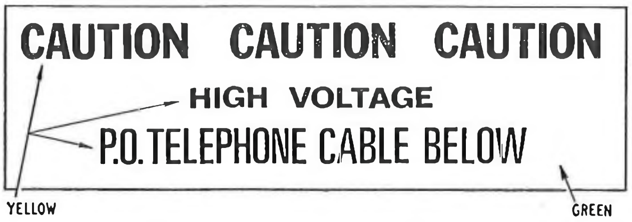

FIG. 2—Marking tape with legend

marking tape of this colour should be placed directly above the 60 MHz system duct at an approximate depth of 300 mm below ground level. The marking tape is heavy-gauge polyethylene film, 150 mm wide and 0·1 mm thick, highly resistant to acids, alkalis and other soil components, and having high tensile strength. The tape colours are opaque and permanent, and the green is overprinted in yellow with the legend shown in Fig. 2. A typical layout for two working ducts, two maintenance ducts and the marking tape is shown in Fig. 3.

The 60 MHz system duct-routes in footpaths and roads are considered to be standard in that the majority of the problems that are expected to arise are likely to be similar to those normally encountered and can be dealt with by current practices. Other routes could pose problems e.g. crossings of rivers, streams and canals, land drains, wooded areas, steep inclines and marshy ground.

In addition, vehicle access will be required to every amplifier and jointing point, and sufficient room, and possibly hard standing for cabling, testing and maintenance vehicles.

Railways are largely free from undertakers' plant and duct could, therefore, be laid with reduced depth of cover (750 mm). The duct would still be in two colours, with maximum separation and marking tape; where the depth of cover was less than 750 mm, the p.v.c. duct would be replaced by steel duct. To maintain the safety of the railway track and ensure the safety of all personnel requiring to work on the cable, any B.P.O. plant would, generally, avoid the immediate vicinity of the track.

JOINTING CHAMBERS

The following types of jointing chamber will be used:

(*a*) *Amplifier Manhole:* a rectangular manhole (modified M.R.11) designed to house two repeater cases,[2] one adjacent to each side wall. A non-standard frame and cover with an entrance hole 760 mm square will be fitted so that the repeater case can be lowered safely into the manhole without risk of damage.

(*b*) *Jointing Manhole:* a rectangular manhole (modified M.R.2 or standard M.R.11) to house a maximum of four (M.R.2) or eight (M.R.11) 2·6/9·5 mm coaxial-cable joints; a maximum of four joints per side wall.

(*c*) *Turning Manhole:* a triangular manhole (modified M.R.T.9) designed to turn the route through 90° and accommodate a maximum of eight cables and joints.

(*d*) *Turning and Lead-in Manhole:* a double-triangular manhole (modified M.R.T.8) for lead-in purposes to terminal and power-feed stations, providing accommodation for turning and through cable routes and cable joints; a maximum of four coaxial cable joints per wall.

(*e*) *Amplifier Joint-Box:* a rectangular, non-standard, prefabricated, reinforced-concrete joint-box, approximately, 1 m × 1 m × 3 m long with 18 concrete covers, suitable for direct burial.

(*f*) *Buried Repeater Housing:* a non-standard pre-fabricated mild-steel cylinder, 1·8 m in diameter and 2 m internal height. It has a square steel base plate welded into position at one end, and a submarine-type entrance hatch at the other end. The duct entries are parallel to one side of the base plate and offset from the centre by approximately 450 mm.

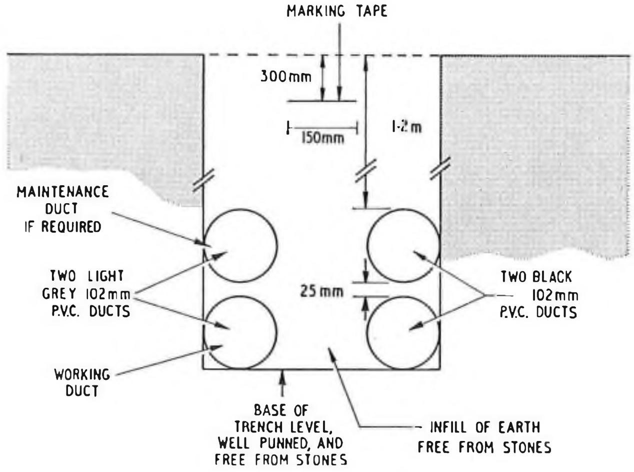

FIG. 3—Cross-section of trench

MISCELLANEOUS CONSIDERATIONS

As has been stated in another article,[2] the repeater case will be manufactured from an aluminium alloy and will be protected overall with a nylon coating. As the possibility of water entering the manhole and the possibility of damage to the nylon coating of the repeater case cannot be discounted, sacrificial anodes will be installed at all amplifier positions to protect the repeater case from corrosion and provide an adequate earth. Magnesium-alloy anodes will, therefore, be provided at all amplifier points on the basis of two per repeater case. To keep excavation costs to a minimum, the anodes will be placed 1 m from each end of the jointing chamber and 300 mm beneath the duct. The anode leads will be housed in 19 mm polyethylene duct and taken direct to the amplifier case, where manholes are constructed, and via a link box fixed to a marking post, where pre-fabricated concrete joint boxes are installed; the latter arrangement permits check of the current flow without the need to excavate the top soil to gain access to the amplifier.

Some situations will require the use of auger-boring techniques, subject to acceptable ground and on-site conditions. Auger-boring involves pushing a steel pipe through the ground from a thrust pit to a receive pit. A rotating cutting head leads the pipe by 50–75 mm and a rotating auger moves the spoil from the head of the pipe to the thrust pit.

The size of the thrust pit is dependent upon the type of machinery and the length of steel pipe sections used; the normal dimensions range from 5 m long by 3 m wide and approximately 1 m deeper than the depth of cover on the steel pipe, to 8 m long by 4 m wide. The receive pit is usually 2 m square and the same depth as the thrust pipe. When each section of steel pipe has been pushed into the ground, the next section of pipe is lowered into the thrust pit, welded into place and pushing recommences.

Auger-bore methods would also be used to lay duct beneath rivers and canals. As in all the above situations, a 300 mm internal-diameter mild-steel pipe would be installed, a minimum of three 102 mm p.v.c. ducts placed inside it, and any remaining space filled with 89 mm or 51 mm p.v.c. duct or both. If necessary, the interstice of the duct, and the space between the duct and the inside wall of the steel pipe will be filled with a sand/cement or pulverized-fuel-ash/cement mix.

The proposed 60 MHz system routes are expected to encounter areas where there is a high ground-water table. Ground water is one of the biggest problems encountered when ductlaying and when working in jointing chambers. Therefore, all duct and jointing chambers will require particular attention at the works stage to ensure they are watertight on completion. In locations where the water table is high, the best results are obtained if all groundwater is removed or immobilized during ductlaying and construction of the jointing chambers.

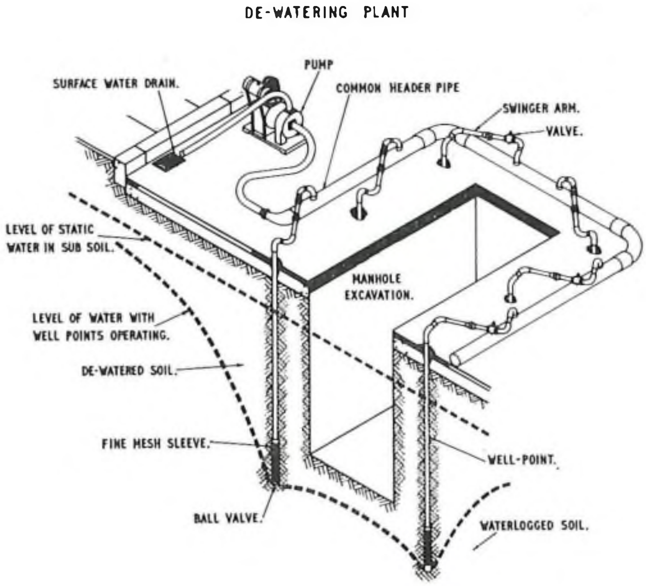

FIG. 4—Ground de-watering

Pumping equipment can satisfactorily remove the groundwater normally encountered in duct and jointing-chamber excavations. Where the level of the groundwater is high and normal pumping will not cope, ground de-watering is necessary. This involves sinking into the area adjacent to the excavation a number of well points with very fine sieves to prevent the removal of fine particles of the sub-soil, linking them together and connecting them to a high-capacity pump; the water is then discharged into a suitable outlet such as river or a drain. (Fig. 4).

There are locations where the use of ground de-watering plant is dangerous, such as when buildings or embankments are close to the excavation. In such cases, chemical consolidation or ground freezing of the area outside the excavation may be required. The basic action of the latter two methods is to create a barrier to prevent water entering the work area. Both methods are, however, very costly.

The introduction of new duct, new jointing chambers, new practices, and change of standard depth of cover on duct to 1,200 mm will require new specifications, drawings and amended contract documents. Prior to the commencement of any ductwork, it will be necessary to inform all ductwork contractors and B.P.O. ductwork supervisors of the changes and new practices. It is proposed to hold a number of one-week courses at the Technical Training College at Stone, Staffs for B.P.O. staff; the syllabus will include the majority of points raised in this article and other relevant information.

CONCLUSION

The need to make the cable and duct for the 60 MHz system free from interference requires improvements to existing working practices. Those described in this article may well form the basis for many new systems to be provided in years to come.

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[1] WALTERS, J. R. The 60 MHz F.D.M. Transmission System: Cable Maintenance (in this issue, p. 198).

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Book Review

"Transistor Circuits in Electronics." 2nd Edition. S. S. Haykin, B.Sc., Ph.D., D.Sc., M.I.E.E., and R. Barrett, B.Sc., C.Eng., F.I.E.E. The Butterworth Group. 367 pp. 356 ill. £2·50 (limp), £3·80 (cased).

The first edition of this book was published in 1964, when transistors had already been commercially established for some time. They had, by then, taken over the functions of thermionic valves and basic forms of circuits using this form of semi-conductor were already virtually stereotyped. The authors were then both lecturing to engineering students, the former in the University of Manchester, Hamilton, Canada, and the latter at Hatfield Polytechnic, and like many other teachers of engineering had no doubt been worried by the lack of a good text book on transistor circuit technology suitable for engineering students. So they produced a book giving a comprehensive coverage of basic transistor circuitry that comprises most of the day-to-day transistor applications. This is a restricted field that had not been adequately covered for engineering students who needed a book on circuitry applications rather than physical explanations of theories of semi-conductor operation.

The authors, in their preface to the second edition of this work, make it clear that they have seen no need to change the original presentation. However, the recent commercial appearance of microelectronics and the perfection of single-wafer silicon and diffused-planar techniques for the production of microelectronic monolithic circuits has led to new concepts of transistor circuitry. As a result, additional material was necessary to bring the original book up-to-date. Chapter 10, on integrated circuit techniques has, therefore, been added in the second edition. In this new chapter, are simple clear descriptions of planar process for forming monolithic integrated circuits on a slice of silicon. The photo-resist process is described and also the diffused-planar process in which bipolar transistors are formed as part of an integrated circuit. The field-effect transistor and the construction of metal-oxide semi-conductor transistors are outlined.

Chapters 1–9 of the book comprise the first edition which is now too well known to need detailed comment. The first chapter contains a brief conventional account of the simple physics of transistor operation. Successive chapters develop the theory of transistors through equivalent circuits using h- parameters, and so analyze most of the basic types of circuit including multi-stage, negative feed-back amplifiers, switching and logic circuits, modulators and demodulators.

This second edition has a wide coverage and provides a good text book for telecommunications and electronic engineering students at H.N.D. or even degree level.

The book is well prepared and presented and the text is illustrated with very clear diagrams.

C. F. F.

The 60 MHz F.D.M. Transmission System: Cable Installation

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U.D.C. 621.315.22: 621.315.232

The decision to provide new trunk routes based upon the use of multi-pair 2·6/9·5 mm coaxial cables has necessitated a review of existing installation techniques and the development of new methods. The mechanical aspects of the cable design are considered and the proposed methods of cable handling are given in some detail.

INTRODUCTION

The concept of using a large and heavy cable for a dedicated route embracing carriageway, footway, cross-country and other environments has raised many installation problems. Some involve the redesign of plant and equipment while others require changes to current cabling practices. This article reviews the mechanical properties of the new multi-pair 2·6/9·5 mm coaxial cables, describes various laboratory tests and field trials which have been made and shows how the experience so gained has led to the development of appropriate methods of cable installation.

USE OF DUCT

Initially, cable installation by the direct burial of a suitably armoured cable was considered, using either moleploughing techniques or conventional trenching methods. However, economic studies indicated that direct burial, in this particular application, would not offer significant savings over duct, especially as it was envisaged that a second cable, over the same route, would probably be required at a later date. Additionally, mechanical tests on various ducts and cables had shown that duct offered comparable protection to armouring, and route surveys showed that there would be little scope for direct burial in long continuous lengths. For these reasons, it was decided that ducted cable rather than armoured cable would be used and that cabling and duct work would take place as two distinct operations.

The ducted cable will, however, be treated as a directly-buried one for maintenance purposes and this implies repairing faults *in situ* rather than renewing faulty lengths of cable.

MECHANICAL FEATURES OF THE CABLE

The design of cable chosen for the project has been adequately described elsewhere[1] and Table 1 shows the important mechanical features.

TABLE 1

2·6/9·5 mm Coaxial Cable

Number of Pairs	Weight (kg/m)	Maximum Overall Diameter (mm)
18	10·3	78
8	5·9	54
6	4·5	46

The following points are of special interest.

(*a*) The cables have a high tensile strength when the load is evenly distributed between the conductors.

(*b*) The coaxial pairs are susceptible to damage should the cable be bent excessively or crushed.

(*c*) The 18-pair cable is large in diameter in relation to the standard British Post Office (B.P.O.) duct.

To establish the limiting parameters for the installation of the cable, a number of laboratory tests were performed to determine the tensile, bending and crushing characteristics. It was apparent that the design itself was sound but that all aspects of handling would have to be carefully controlled in order to avoid damage which, although slight, might cause significant degradation of the electrical performance of individual coaxial pairs.

Cable Sheath

Experience has shown that plain lead sheathing is comparatively simple to extrude but is liable to fatigue failure when subjected to vibration as, for example, on a bridge. In these conditions, a sheath of lead alloy B (99 per cent lead, 0·95 per cent antimony, 0·01 per cent tin and 0·04 per cent other materials) is to be preferred. Although more difficult to extrude, this alloy has a greater resistance to fatigue stress and is less prone to creep. Furthermore, it is less susceptible to crushing.

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CABLING IN TUNNELS

Access to tunnels for cable installation may be difficult. Sometimes, direct cabling may be possible, but often, cable drums will have to be lowered to tunnel level by lift so that individual cable lengths will be limited by lift capacity. For this reason, it is intended to provide a 6-pair cable so that an 18-pair route can be split into three separate cables, thus avoiding the multiplicity of coaxial-pair joints which the use of short lengths of 18-pair cable would involve. It will be prudent to use lead alloy B sheathing for tunnel cables rather than plain lead as a lead alloy B sheath is less susceptible to damage in handling and less prone to long-term crushing on cable bearers.

PULLING EYE

For the new 2·6/9·5 mm coaxial cables, the need for some kind of pulling eye to replace the existing braided-steel stocking was recognized. An effective moisture seal was essential and it was realized that a properly-designed pulling eye fitted to each cable length in the factory could be used to form a pneumatic seal so that it was possible for cables to be delivered to site under pressure. Some years ago, a pulling eye was devised for polyethylene-sheathed cables and it has been fully described.[2] This design has been adapted for use with the 2·6/9·5 mm coaxial cable and the component parts are shown in Fig. 1. The essential feature is a tapered nylon pin. A cross section of a completed fitting is shown in Fig. 2.

The cable end is first cut off at right angles and dressed back to its circular shape. The polyethylene oversheath is then cut back from the end to expose the lead. Using a hollow tube, the polyethylene disks of each coaxial pair are then pushed back along the cable to allow the pairs to collapse when the nylon pin is driven in. The disks then form a block for the resin.

The nylon pin is then driven into the centre of the cable end and the coaxial pairs are distributed around the steel shank of the nylon pin. The resin filling is next mixed and used to fill the exposed coaxial pairs and the air space in the cable end to the level of the lead sheath. Whilst the resin is still fluid, the lead sheath of the cable end is dressed into a conical shape to fit inside the tapered collar which is then fitted over the sheath. The resin is topped up to the top of the collar and the washer and nut fitted to the steel shank of the nylon pin. The nut is then tightened against the washer to draw the pin back into the collar and the whole fitting is left for 24 hours to allow the resin to cure. During the fitting operation, the cable end must be supported vertically to prevent spillage of the resin.

Tensile tests on short lengths of 18-pair cable, fitted with pulling eyes in this manner, have given consistent values in excess of 40 kN without failure and repeated loading up to 40 kN (200 repetitions) has shown no disturbance of the resin filling or fracture of the component parts.

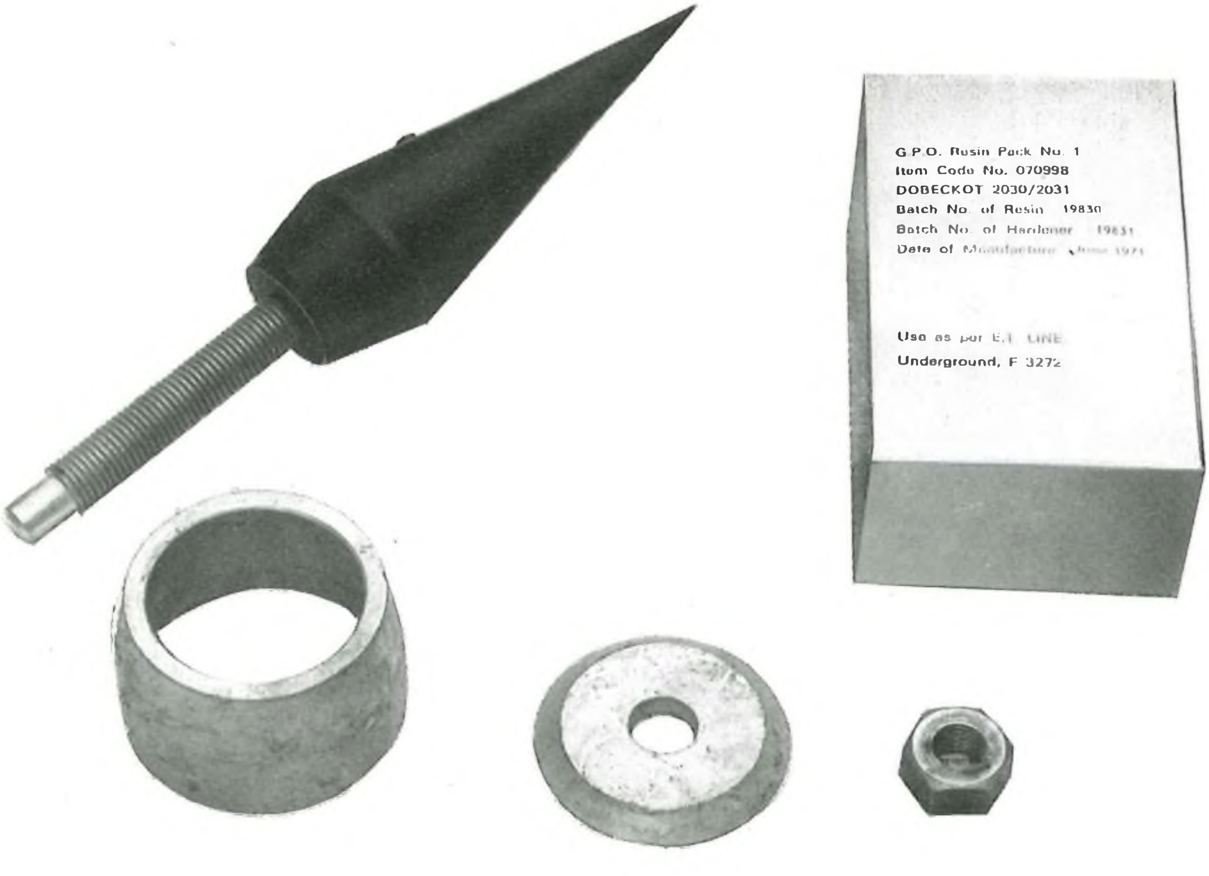

FIG. 1—Component parts of pulling eye

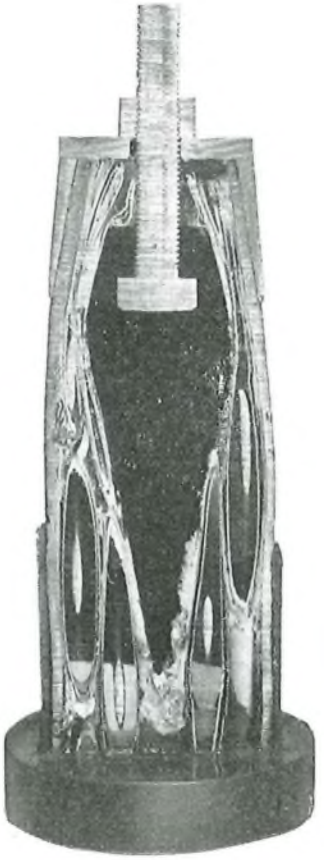

FIG 2—Cross-section of pulling eye fitted to an 18-pair 2·6/9·5mm coaxial cable

CABLE LENGTHS

Preliminary calculation and experiment indicated that individual lengths of 18-pair cable would have to be limited to 250 m unless some kind of lubricant were used. It was, therefore, apparent that the successful development of an appropriate lubricating technique would lead to considerable financial savings by reducing the number of joints in any 1,500 m repeater section. In any case, the use of the minimum number of joints was seen to be desirable for reasons of reliability and cost, although the introduction of a new and improved jointing technique[3] has made this aspect less significant than was at first thought.

A slurry of talc and water was in widespread use at the time for lubricating local network cables, but laboratory tests had suggested that liquid paraffin (medicinal grade) would be just as effective and more easily handled. Experiments in the laboratory with short lengths of cable showed that it should be possible to pull in 500 m lengths of 18-pair cable, without trouble, provided liquid paraffin was used as a lubricant.

Installation of a cable at Marlborough, Wiltshire, provided for a field trial of the new 60 MHz f.d.m. transmission system, presented the opportunity of proving the practicability of 500 m lengths and a controlled experiment was carried out in 1970 to confirm the calculations.

The part of the route chosen for the experiment is shown in Fig. 3, and it was necessary to draw through an intermediate manhole to allow for a 500 m length of cable. The duct had been previously lubricated with liquid paraffin and more paraffin was sprayed on the cable as it entered the duct. Despite the fact that this part of the route was on a rising gradient of about 1 in 20 and was not entirely straight, the pulling tensions observed were very close to those predicted and well within the allowable limit for the cable. Use of

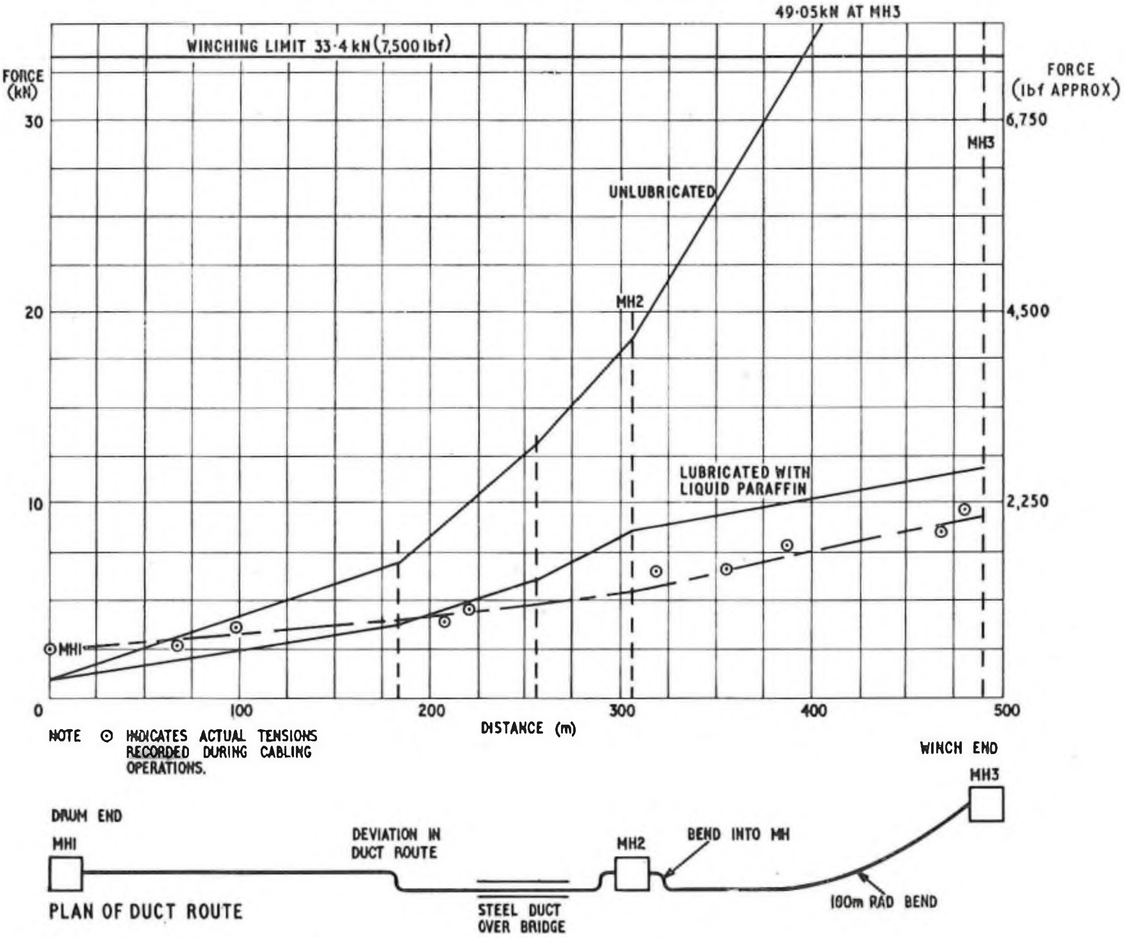

FIG. 3—Marlborough field trial graph showing pulling tensions

FIG. 4—Lubricating brush and storage container

500 m lengths was, thus, seen to be a practical proposition, although it was realized that the method of lubrication would need to be improved. This experiment showed that the use of 750 m lengths would be possible, but it was recognized that the consequent saving of one joint in each 500 m repeater section would not compensate for the extra cost of the special plant which would be needed for handling 750 m lengths of cable.

The results of this experiment, together with further laboratory assessments, formed the basis of the recent successful installation of 700 m lengths of cable in polyethylene ducts laid beneath the bed of Beauly Firth.[4]

DEVELOPMENT OF LUBRICATION TECHNIQUES

There are various methods of applying lubricant to a ducted cable and they fall into two distinct categories which are

(*a*) application of lubricant to the cable as it enters the duct, and

(*b*) application of lubricant to the duct before cabling commences.

Each of these techniques has been assessed in relation to the new 2·6/9·5 mm coaxial cable and a combination of both methods was used for the first cable lengths installed at Marlborough. For later ones, it was found that lubrication of the duct itself was quite sufficient. This was done by passing a pad of cotton waste soaked in liquid paraffin through the duct bore—a comparatively crude procedure, but necessary to prove the possibility of the method.

In the event, a horsehair brush as shown in Fig. 4 replaced the cotton pad. Each brush is supplied in a storage container in order to minimize the handling of the lubricant-soaked brush. The method of using the brush is fairly simple and requires little or no modification to the normal cabling procedure. The brush is connected between the drawrope and the cabling rope and is automatically pulled from its container, previously filled with liquid paraffin, as the cabling rope is pulled into the duct, as shown in Fig. 5. On reaching the far end, the brush is removed and dropped into a second similar container already charged with liquid paraffin ready for re-use. Thus, in one operation, the wall of the duct is lubricated and a winch rope is provided ready for pulling in the cable.

A single charge of liquid paraffin is sufficient to lubricate some 550 m of duct. There is little, or no, spillage of lubricant and the technique has been found acceptable to the staff. Use of this method of lubrication is now being extended to the remainder of the cable network and it has already been shown to be particularly effective when a new cable is to be drawn over others already occupying a duct. A range of brush sizes will be necessary to cover all requirements.

EFFECT OF DUCT ALIGNMENT

Whatever the type of cable, the kind of duct or the lubrication method adopted, the acceptable pulling length depends upon the duct alignment. In general, the presence of deviations increases the pulling tension. The planner must, therefore, take the alignment of the proposed duct route into account when determining the acceptable length of cable between any two jointing points. Each individual case could well involve tedious calculations and, in order to simplify the task of the planner, a guide has been prepared by which the effect of deviations can be assessed rapidly.

EXPERIENCE AT MARLBOROUGH

The installation of 6·75 km of 18-pair 2·6/9·5 mm coaxial cable in Duct No. 54 at Marlborough, in 1972, provided valuable experience in handling the new cable. The route was partly in footway, partly in grass verge alongside the carriageway and partly across cultivated land. As each length of cable was drawn in, the pulling tension was recorded and compared with the forecast which had been calculated from a knowledge of the duct alignment.

The main points which emerged from the Marlborough installation were that

(*a*) the pulling eye was entirely satisfactory,

(*b*) the method of lubricating the duct was effective,

(*c*) accurate calculations of probable pulling tension were possible given detailed information of duct alignment,

(*d*) it was a practical proposition to use flexible guides, up to 30 m long, to allow a cable drum to be placed some distance from the entering manhole and so remote positioning of a cable drum would be possible in cases where direct access is difficult, and

(*e*) wooden drums were not sufficiently robust to withstand the harsh treatment received during cross-country operations.

REQUIREMENTS FOR NEW CABLING PLANT

As a result of experience gained at Marlborough, it was recognized that new cabling plant would have to be developed to cater for the problems of using the 18-pair 2·6/9·5 mm coaxial cable on routes which were not entirely along the public highway. The essential requirements included a new winch unit, a new cable drum and trailer, a long flexible cable guide and a method of assessing accurately the length of an existing duct line without reliance on surface measurements. These requirements are detailed below.

Winch unit

The winch unit should consist of a cross-country vehicle, preferably with four-wheel drive, having large wheels and tyres with low values of ground pressure. The vehicle should be fitted with a winch capable of providing a tension of 35·5 kN and containing 550 m of flexible steel rope. Storage facilities for cabling odds and ends will be required and the provision of a compressor and ductmotor will be necessary

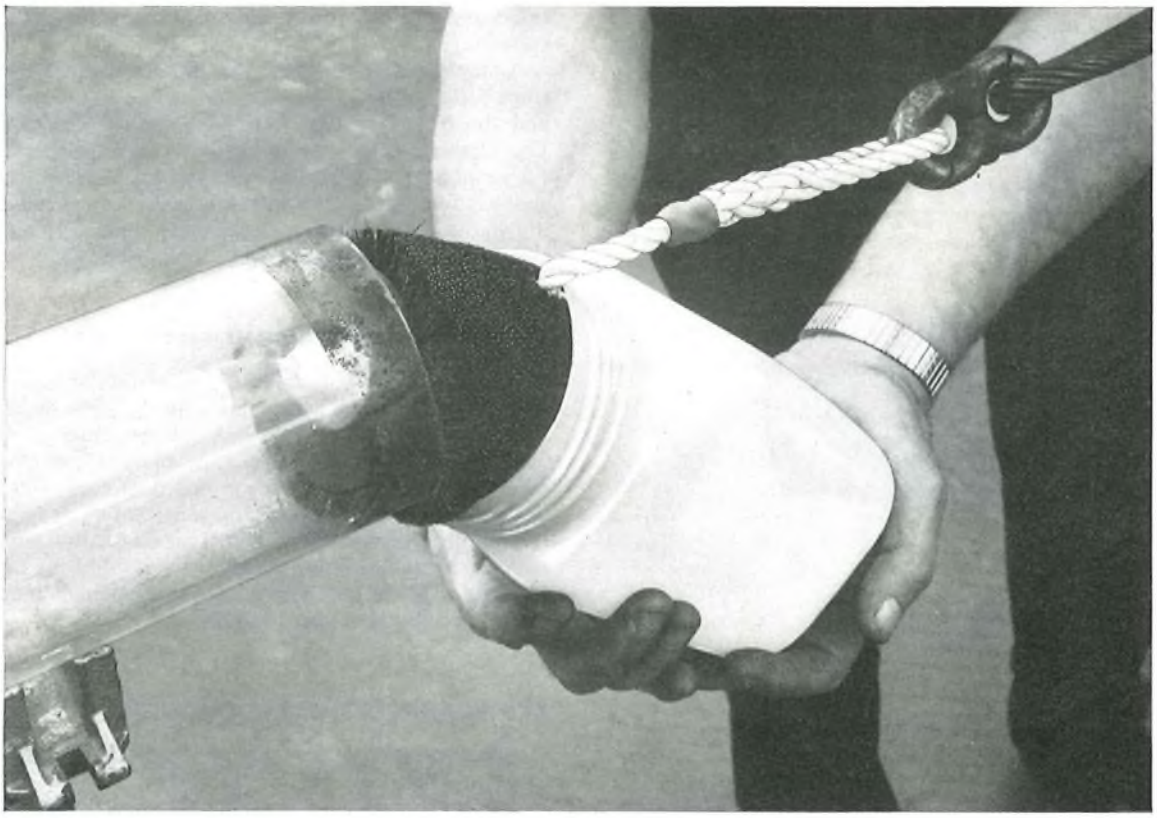

FIG. 5—Lubricating brush entering duct

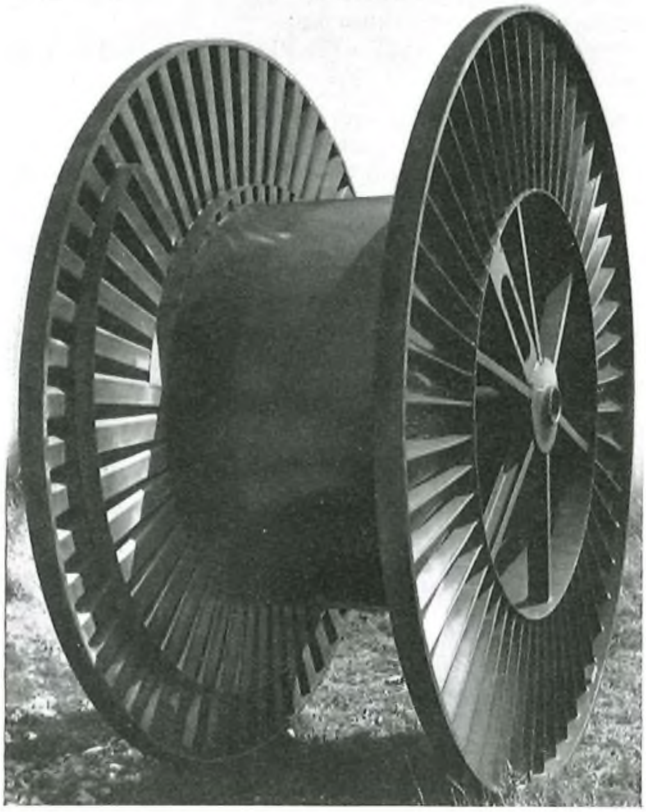

FIG. 6—Cable drum less battens

to cater for the accidental breakage of a drawrope during installation of the cabling rope. The vehicle should be fitted with a towing hitch of sufficient strength to tow a fully-laden cable-drum trailer. The unit is required to operate in a cross-country environment and should be able to pull into manholes or precast concrete boxes not fitted with anchor irons.

Cable-drum trailer

The cable-drum trailer should be suitable for cross-country and normal carriageway use and should accommodate a fully-laden cable drum the dimensions of which are:

flange diameter	2,700 mm,
overall width	1,360 mm, and
maximum weight fully loaded	7,200 kg.

The trailer should be fitted with a towing eye suitable for use with the winch unit or other suitable towing vehicles.

The design should include a *drum-override* facility to prevent the drum overrunning during cabling operations and should allow for the drum to be driven for handling convenience (this facility is not required for the cabling operation). A draw-rope winch unit for pulling in the cabling rope, prior to cabling, is required and storage facilities for the recovered drawrope should be provided.

Cable Guides

To facilitate cabling when the drum is remotely positioned from the duct entry, cable guides of lightweight flexible construction are required. They should be manufactured in section lengths of 5 and 10 m and be fitted with couplings for attachment to each other and for duct entries.

Cable Drum

The drum should be of robust construction suitable for repeated operations and should be suitable for use with wishbone and flatbed trailers having a cable capacity in the region of 550 m. The barrel diameter should be such that the cable will not be bent to too small a radius. A testing ramp is required to enable the inner end of the cable to be brought out for testing purposes.

FIG. 7—Cable drum ready for transit

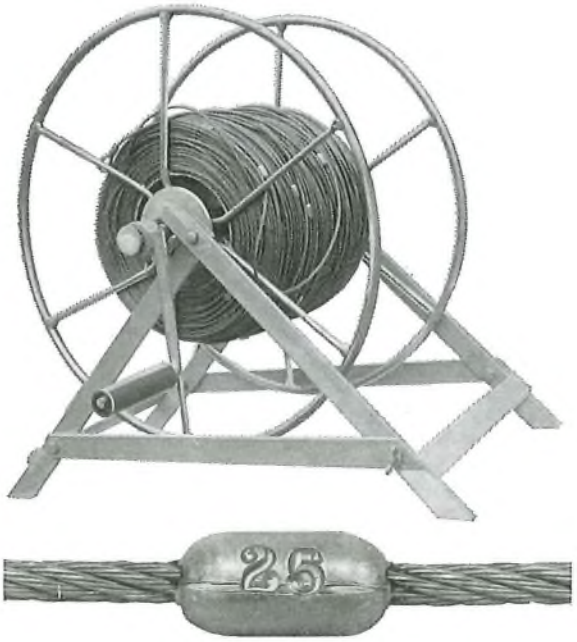

FIG. 8—Length-measuring device and close-up of ferrule

Length-Measuring Device

Duct-length measurements between manholes or jointing points are initially obtained from records which are compiled in conjunction with the duct-laying contractor. At a later date, after the in-filling has been completed, it is not always possible to determine accurately the exact course of the duct route in order to measure duct lengths, although planners frequently need to do this. Difficulties can arise over wayleave access if a surface measurement is required immediately prior to cabling and, in any event, a double survey is uneconomic. Some simple kind of measuring device is clearly needed.

DEVELOPMENT OF NEW PLANT

Implementation of the proposals for a winch unit, a cable-drum trailer and flexible cable guides is proceeding. Design of the cable drum and length-measuring device has been completed.

Cable Drum

The new cable drum design is shown in Figs 6 and 7 and the dimensions are:

overall diameter of flange	2,700 mm,
barrel diameter	1,500 mm,
width between flanges (excluding ramp)	1,020 mm,
ramp thickness	80 mm,
overall width	1,360 mm, and
capacity	550 m of 18-pair 2·6/9·5 mm coaxial cable.

The drum is made from pressed steel, protected by galvanizing and painted golden yellow to match B.P.O. telecommunications vehicles. Steel has been chosen in preference to wood because of its robustness and lasting qualities, particularly for the long-term storage of strategically-placed spare lengths.

Length-Measuring Device

Two different forms of measuring device have been assessed. One comprised a 3 mm outside-diameter, galvanized-steel-wire rope on which were swaged small aluminium ferrules at set intervals. The other was a flat resin-bonded, fibreglass tape marked in ink. Tests soon showed that the flat tape deteriorated rapidly in use and was insufficiently robust. The steel-wire rope was, however, successful and is illustrated in Fig. 8.

The steel rope is 550 m long. The first ten metres is marked at 1 m intervals and the remaining 540 metres at 5 m intervals. Each ferrule is marked sequentially.

During the course of the normal acceptance testing, a mandrel and brush followed by a draw rope are pulled through the duct. The draw rope is then left in the duct for future use on cabling. It is intended that the steel measuring rope shall be pulled in behind the mandrel and brush during the acceptance test and the duct length observed. The drawrope is then attached to the end of the measuring rope and the drawrope is pulled in as the measuring rope is recovered.

This length-measuring device was used successfully on the cabling survey for the Marlow pilot installation and is now being employed on surveys of the route of the first 60 MHz system to be installed in the U.K. There is every reason to suppose that it will be used in cable installation operations generally and, thereby, lead to considerable savings in the planning stage.

CONCLUSIONS

The problems of cable installation for the 60 MHz f.d.m. transmission system have been reviewed and the needs for the development of new cabling plant have been identified. Although the 2·6/9·5 mm coaxial cable is basically of robust construction, it is apparent that careful route planning will be necessary and appropriate installation techniques adopted if success is to be assured.

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The 60 MHz F.D.M. Transmission System: Cable Maintenance

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Special attention has been paid to all aspects of cable maintenance and reliability during the development of the 60 MHz f.d.m. transmission system. New designs and techniques have been produced with the object of reducing maintenance and repairs to a minimum and several special features have been introduced with the aim of improving the overall reliability of the cable system.

INTRODUCTION

For the new 2·6/9·5 mm coaxial cables used with the 60 MHz f.d.m. transmission system some special maintenance procedures will be required for live-working on the cable, that is with power supplies connected to all working coaxial pairs. In other respects normal maintenance procedures will be adopted.

The system is designed for protection against the influence of nearby lightning discharges and it will continue to work satisfactorily under extreme conditions of power induction.

In all circumstances at present foreseen interference will not be excessive and the system has all the outer conductors of the coaxial pairs, the lead sheath and the metalwork of the repeater housings connected to earth at the terminal ends by means of magnesium-alloy anodes at each repeater housing (1·5 km intervals). However, the system has been so designed that if required it is possible to isolate the outers of the coaxial pairs from earth should this be necessary in order to reduce any severe interference due to earth faults on power lines or electric railways.

A much better availability is required from the new system than is at present attained on the existing high-frequency trunk network, and a careful balance has been made between the initial capital cost of the new features and the improvement in service required.

DUCT ROUTE

Wherever possible a route with a minimum cover of 1·2 m has been chosen, separate from the normal trunk and junction routes. This is not always possible in urban areas and in these circumstances the duct route may be laid with other ducts, passing through jointing chambers, tunnels, etc, designed to accommodate cables carrying both old and new systems. However, where the jointing chamber is common the layout is such that there is special segregation and protection for the new system to obviate disturbance by working parties entering and working in the underground structures. At a few sites, silo-type buried steel chambers are provided as described elsewhere to house amplifier equipment.

Provision has been made for two duct-ways to be provided to permit the installation of a maximum of two high-capacity cables. At river, road and rail crossings a third duct is laid to accommodate interruption cable if required. Jointing chambers are sited to permit safe and proper mounting of cable drums, winches and vehicles should maintenance replacement of cable lengths be required.

ROUTE MARKING

In general, cable joints are provided at 500 m intervals, and in addition to precise plant records, special marking of ducts, joint positions and cable sheaths is required. Because of the high electrical performance of the special coaxial-pair joints it is the intention, wherever possible, to repair damaged cable *in situ* without regard to the position of existing joints. This policy is not always practicable, for example, where road surfaces cannot be broken up the cable length between consecutive jointing points may need to be replaced in the event of a cable fault.

To ensure that the correct duct is exposed and opened up at an excavation, the polyvinylchloride (p.v.c.) ducts are coloured individually and the polyethylene protective sheath on each cable is also provided with a distinctive colour. Marker posts are used to indicate the line of route and the position of joints, and tone-location techniques are employed to identify the duct when excavating at a fault point.

A warning to working parties excavating in the vicinity of the duct route is provided by means of a green 150 mm wide p.v.c. marking tape with the legend "Caution, High Voltage P.O. Telephone Cable Below". The tape is buried longitudinally immediately above the ducts at a depth of about 300 mm.

PROXIMITY TO RAILWAYS

At present, it is envisaged that the 60 MHz system will not be laid adjacent to electrified railways, but should part of a railway system be subsequently electrified the cable system screening that will be provided initially can be supplemented by installing booster transformers with return conductors and the system operated on an earth-free basis. Additional earthing to the cable sheath will be provided at amplifier points in order to safeguard adequately the system and personnel against voltages induced by traction and fault currents should this be necessary.

CABLING AND JOINTING METHODS

Special cabling equipment is held at strategic points for subsequent maintenance work. To ensure that this apparatus is kept in perfect working order for emergencies it may be

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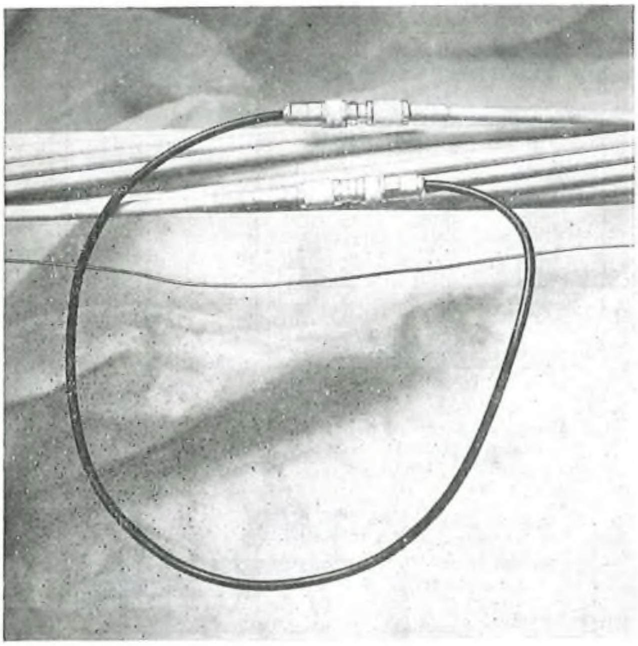

FIG. 1—Temporary repair using patching cable

desirable to use this equipment occasionally for other cabling work. Jointing vehicles and equipment, together with special tents, wooden shuttering and protective sheets, will also be provided at various points to enable rapid jointing repairs to be made. The jointing equipment[1] includes ample mobile power supplies, thus enabling the coaxial pairs to be brazed and electric lighting and electric pumps to be operated.

Special split outer-conductor jointing ferrules are used to repair damaged coaxial pairs, using portable brazing equipment. Repair kits comprising sleeves, insulating disks and shrink-down sleeves are made up in packets to ensure that the piece parts are clean and undamaged and also to provide a method of checking that the correct number of insulating disks are inserted in each conductor joint.[1] The cable joint and jointing methods have been specially designed to meet stringent electrical and safety requirements.

INTERRUPTION CABLES

Because of its location and the mechanical protection provided it is expected that most cable repairs will be concerned with small perforations in the lead sheath, involving repairs to one or two coaxial pairs in the outer layer rather than catastrophic damage to the whole cable. Despite the depth at which the cables are laid, and the various methods of marking the depth, course, position and identity of the cables, severe damage by excavating plant or from other causes may however also occasionally occur. Most repairs will therefore involve an excavation at the fault point in order to repair the cable *in situ*. At times, this may involve a length of cable being replaced within the few metres exposed at the excavation. At points where access may be difficult, spare duct is provided so that interruption lengths up to about 500 m long can be installed.

Long lengths of cable for repairs are kept on metallic cable drums that will give long storage life and these will be held and maintained at suitable sites along each route. Single-coaxial-pair flexible interruption cables are also available for the rapid restoration of damaged coaxial pairs. Flexible patching-out cables (see Fig. 1), about 1 m long, prepared with special coaxial connectors at each end are held by jointers as aids in the jointing techniques prescribed so that individual coaxial pairs at joints or at repair sites can be rapidly restored to give temporary service. Similar arrangements will apply should route diversions or rearrangements of cables be necessary.

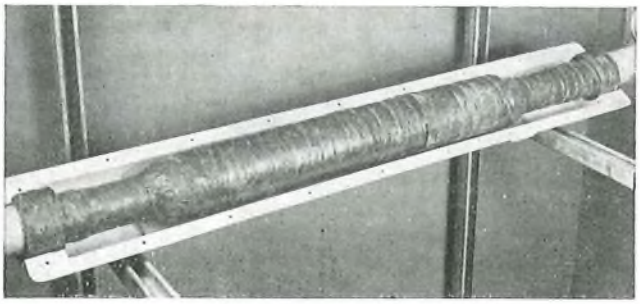

FIG. 2—Casing for protection of joints

SAFE POWER FEEDING

A special method of power feeding and special terminal power-feeding equipment has been developed[2] to enable jointers to work in safety on a coaxial pair with power applied to all the other working pairs in the cable. At all amplifier housings the exposed metalwork is earthed, but if the prescribed method of working is not followed it may be possible, exceptionally, for a jointer to touch a live inner conductor when working at a repeater housing or on the cable core. In this event, a moderate but safe electric shock could be felt, but the action of touching the inner conductor should very rapidly switch off the power supply.

All the maintenance jointers are trained in a step-by-step method of working which ensures that a live inner-conductor cannot be touched. The procedure requires access to be made in the first instance to the amplifier housings on each side of the fault point, the disconnexion of power from the coaxial pairs concerned, the removal of the amplifiers associated with the coaxial pair to be worked on and their replacement with special test boxes to assist in identifying the correct pair. To ensure that the correct identifying procedure is used, and more especially to simplify the layout of coaxial pairs at the joints, the pairs are not numbered in the cable lengths.

The plugging-in of test boxes in place of amplifiers enables the coaxial pair at the two amplifier points to be earthed leaving the coaxial pair between the two text boxes isolated, thus providing facilities to enable tones, d.c. pulses or test equipment to be applied as required to assist in precision fault location on the faulty pair.

SPEAKER CIRCUITS

During cable repairs, co-operation is required between the cable repair party and staff at the power-feeding stations, and also between jointers working at the fault point and those assisting at the adjacent repeater housings. For this purpose, communication can take place, before the repeater housings are opened, by means of a speaker circuit terminated under a sealed cover mounted on the side of the repeater cases.

Silo-type buried repeater stations also have the same speaker circuit facilities as the repeater housings.[3] Access to one speaker circuit is obtained in the entry shaft of the silos, and power for lighting the buried repeater station is supplied by portable 110 volt, 50 Hz a.c. generators which are connected to waterproof plugs which are also fixed in the entry shafts. To assist maintenance staff working on the cable route, portable loudspeaker equipment is provided for intercommunication via the speaker circuits.

CORROSION PREVENTION

Special care has been taken in designing the cable and repeater housings to ensure that failures due to corrosion of metalwork are eradicated or kept to a negligible amount. The lead-sheathed cable is provided with an outer polyethy-

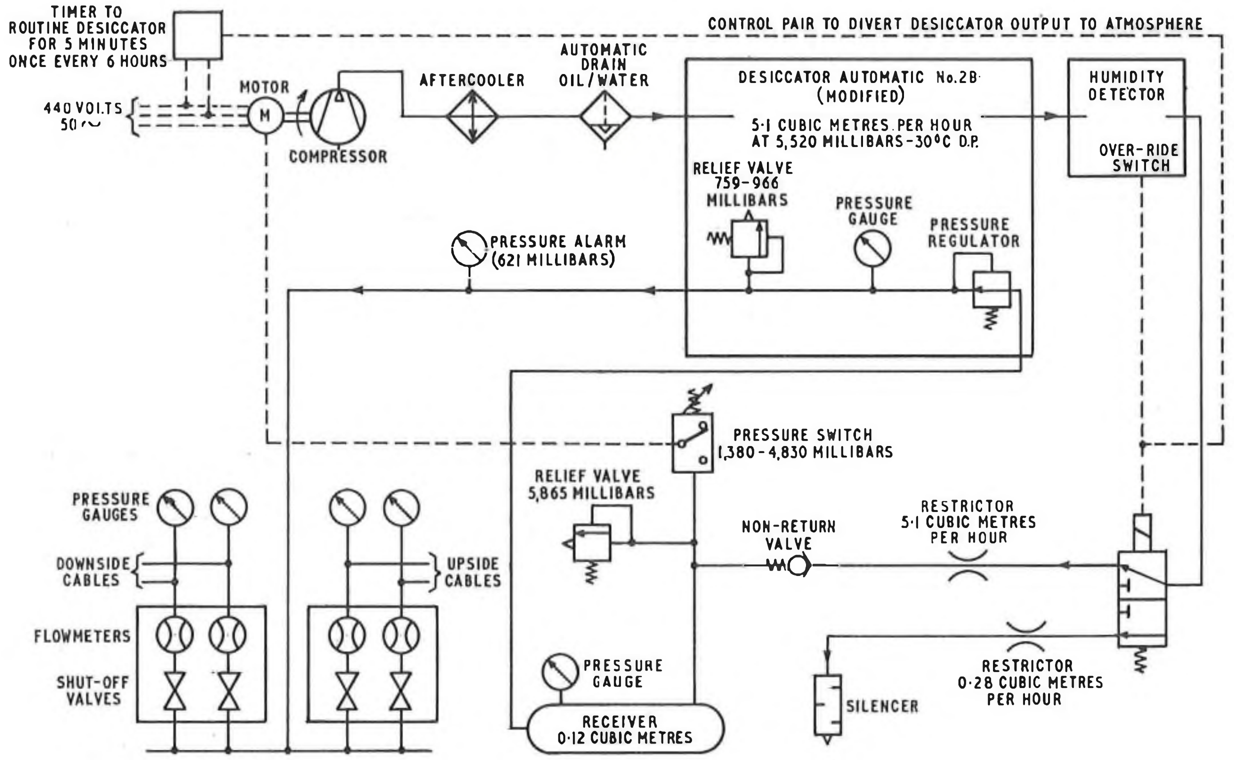

FIG. 3—Schematic diagram of compressor and desiccator arrangements

lene protective sheath and a bitumastic-layer seal is added between the lead sheath and polyethylene outer covering. At all buried joints the lead sleeves are protected with a glass-fibre-reinforced plastic outer-casing filled with a protective compound. Joints in jointing chambers are given special supports and additional corrosion and mechanical protection (Fig. 2).

At repeater housings, the joints between the cable and the gunmetal tube of the housing are made by plumbed lead sleeves protected by outer aluminium-alloy split couplings filled with a protective compound. The split couplings and the aluminium-alloy repeater housings are protected on the outside with a nylon coating. The whole housing is mounted on racking at a comfortable working level so that the case is well clear of the floor of manholes or concrete joint boxes.

After installation, an epoxy paste is applied to cover pinholes and areas of the nylon coating damaged during installation. As a further precaution, two magnesium-alloy anodes are buried in the adjacent soil and connected to each housing to provide sufficient cathodic protection to safeguard for the foreseeable future against subsequent deterioration of the nylon and epoxy-paste coatings. A link box is provided in the connecting lead to the anodes so that output current and the potential between the aluminium-alloy case and temporarily-installed copper/copper-sulphate reference electrodes can be measured to provide a check of the condition of the coatings.

Similar corrosion protection is provided at silo-type buried repeater stations. The outside of the cylindrical steel housing is zinc coated, wrapped with impregnated tape and cathodically protected by means of four magnesium-alloy anodes buried in the adjacent soil. The inside of the housing is protected with white epoxy paint and the humidity monitored by means of humidity detectors connected to an alarm which operates at the power feeding stations when the humidity rises to above about −10° C dewpoint.

If the route passes close to a cathodically-protected buried structure, or near a cathodic-protection ground bed, joint cathodic-protection tests are initiated to decide whether the amount of corrosion interaction justifies bonding between the cathodic-protection schemes.

VIBRATION AND CREEPAGE

Lead alloy B is specified for sections of the cable sheath where severe vibration is expected, for example, on bridges. Sufficient damping is provided inside the repeater housings to protect the amplifier equipment against vibration caused by traffic.

Standard anti-creepage devices are not entirely suitable for the 18-pair coaxial cable and for parts of routes exceeding about 1 in 10 gradient consideration may be given to burying the cable directly into the ground. Trials are in progress of a new design of anti-creepage device, and if this is successful, the new design will be used in preference to current anti-creepage devices or to direct burial in the ground. Creepage of the cable core or of individual coaxial pairs is not expected, but the special brazing technique adopted for jointing takes account of possible stresses.

CABLE PRESSURIZATION

The large traffic capacity of the cable system justifies a high degree of protection by air pressurization. A combination of the best features of the continuous flow and static pressurization systems has been adopted so that a uniform static pressure is attained from end to end of the cable pressure section, including the repeater housings. The repeater housings are normally connected to the cable pressurization system.[3] In addition, air is fed automatically into the system for topping-up and also to provide instantly a large supply of air if an abnormal leakage occurs. A large reservoir of air is needed in view of the exceptionally large pneumatic capacity of the cable system and the very low pneumatic resistance of the cable. A modified form of the pressurization equipment at present used for trunk and junction cables is utilized, and a stringent control is exercised of air leakages from the various pressurized parts of the system together with the use of improved methods of pressure-leak location and detection.

Each power feeding section is treated as a separate cable pressure section and air is supplied to the cable from each end of the section at a pressure of 621 millibars.

PRESSURIZATION EQUIPMENT

It is thought desirable from a serviceability point of view to adopt standard well-tried compressors and desiccators, and the equipment provided at the power feeding stations therefore consists of standard rotary sliding-vane compressors supplying air to standard large-capacity desiccators feeding the dried air, via humidity detectors, to 0·12 m^3 vertical air receivers. The dry air from the air receivers is then passed via flow meters and pressure gauges into the cables (Fig. 3). Sufficient dry air is available to pressurize other cables terminating at the power feeding stations.

The power supply to the 1·5 kW 3-phase induction motors driving the compressors is by direct on-line starting from the mains, and arrangements are made to run the motors if necessary from the 3-phase emergency supplies at the station. The compressors are each capable of supplying a free-air delivery of nearly 12 m^3 per hour, and are provided with automatic oil filters and water drains on the outlets of the after-coolers.

The air receivers have four main functions:

(*a*) to supply dry air at very low flow-rates to sustain residual leakages so that the compressors are not required to run continuously,

(*b*) to supply, instantly, on demand, dry air at high flow rates to cater for leakages in the cable or at amplifier housings,

(*c*) to provide a reserve of air in the event of a power failure or a fault occurring in a compressor, and

(*d*) to provide alternative reserves of air in the event of a power failure or loss of air from a compressor or receiver at the far end of a pressurized section.

If the cable system is maintained in good condition with the specified leak rate for the whole cable pressure section not exceeding about 1 m^3 per month, the two receivers at each end of each cable pressure section are able to maintain adequate pressure in the cable for several weeks, even if both compressors are out of commission. With a substantial leakage at the mid point of a pressurized section, the two receivers alone can maintain adequate pressure for at least 24 hours.

The air supply system is arranged so that dry air is stored at a maximum pressure of about 4,800 millibars, and when the pressure falls to about 1,400 millibars the compressors start-up automatically to recharge the receivers in about 30 minutes.

With the specified low air flow, the desiccators would lie idle for long periods and moist air collecting in them could be passed through the humidity detectors as the compressors are switched on. To avoid this, timers are provided to switch on each compressor for about five minutes in every six hours, and during this period the desiccator output is vented to the atmosphere.

A specification has been prepared giving maximum permissible leakage rates for sections of the repeater housings, for the housings as a whole, for 1·5 km sections of cable and for the whole pressurized section.

IMPROVED METHODS OF LEAK LOCATION AND DETECTION

Initially, close-tolerance pressure-sensitive switches (contactors) will be installed in all repeater housings. At each power feeding station a chart recorder, receiving signals via supervisory quads in the cable in the event of a pressure fault, records which particular contactor first operates and the time of operation, followed by timings as other contactors operate successively on each side of a leak. If the contactors are all uniformly adjusted to operate when the pressure falls to, say, 500 millibars, the approximate position of the leak can be calculated from the recorded information. A more accurate location can then be made from the repeater housings in the vicinity of the estimated position of the leak, and finally by making accurate pressure measurements using portable manometers. A graph of the local pressure gradient can then be prepared after making corrections for height, atmospheric pressure and any differences in pneumatic resistance of the various cable lengths. An excavation can then be made at the calculated fault position and a final, precise location made on site with sulphur hexafluoride (SF_6) tracer-gas or other appropriate equipment. Small-diameter rodding equipment with a small-diameter detector head is pushed along the gap between the cable and the duct wall in order to locate the actual leak. The perforation in the lead sheath may not necessarily coincide with the perforation in the polyethylene sheath and allowing for the effects of the intermediate bitumastic layer the leak location will be at the perforation in the polyethylene.

To facilitate leak location and other work on the cable, a three-position gas switch and Schrader valves are provided on the outside of each repeater housing. This enables repeater sections and repeater housings to be isolated so that the pressure in each section, or in the housing, can be separately measured, and if necessary air can be applied to the cable from air cylinders via the Schrader valves.

PRESSURE TRANSDUCERS

Development work is in progress with the aim of providing accurate pressure-sensing transducers at each repeater housing in lieu of contactors. These transducers are required to maintain their accuracy over many years, and in view of the large number required for each system, they must be reasonably economic to provide and install. The aim is to provide a pressure transducer system on these high-capacity cables as quickly as developments and trials permit, so that the state of cable and repeater housing pressures throughout the length of the cable can be continuously monitored and leakage points identified from the terminal ends.

CONCLUSIONS

The design aim for a 60 MHz line system carrying 10,800 telephone channels is a mean time between failures of four years and an availability of 99·99 per cent per 160 km.[4] On some existing systems, interference and damage caused by Post Office and other external working parties and cable failures not caused by human activity accounted for 70 per cent of all out-of-service time. The high percentage of out-of-service time is primarily due to the effects of travelling time, site preparation and time-consuming repairs to cables. The aim of all the new design features and maintenance precautions for the 60 MHz system is to reduce the number of faults or to bring them to attention immediately.

In addition, it should be possible to reduce the number of long-duration faults and to provide maintenance attention before services are affected.

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The 60 MHz F.D.M. Transmission System: Test Results of a Field Trial

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This article describes briefly the facilities and apparatus provided for the experimental 54 km section of 60 MHz line system which has been set up at Marlborough, and then summarizes the test results so far obtained. These results indicate that the 60 MHz line system is capable of meeting the planned design objectives with very comfortable margins.

INTRODUCTION

After studies of the problems and feasibility of a 60 MHz f.d.m. transmission system,[1] the British Post Office (B.P.O.) placed a contract in July 1970 for the development and manufacture of equipment for a field trial of the line system, the form and performance aims of which have been described in another article.[2]

For the trial, the B.P.O. installed a length of about 6·5 km of cable starting from the repeater station at Marlborough, Wiltshire and roughly following the line of the A4 trunk road. In January 1973, an initial installation of the line system was carried out and results obtained from the tests conducted are summarized in this article.

FEATURES OF THE TRIAL ROUTE

Cable

The cable comprises eighteen 2·6/9·5 mm coaxial pairs laid up in two layers, 6 in the inner and 12 in the outer, lead-sheathed with an overall protective sheath of polyethene. Twelve quads are also provided for such facilities as engineering-speaker circuits and gas-pressurization monitoring. The coaxial pairs, of type laid down by the C.C.I.T.T.‡, have been made using existing cable-making machinery as far as possible. Special attention was paid during manufacture to obtain as high a uniformity of product as was economically possible. Joints between factory lengths of cable (between 185 and 379 m) have also been specially designed to obtain good matching at high frequencies.[3] The cable is laid in p.v.c. duct at a depth of 1·2 m, the cable almost completely filling the duct.

Electrical Properties of the Cable

The individual lengths of cable were measured in the factory and the impedance, attenuation at given temperatures and the temperature coefficient of attenuation were all accurately known. In order to enable the gains of individual repeaters to be set accurately before installation, the lengths of laid repeater sections were measured in the field by means described elsewhere.[4]

The Repeater Accommodation

At the amplifier points AP1, AP2 and AP3 of Fig. 1, the repeaters are housed in rilsan-coated silumin repeater housings[5] accommodated in precast concrete manholes, access to which is via a manhole cover at ground level. At amplifier point AP4, an alternative type of accommodation known as a *silo* is used. This comprises a large cylindrical tank with axis vertical, access again being via a cover at ground level.[6]

Marlborough Repeater Station

This is a surface station at which the multiplex equipment (for 4 MHz hypergroups), line-protection switching equipment, together with the 60 MHz line terminal equipment and a main-station equipment are installed. In addition, a repeater housing and apparatus forming, in effect, a dependent repeater station, are mounted on a bench in the station. To facilitate the setting up of various circuit arrangements for the trial, patching facilities as indicated in Fig. 1 were also provided.

ADJUSTMENT OF REPEATERS

The gain/frequency characteristic of the repeaters is of major importance. Accurate measurements of the cable-loss characteristics were, therefore, made shortly after the cable was laid and this, together with information on this type of cable from other sources, was used in determining the required gain/frequency functions of the repeater amplifiers. A pilot production batch of 60 repeaters has been made to cover the trial and other purposes. The gain/frequency responses obtained on a pilot production batch were within 0·02 dB of the required characteristic and uniform to within 0·01 dB.

The repeater gain can be set to cope with section lengths deviating from the nominal 1·5 km, or the 27·45 dB nominal gain at the pilot frequency of 61·16 MHz. The gain can be set to values between 26·45 and 29·45 dB. More adjustments may be made by using the line build-out networks enabling the effective gain to be reduced to about 20 dB.

On the basis of the detailed route information and the loss per kilometre of the coaxial pairs at the pilot frequency, the settings of line build-out networks and/or gain-adjustment networks were tabulated for the 35 repeaters to be used on the trial. Due allowance was made for the differences in length of pairs in inner and outer layers in the cable and for the effect of additional end cables in the surface station. In

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

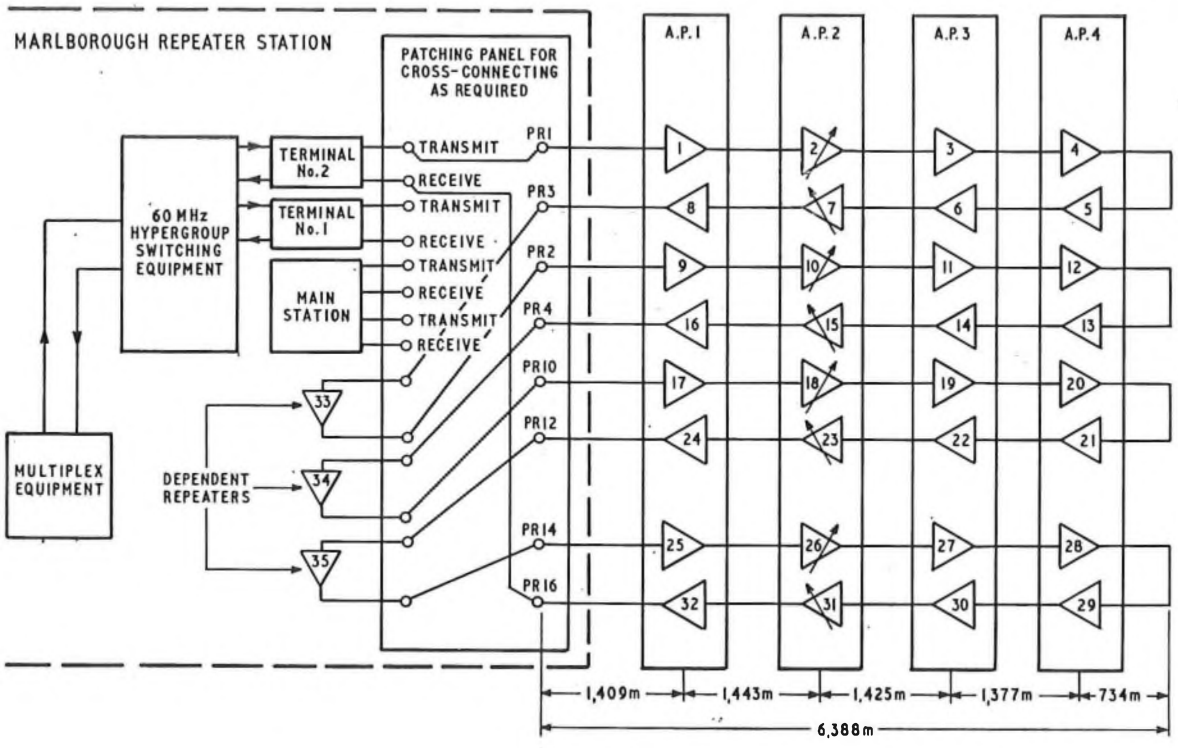


FIG. 1—Layout of Marlborough field trial

accordance with normal installation procedure, the repeater gains were set to these requirements (by soldered straps). This soldering can be done at any convenient place, for example, in surface station or factory, thereby reducing the installation work to simply plugging-in the units.

TEST RESULTS

Residual Gain

The system was set up as shown in Fig. 1 to allow the measurement of the residual error in gain/frequency response over the 36 cable sections having a total length of about 54 km. For this purpose, the gains of the regulated amplifiers were set by manually controlling the remote regulation frequency applied to bring the received level of the 61·16 MHz pilot to nominal level. From the resultant value of regulation frequency arrived at in this way, the cable temperature was calculated to be about 3°C. This appeared to be in accordance with temperature measurements carried out in different ways. Curve A of Fig. 2 shows the residual error before adjustment of correction equalizers in the surface station. The maximum deviation occurs at about 35 MHz and has a magnitude of about 0·8 dB or approximately 2 mB (0·02 dB) per repeater. Repeating this measurement with a half-length system of 17 repeaters showed that the result was proportional to length. After proper setting of a correction equalizer in the receiving equipment, the curve B of Fig. 2, showing a maximum deviation of 0·1 dB, was obtained. In this case, a better adjustment is impracticable. On longer systems, for example, the C.C.I.T.T. 300 km homogeneous section, the level deviations are greater, a more effective setting of the equalizer is possible and it is, therefore, confidently expected that the objective of ±0·5 dB for a 300 km length will be met.

Roll Effect

With the resolution of the level measurements increased by a factor of 20, a fine structure ripple in the characteristic of curve B of Fig. 2 can be observed. Figs. 3 and 4 show this *roll effect*, which is caused by mismatches between repeater and cable impedances and/or between cable impedances at cable joints. Repeated reflexions between the different reflexion points give rise to the rolls, the frequency spacing of which is a measure of the distance of these points and the amplitude a measure of the degree of mismatch.

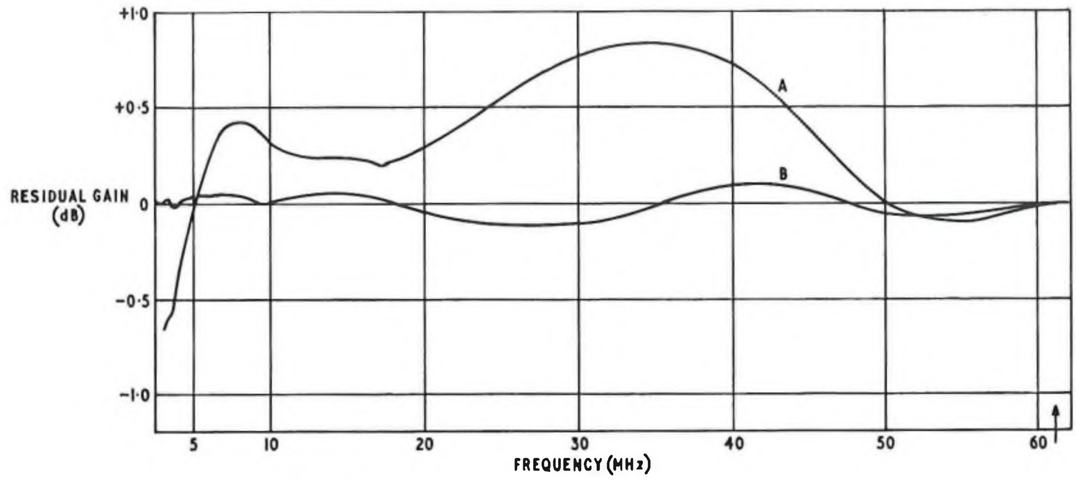
At the lower end of the transmission band, Fig. 3 shows rolls with an amplitude of about 0·5 mB peak-to-peak and a spacing of 100 kHz corresponding to 1,400 m between reflexion points, which accords with the repeater intervals. Near the upper edge of the band, Fig. 4 shows the roll amplitude to be about 1 mB peak-to-peak and the spacing corresponds to repeater-to-cable-joint distances. The small amplitudes of the rolls show that the quality of matching of both repeaters and splices is high. Since the trial installation consists of 8 looped pairs, reflexion distances are repeated very systematically, which is unlikely to be found on normal routes. If random distances are applied, the rolls will increase with the square root of the length. For the reference circuit of 2,500 km, this results in a roll amplitude of the order of 0·1 dB.

The effect is of most importance in considering the suitability of the system for television transmission and the results indicate that completely acceptable performance is possible, even for circuits up to 2,500 km in length.

Group-Delay Distortion

Another important system property, when television or wideband data transmission is considered, is the group-delay distortion. It must be possible to reduce this type of distortion, by means of group-delay equalizers, to within the tolerated limits at intervals in the order of 300 km. The group-delay distortion introduced by 35 dependent repeaters is shown in Fig. 5.

A television channel situated at the lower end of the band is the most affected and will suffer a distortion of about 130 ns or 2·5 ns/km. To make an estimate of the distortion on a system length of 300 km, about 10 per cent should be



Curve A is without equalization and curve B is after equalization

FIG. 2—Residual gain

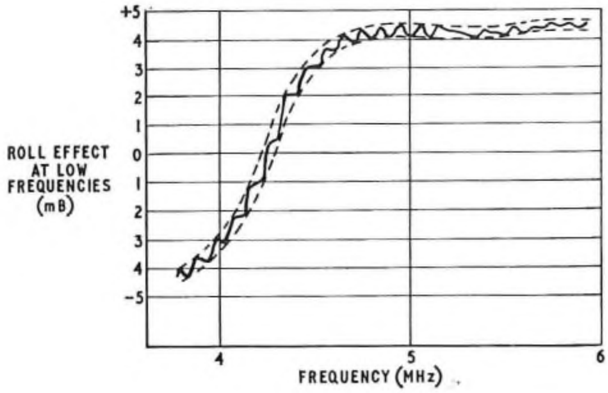


FIG. 3—Roll effect at low frequencies

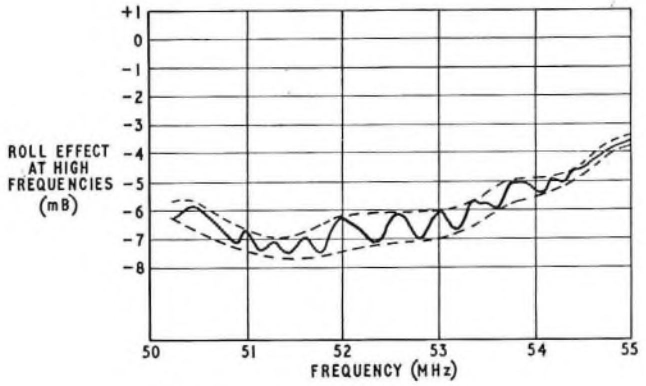


FIG. 4—Roll effect at high frequencies

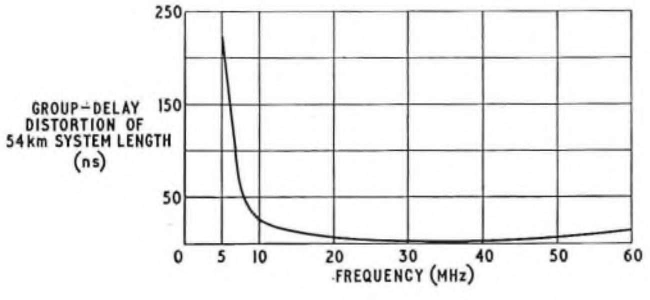


FIG. 5—Group-delay distortion

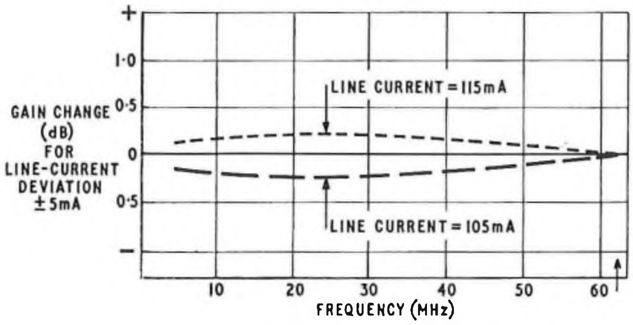


FIG. 6—Gain change with change of line current

added for the influence of main stations, thus arriving at 2·8 ns/km. As shown in Fig. 5, group-delay distortion in other parts of the band is only fractional and, often, equalization will be superfluous.

Line-Current Variation

On the 54 km length, a change in the line-feed current of 5 mA, in either direction, from the nominal 110 mA produced a corresponding change in received level of 0·25 dB. See Fig. 6. The normal current stability of the generator is better than 1 mA which corresponds to a change of less than 5 mB. Since a homogeneous section will consist of several power-feeding sections and current variations of the same magnitude and polarity are unlikely to occur simultaneously, the effect of the system behaviour will be negligible.

Frequency Response of the Regulating Action

To investigate the influence of the seasonal cable temperature changes on the system level stability, a temperature increase of the cable was simulated by inserting in the main station an artificial cable network. This represents the loss of a 1·5 km section. As the total cable loss equals 54 km × 18·3 dB/km = 990 dB and the temperature coefficient of the loss is about 0·2 per cent/°C, the 27·45 dB loss increase, caused by the artificial cable, corresponds to a temperature rise of 14°C.

This loss increase is compensated for by a gain increase of the regulated repeaters, remotely controlled by the pilot regulator in the main station. The difference between the residual response before and after this action then gives the shape error introduced by the regulation system. As shown in Fig. 7, the maximum error is just greater than 0·5 dB at about 25 MHz. The range of loss variation on a 300 km

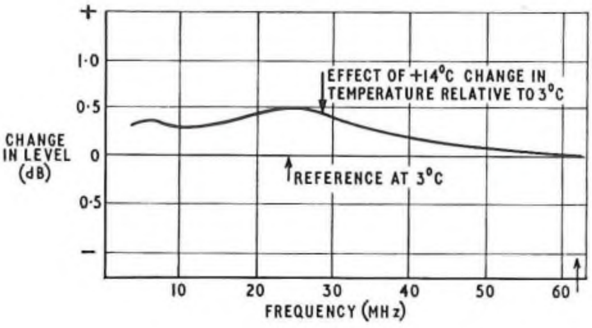


FIG. 7—Regulation design deviation

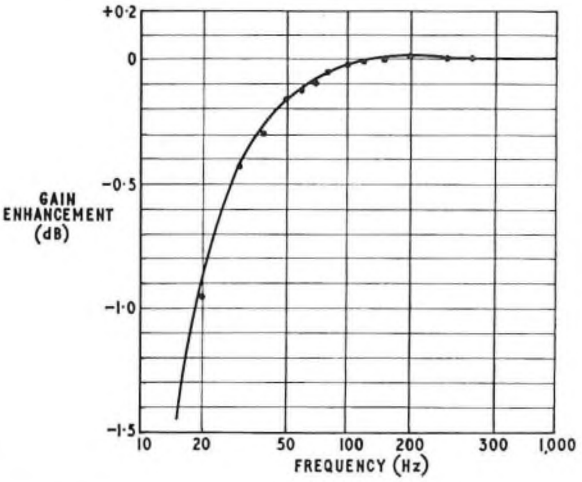


FIG. 8—Gain enhancement characteristic for one regulator

system is expected to be ±110 dB for a ±10°C temperature excursion, which is exactly four times more and, thus, the regulation error may be expected to be about ±2 dB. In view of the simple shape of the curve, reduction to well within the design objective of ±0·5 dB is possible by means of additional compensating networks at surface stations. These networks are automatically controlled by the regulation frequency.

Gain Enhancement

The dynamic performance of the pilot regulator fitted at each surface station may be expressed in terms of gain enhancement defined as follows:

If the pilot-frequency signal, applied to a pilot regulator, is modulated with a low frequency f_1 (1–1,000 Hz) and a voltage amplitude A and, as a result, the pilot frequency at the output of the regulator is modulated to amplitude B, then the gain enhancement is 20 $\log_{10} B/A$ dB.

Fig. 8 shows the gain enhancement characteristic for one regulator as a function of the frequency f_1 which shows that the only positive value of gain enhancement observed is about 0·01 dB at 200 Hz. The design objective was for a minimum positive value, but, in any case, not more than 6 dB for a 300 km route. Even in the unlikely case of 10 main stations on such a route, the gain enhancement is negligible.

Noise Performance

The noise performance of the system was measured by loading with a white-noise signal in accordance with the C.C.I.T.T. conventional loading of −15 dBm0 per channel and observing the noise performance in narrow bands representing telephone channels situated at about 5·4 MHz, 35·7 MHz and 55·5 MHz. Fig. 9 shows an extrapolation of the results to a 300 km circuit taking power addition of thermal and second-order intermodulation noise and voltage addition of third-order intermodulation noise.

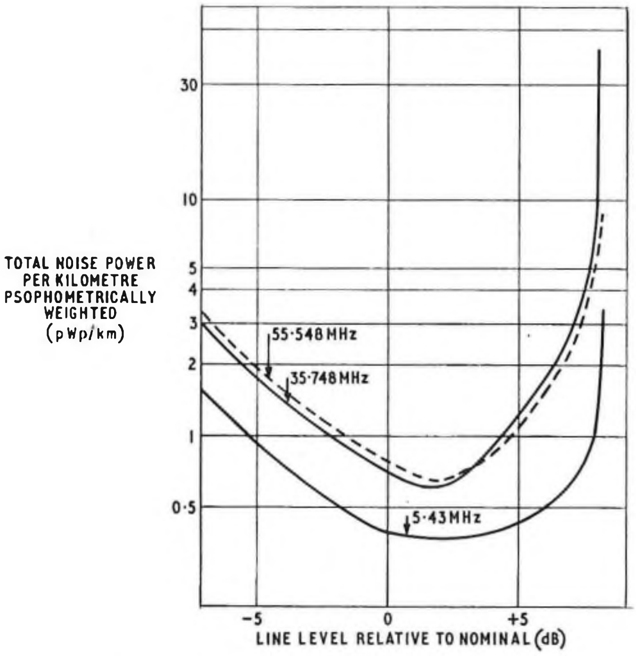


FIG. 9—Noise performance results extrapolated to a 300 km circuit

The results are expressed in pWp/km (psophometrically weighted and referred to a point of zero relative level) against line level shown relative to the nominal level of −19 dBr at 61·16 MHz.

As levels are reduced below nominal, the graphs rise because the signal-to-thermal noise ratio falls. Because the graphs are linear and increase by 1 dB for each reduction of 1 dB in input level, the contribution of intermodulation noise may be taken as negligible. Several decibels above nominal level, the increasing intermodulation noise becomes the major factor. In the low-frequency slot, the graph rises initially by 1 dB for each increase in input level of 1 dB, showing that second-order distortion is predominant, while, at the higher frequencies, the slope is doubled, indicating third-order distortion. At about 8 dB above nominal, the system goes into overload. At nominal level, the worst channel noise is about 0·8 pWp/km. An objective 1·5 pWp/km is, thus, met over a level range of about −3 dB to +5 dB relative to nominal. The range increases to −6 dB to +7 dB for the C.C.I.T.T. limit of 3 pWp/km.

Hum Modulation

To gain an impression of the quality of the performance of the system with respect to hum modulation as a result of power-line frequency induction, 30 mA (50 or 60 Hz) was superimposed on the 110 mA power-feed current over the 54 km section. Fig. 10 shows that a telephone channel at the top of the band is the most affected. At a frequency of 60 MHz, the ratio of the envelope amplitude (50 or 60 Hz) to the amplitude of the signal is about −52 dB. In a C.C.I.T.T. document, it is recommended that a minimum side component attenuation of −57 dB should be observed on a power-feed section under the influence of 150 volts r.m.s. induced cable voltage. Expressed in terms of envelope-to-signal amplitude ratio, this is −51 dB. Assuming the 150-volt induction and coaxial pairs having earth-isolated outers, the inner-conductor current could be of the order of 5 mA. As the hum modulation is proportional to the alternating current, figures 16 dB better than shown in Fig. 10 would be obtained in this case, easily meeting the C.C.I.T.T. requirements.

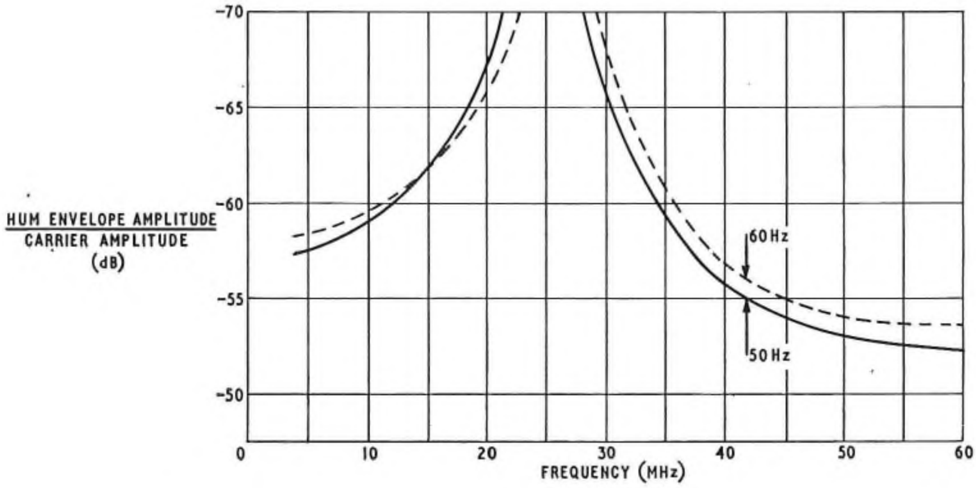


FIG. 10—Hum modulation

CONCLUSIONS

The results obtained from this preliminary trial have shown that the 60 MHz line system is capable of meeting the planned design objectives with very comfortable margins. In many respects, these objectives were set even within the recommendations of the C.C.I.T.T., and thus, the system has a potential for very high standards of transmission in a wide field of application with all types of traffic.

ACKNOWLEDGEMENT

The authors acknowledge the contributions made by each of the organizations involved in the 60 MHz field trial.

This article was originally published in the *Philips Telecommunication Review*. Permission to include it in this Journal is gratefully acknowledged.

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Notes and Comments

Publication of Correspondence

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

Letters of sufficient interest will be published under "Notes and Comments". Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will only be possible to consider letters for publicaton in the January issue if they are received before 18 November, 1973.

Letters intended for publication should be sent to the Managing Editor, *P.O.E.E. Journal*, 2–12 Gresham St., London, EC2V 7AG.

Notes for Authors

Authors are reminded that some notes are available to help them prepare the manuscripts of the *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal's* printer and draughtsmen, and help ensure that authors' wishes are easily interpreted. Any author preparing an article for the *Journal* who is not already in possession of the notes is asked to write to the Managing Editor to obtain a copy.

It is emphasized that 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.

Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that are 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. Negatives or plates are not needed and should not be supplied.

Correction

In the article "Cabling Across Estuaries" by W. T. King published in the July 1973 issue, line 8 of the first paragraph on p. 117 should read

"The cables were then pressurized to 690 mbar (10 lb/in^2) . . . ."

Note

Associate Section Notes and Regional Notes have been held over this quarter because of shortage of space.

Selling Price of the Journal

The Board of Editors regrets that, from January 1974, the price at the Journal to non-Post Office readers will be increased to 26p per copy (£1·44 per year) $3.75 Canada and U.S.A. per year. The price to Post Office staff remains unchanged.

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To further interest in the performance of engineering duties and to encourage the expression of thought given to day-to-day departmental activities, the Council of the Institution of Post Office Electrical Engineers offers prizes totalling £40 for the five most meritorious essays submitted by Post Office engineering staff below the rank of Inspector. In addition to the five prizes, the Council awards five certificates of merit. Awards of prizes and certificates made by the Institution are recorded on the staff dockets of the recipients.

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

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

Copies of previous prize-winning essays have been bound and placed in the Institution Central Library. Members of the Associate Section can borrow these copies from the Librarian I.P.O.E.E., 2–12 Gresham Street, London, EC2V 7AG.

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

The Associate Section National Committee Report

The National Committee Conference was held at Stone Training College in April and was well attended. All member Regions and Centres were represented.

Some lively business was covered and some very controversial propositions were discussed. South West Region were particularly active bringing three propositions to Conference.

The Chairman gave reports on all of the member Regions and gave special mention to Northern Ireland who have continued so well under the appalling circumstances. Northern Ireland were also the first winners of the "Cotswold Trophy" which was presented by the Gloucester Centre and shall be awarded annually to the Centre or Region that has in the opinion of the National Committee done the most for the aims of the Associate Section. Well done Northern Ireland; this award was very well deserved.

The Treasurer gave a very good financial report detailing our past expenses and our possible future costs. He also thanked the Main Institution on behalf of the Associate Section for the £100 cheque which was handed to him by Mr. B. Wherry, General Secretary of the Main Institution.

The new committee was elected—there is only one change—and reads as follows:

Chairman: Mr. A. J. Dow, London Telecommunication Region; *Vice-Chairman:* Mr. J. McCallum, Scotland Directorate; *General Secretary:* Mr. P. L. Hewlett, London Telecommunications Region (Telephone 01–261–4860); *Assistant Secretary:* Mr. T. F. Kinnaird, South Western Region; *Treasurer:* Mr. P. G. White, South Western Region; *Editor:* Mr. C. F. Newton, North Eastern Region; *Quiz Organizer:* Mr. T. Hopkins, Northern Ireland Directorate; *Projects Officer:* Mr. E. W. F. Philcox, Eastern Region; *Visits Secretary:* Mr. B. Hickie, Wales and the Marches Region; *General Purpose and Finance:* Messrs. B. Hickie and E. W. F. Philcox.

This is a brief report of the meeting which took place at Stone, but many points were covered and from them I would like to ask for your co-operation in helping with certain matters.

The National News will now be printed to order, that is to say that from now on members or Regions will order and pay for their own copies. Providing that the Journal can get more advertising revenue we may revert to free copies sometime in the future. Please support this journal by buying your own copy it only costs five pence and is well worth it.

The Quiz Organizer needs as many questions as possible. If you think of any good technical questions or general B.P.O. questions send them along to Tom in Northern Ireland.

The Visits Secretary would like as much information about interesting visits as possible. Send him details of your programmes, past and present. Also the Projects Officer would like to hear of any Associate Section activities going on in the Centres; please keep in touch with him and keep him informed.

Mr. Hickie would like to start a list of talks and lectures. Please send him your current program cards, together with any other papers on interesting talks which you may have had in your centre.

All names and addresses and telephone numbers of the Committee Officers can be found in the National News.

For further information please do not hesitate to contact the General Secretary on the number given.

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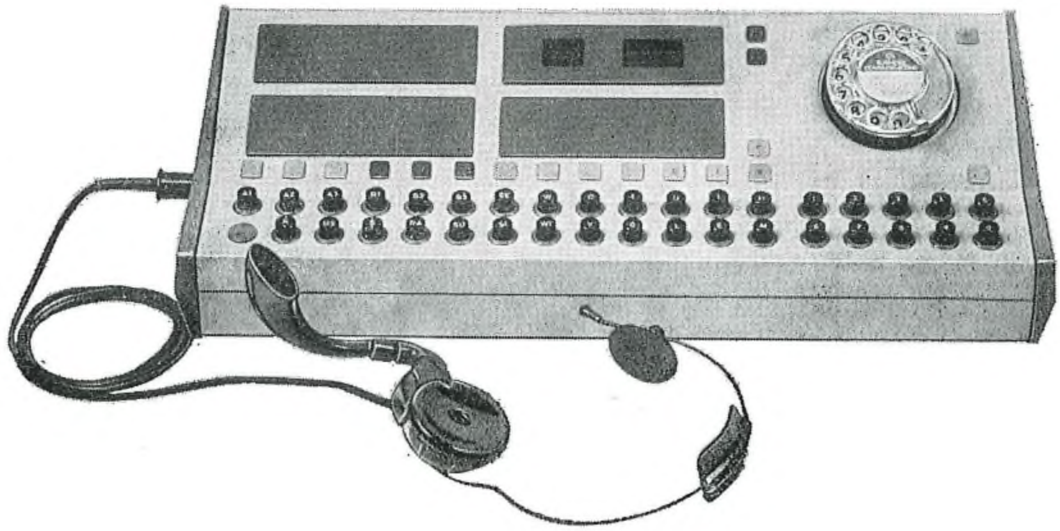

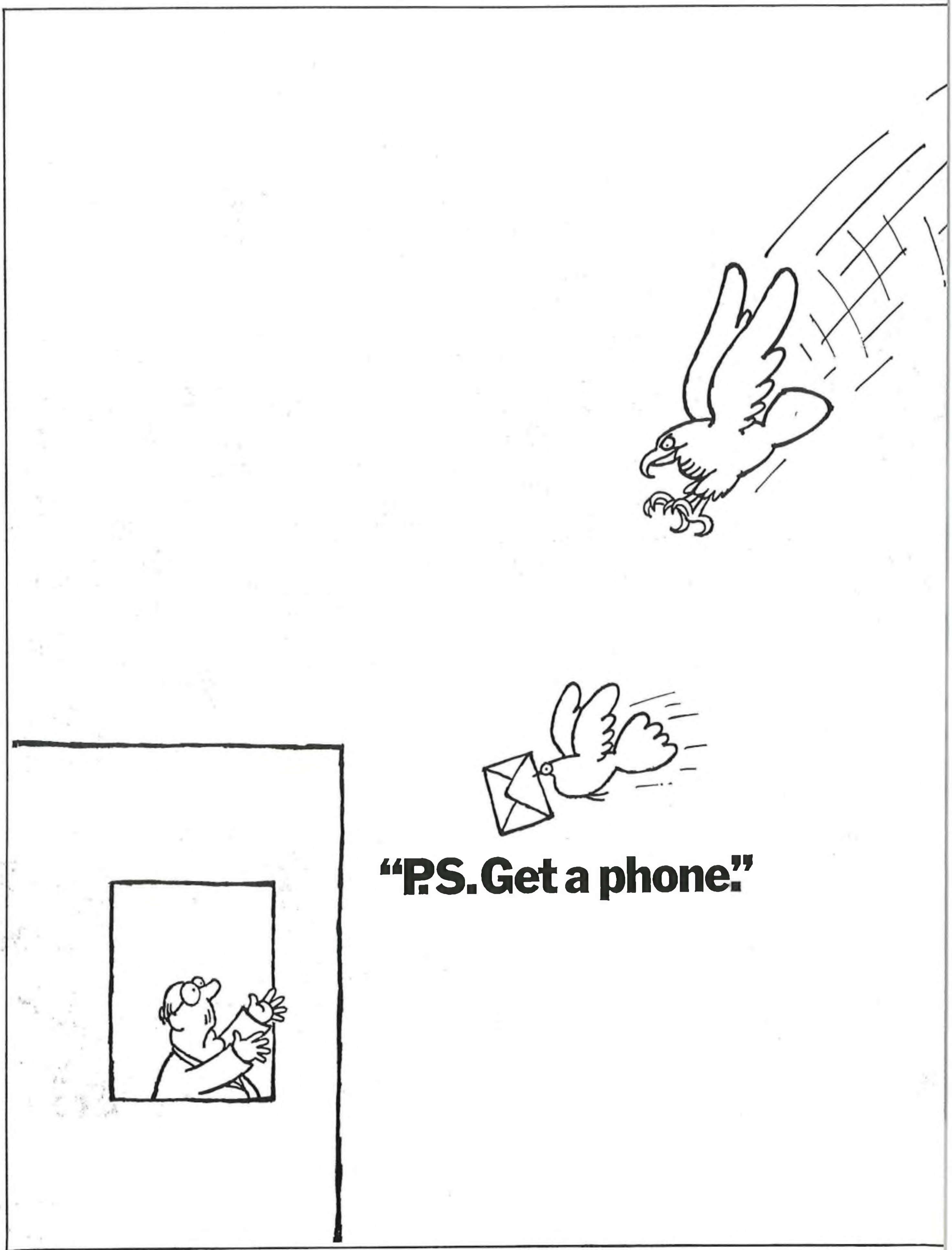
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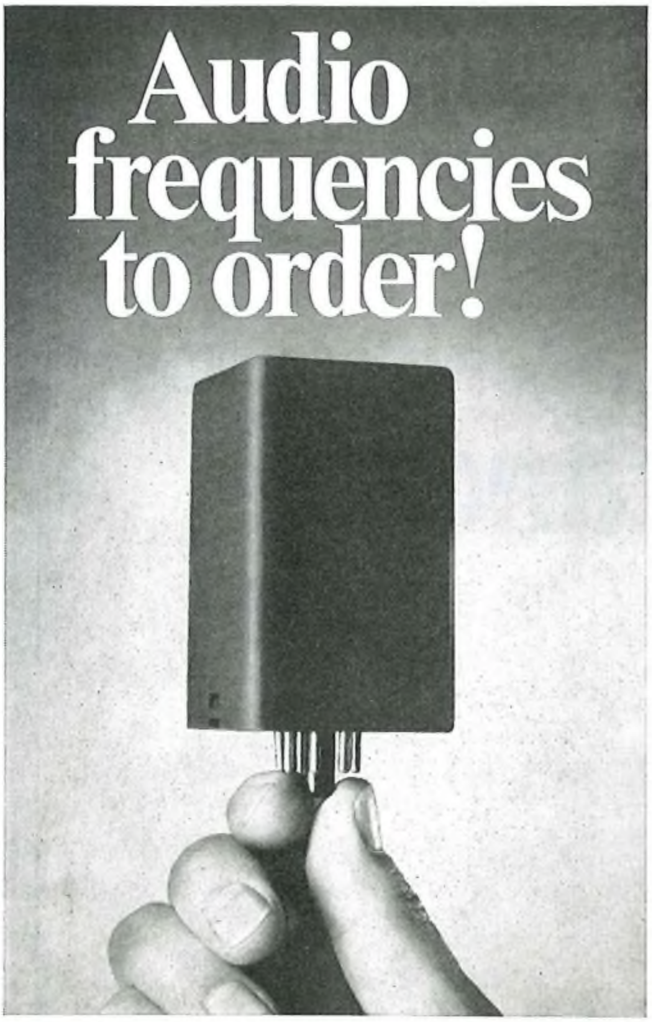

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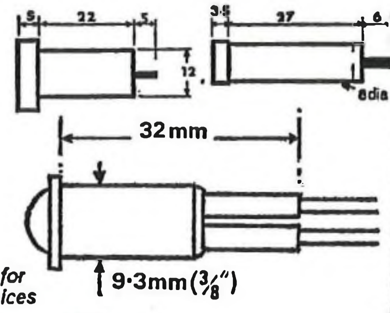

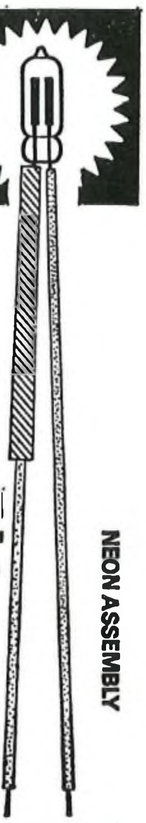

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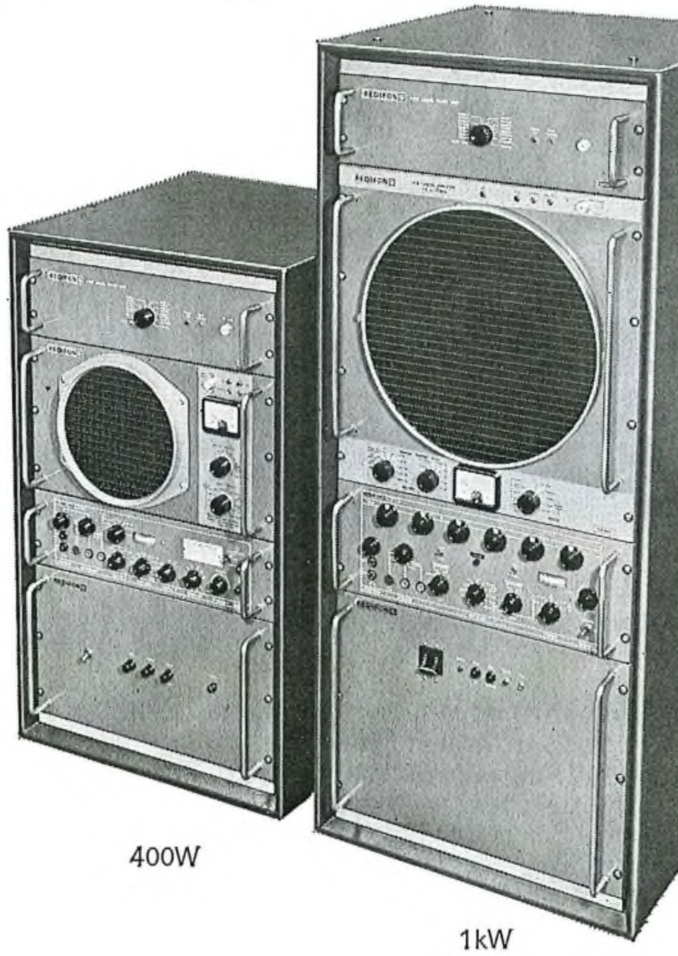

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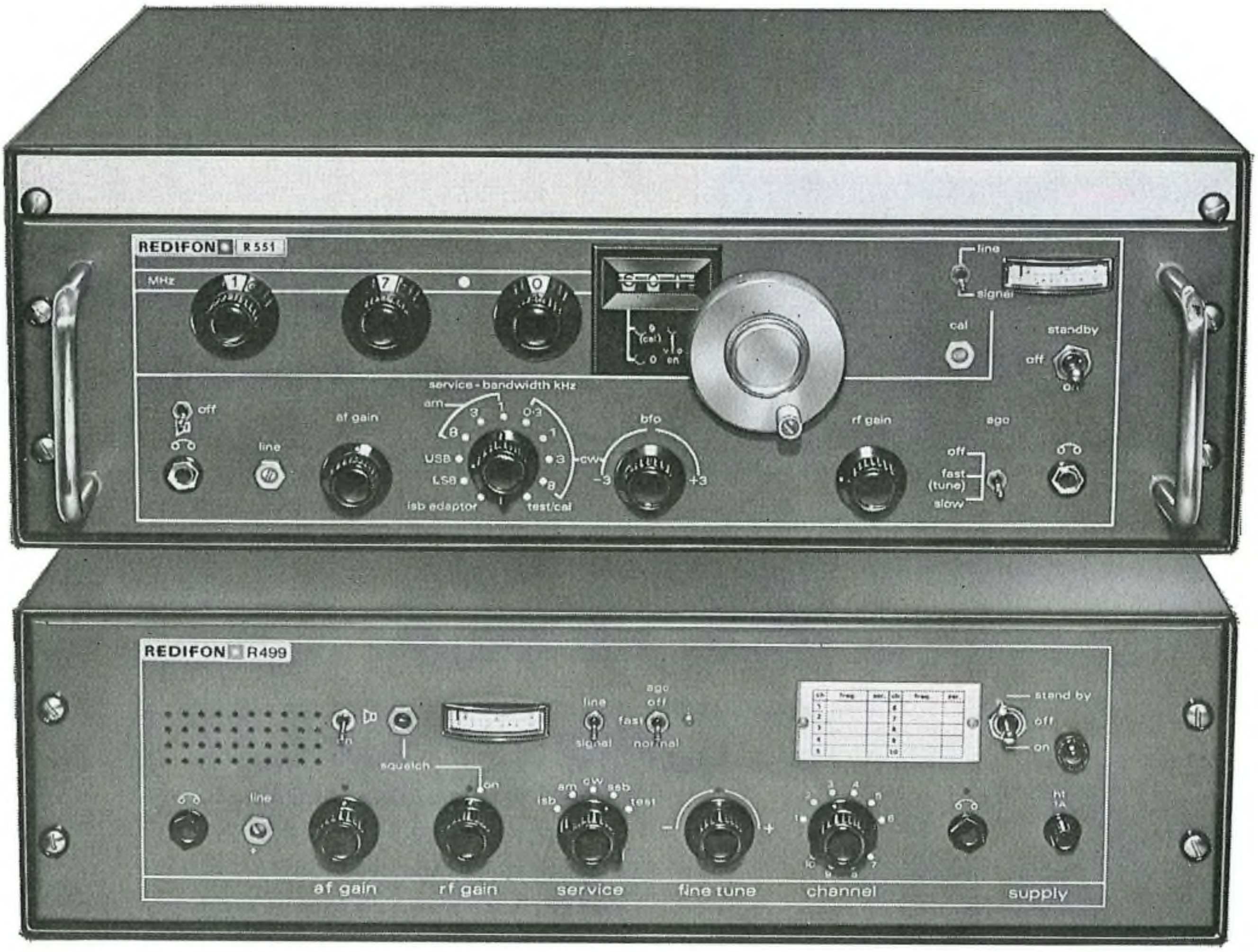

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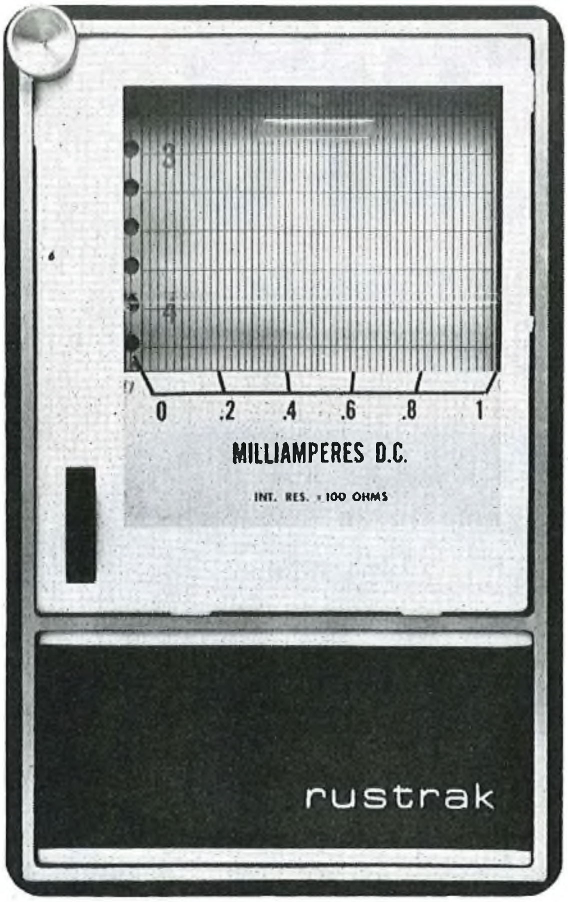

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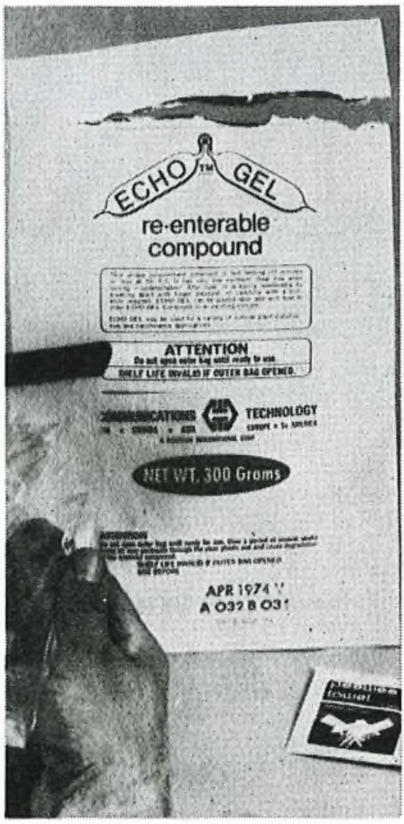

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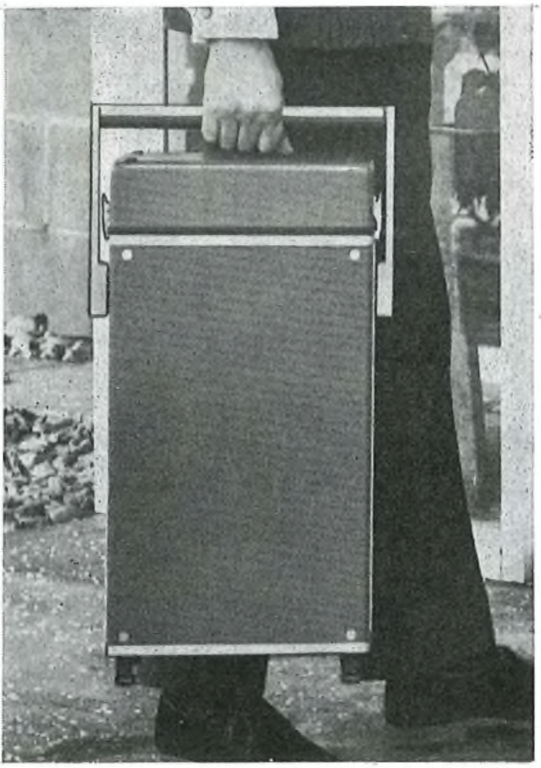

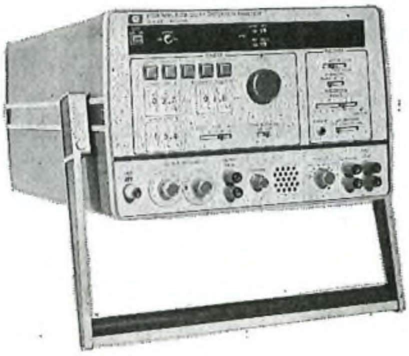

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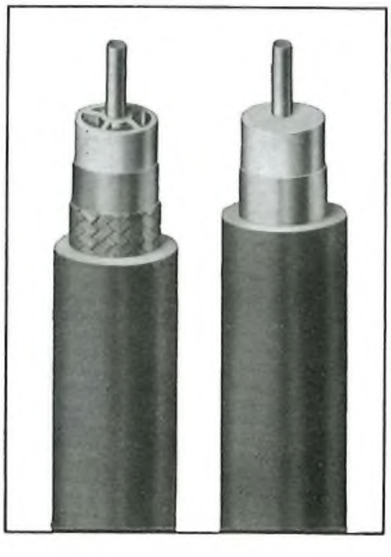

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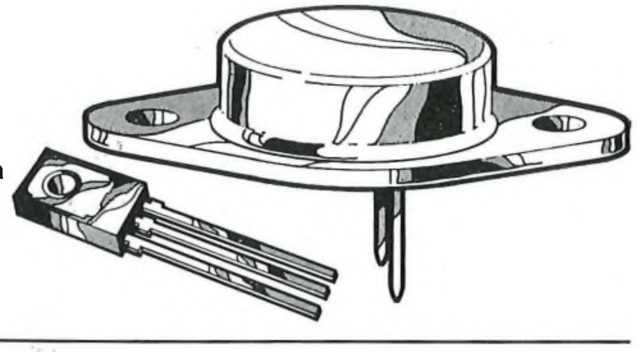

Switched Mode Power Supplies are now very much in the limelight since a wide range of transistors is now available to provide the required performance and reliability. Mullard have developed many new types for this duty and the table below summarises the present position.

These devices combine high voltages with the necessary fast fall times and are suitable for power supplies up to 800W output power.

The current range includes the BDY93 and BDY96 families of output transistors for mains-operated power supply units and the BDY90, BD131 and BDX35 families for Battery systems. Drive transistors include BD232 and BSW66.

In addition to the types shown, others are in advanced stages of development—including improved versions of the BDY90 and BDY96, and also a PNP complement to the BD232.

Full technical data on any or all of these types are, of course, available.

Type	V_{CEO}	I_C	t_f max.	Encapsulation
BDY90	100V	10A	0.2 μs at 5A; 0.05 μs at 0.5A	TO-3
BDY91	80V	10A	0.2 μs at 5/0.5/0.5A	TO-3
BDY92	60V	10A	0.2 μs at 5/0.5/0.5A	TO-3
BDY93	350V	3A	0.6 μs at 2.5/0.5/0.5A	TO-3
BDY94	300V	3A	1 μs at 2.5/0.5/0.5A	TO-3
BDY95	250V	3A	1 μs at 2.5/0.5/0.5A	TO-3
BDY96	350V	10A	0.4 μs at 5/1 /1A	TO-3
BDY97	300V	10A	0.9 μs at 5/1 /1A	TO-3
BDY98	250V	10A	0.9 μs at 5/1/1A	TO-3
BD131	45V	3A	0.15 μs at 2/0.2/0.2A	TO-126
BDX35	60V	5A	t_{off}: 0.8 μs at 5/0.5/0.5A	TO-126
BDX36	60V	5A	t_{off}: 0.8 μs at 5/0.5/0.5A	TO-126
BDX37	80V	5A	t_{off}: 0.8 μs at 5/0.5/0.5A	TO-126
BD232	300V	0.25A	f_T (typ.): 20 MHz	TO-126
BSW66	100V	1.0A	t_{off}: 1 μs at 500/50/50mA	TO-39
BSW67	120V	1.0A	t_{off}: 1 μs at 500/50/50mA	TO-39
BSW68	150V	1.0A	t_{off}: 1 μs at 500/50/50mA	TO-39
458BDY/A	400V	10A	0.8 μs at 5/1/1A.95°C	TO-3
458BDY/B	400V	10A	1.2 μs at 5/1/1A.95°C	TO-3
424BDY/A*	100V	7A	t_{off}: 0.65 μs at 7/1.7/0.7A	TO-3
426BFY/A	300V	0.5A	f_T (typ.): 60 MHz	TO-39
426BFY/B	250V	0.5A	f_T (typ.): 60 MHz	TO-39

**Also available as CV9936.*
All devices are NPN polarity except the 426BFY which is PNP.

Microwave transistors

Additions to the high-frequency families

A recent addition to the Mullard range of devices for Post Office high-frequency equipment is the 551 BFY/A: this transistor has a typical f_T of 5GHz and is in a true microwave encapsulation which makes it suitable for 'S'-band amplifiers.

In addition microminiature versions of BFR90/1 are now available (new number BFR92/3) and for BFY90 (new number BFS17R). Please ask for data sheets on any or all types.

Operating current	f_T: 1.5—2GHz	f_T: 3—5GHz
14mA	BFX89 BFW92 BFY90 BFS17R	BFR90 551 BFY/A BFR92/3
30mA	BFW30 BFW93	BFR91 BFR96
75mA	BFW16A/17A	BFR94

New Linear IC's

Additions to the Mullard range of linear integrated circuits include:

Level sense switching device, TAA320A: this device acts as a switch circuit with very high input impedance (1pA input leakage current) and high output capability (60mA). The switching reference voltage is so constant that the device can be employed as a stable reference in RC timing circuits.

Drain source voltage: 20V max.
Drain current: 60mA max.
Gate source voltage (selected):
Group 1 10.0 to 11.2V
2 10.7 to 11.9V
3 11.4 to 12.6V
4 12.1 to 13.3V
Gate source leakage current (typical): 1pA.

Clock circuit, SAJ250: a 32kHz clock comprising an oscillator, 15-stage frequency divider and supply current regulator.

Frequency division: 2^{15} (32768)
Supply voltage range: 0.9 to 3V
Supply current: 20μA (typical)
Output current: 15mA (typical)

Full technical information will be sent on request.

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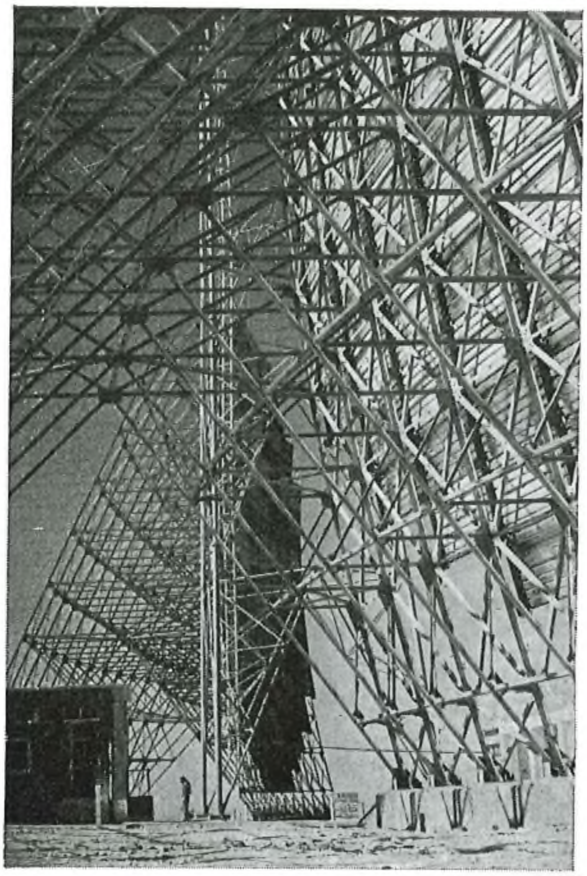

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The range includes

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Hydrus H2001 Series

General purpose receivers for international trunk routes. Versatile and reliable. High stability performance with built-in frequency synthesis.

H2311

Economical general purpose receivers with exceptional wide coverage from 10kHz to 30MHz. Compact, reliable, stable.

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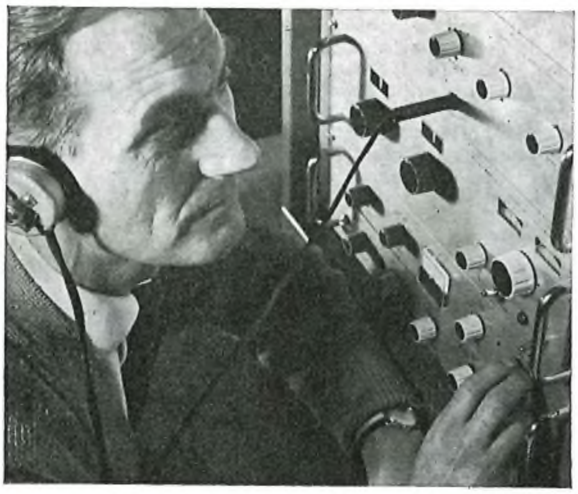
Designed to stringent defence specifications, these high-stability, robust h.f and m.f receivers are designed for naval or similar applications.



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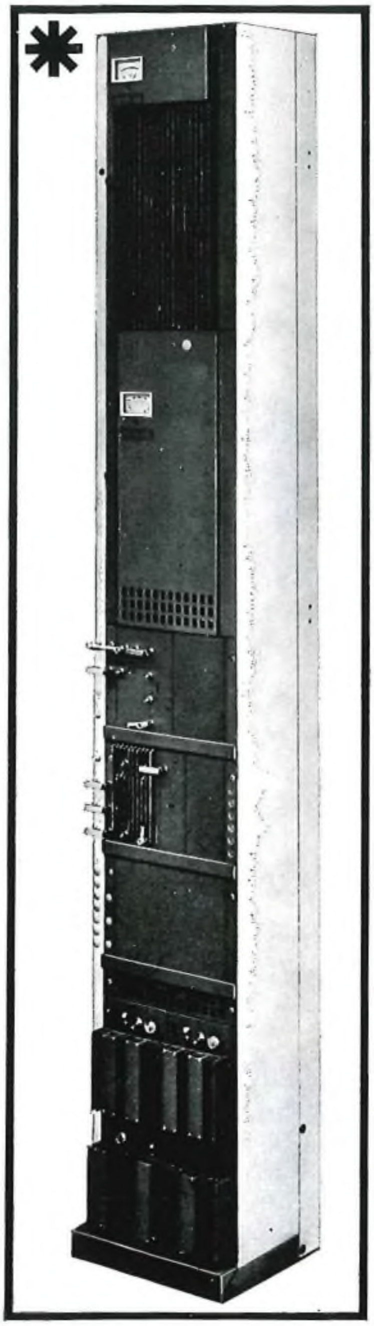

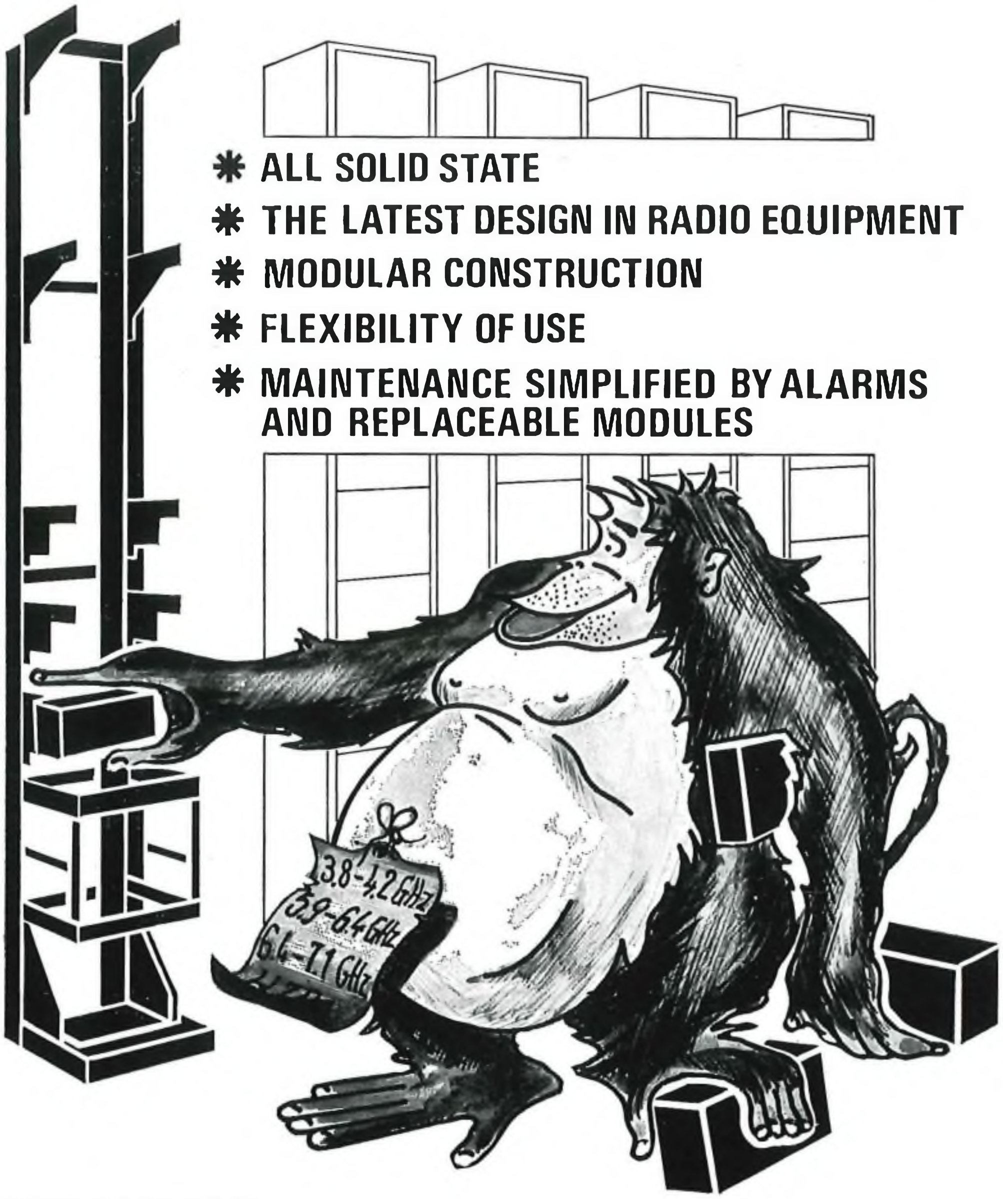

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