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The Institution of Post Office Electrical Engineers

Recent Developments in Line Transmission Systems

R. H. FRANKLIN, E.R.D., B.Sc. (Eng.), M.I.E.E.
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M. B. WILLIAMS, B.Sc. (Eng.), A.M.I.E.E.

A Paper read before the London Centre of the Institution on 3rd February, 1958, and at other Centres during the Session

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I. INTRODUCTION

The trunk network of the B.P.O. has seen, during the past 40 years, many developments which have improved its performance and, at the same time, reduced its cost. In the future there will be new requirements, such as those for industrial television and the needs of automation, which will set new problems and standards; these, together with technical developments to reduce cost still further, will change, materially, the network as it exists today.

This paper traces briefly, the build-up of the network, deals with the economics of the present network, and then reviews the new systems being introduced into the trunk system.

2. OUTLINE OF PRESENT AND FUTURE TRUNK NETWORK

2.1. Growth of the Trunk Network

During the past 40 years there have been four distinct phases of growth each of which resulted from an advance in transmission techniques; the network existing at each particular date influenced the next stage of development. Although a number of underground telephone cables were laid as early as 1910*, the war slowed up the work and it was not until after 1920 that underground cables superseded the heavy gauge overhead conductors. The cables were paper core multiple twin with 40 and 70 lb. conductors and the phantoms were used for the longer circuits. Many of these old cables have since been recovered at a profit, particularly those with few pairs and where the duct space was required; many others are still giving excellent service. The development of 2-wire and 4-wire valve repeaters in the early 1920's saw the gradual introduction of cables with lighter conductors. Reductions in the costs of repeaters soon led to the use of the 20 lb. P.C.Q.T. cables with d.c. signalling on the phantoms (500/20 c/s signalling on the longer circuits). The amplified circuits used 4-wire repeaters, and 2-wire repeaters soon ceased to be provided. The 20 lb. conductor cables were found to give transmission and signalling meeting the requirements of short and long distance circuits at reasonable cost without imposing the restrictions on plant utilisation that would have occurred if composite cables had been provided with a mixture of 20 lb. and 40 lb. conductors. Thus, by 1930, the 20 lb. P.C.Q.T. cable became the standard method of provision and is still used extensively to provide circuits under 50 miles in length.

The next significant change in technique came in the early 1930's with the development of the one, three and four circuit carrier systems. These were quickly followed by the 12-circuit carrier system using separate 24 pair "GO" and "RETURN" cables. The introduction of carrier working significantly reduced the cost of long distance circuits (cost was no longer directly proportional to length) and it was possible to reduce the tariffs on calls over 100 miles. 2 V.F. dialling on zone-to-zone routes was introduced at the end of this period.

The 12-circuit carrier network expanded rapidly between 1935 and 1945. The intermediate buildings and power plants were provided to meet the needs of two such 12-circuit systems in the 20-year period, but in the event this was not the method of expansion generally adopted.

The development of the coaxial cable system followed closely on the heels of the 12-circuit carrier system, the first system, between London and Birmingham, being designed for 320 circuits. Although relatively expensive at first, with subsequent improvements in design the coaxial cable system soon became the cheapest method of providing large blocks of circuits over distances above 50 miles. One important new feature was power feeding over the cable of the intermediate repeaters; the cost of providing a reliable source of power at each intermediate station would have been prohibitive.

During this period it was found that the existing 12-circuit cables could transmit satisfactorily up to 108 kc/s and thus it was possible to double the capacity of the carrier network by providing new line equipment only. Although the coaxial cable system had become cheaper than a new 12- or 24-circuit carrier system, it was not cheaper than buying new equipment and a few additional buildings for the existing carrier cables. Trunk growth over carrier routes was thus met by 24-circuit conversions; this method of expansion started in 1945 and is now nearly completed. The growth of a coaxial cable network was thus retarded by the successful and economic conversion of the existing 12-circuit carrier network.

The latest phase of growth, from 1948 onwards, on the main trunk network has been the widespread provision of coaxial cables on all main routes of the country. The build-up of the network is shown in Fig. 1 and the various phases of provision can be clearly seen. In order to indicate the relative magnitude of audio and h.f. cables, the former has been shown in miles of 1,000 cable pairs (500 4-wire circuits). The advent of television transmissions, which may be co-ordinated with telephony by providing coaxial cable systems which can alternatively carry 900 or 960 telephone channels, has added fresh

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* Underground telegraph cables were laid somewhat earlier; the London–Birmingham No. 1 Cable laid in 1898 with 150lb. conductors in star-quad formation is still in use for telephony.

impetus to the growth of the h.f. network. Radio links have been used in many instances to meet urgent television requirements which could not have been met by cable provision on account of the time required to lay duct and provide intermediate repeater buildings, or where no telephony demand exists, etc. More recently radio systems to carry both telephony and television have been planned and the first of these from England to France is about to be installed.

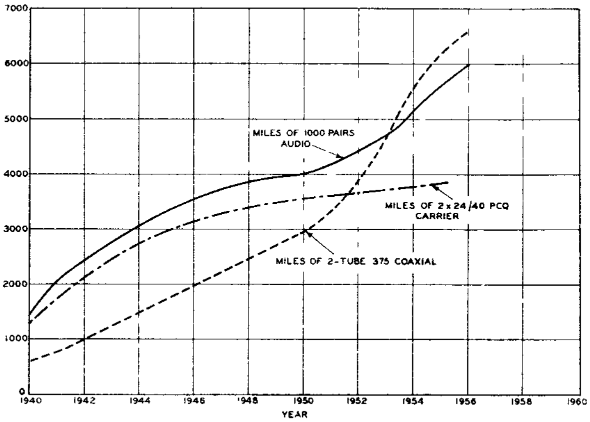


Fig. 1.—Growth of Cable Mileage.

2.2. Effect of Improved Techniques on Costs

The extent by which transmission development has been successful in reducing circuit costs can be assessed by comparing the cost of the various methods of provision at present day prices. Such a cost comparison for a 100-mile trunk circuit is given in Fig. **2**, which shows that by employing new methods of transmission the real cost of provision has been reduced by over 90 per cent. from 1914 to the present day. Technical development in this mileage range has managed to keep pace with inflation and the "paper money" cost of provision has not increased.

For circuits having lengths under about 50 miles, carrier working is not yet economic and the method of provision has not changed since 1930 ; cost has thus risen with the rising level of prices.

It is interesting to note (see Table 1) that trunk call charges have followed the trend of line plant costs even though they take account of the other expenses incurred in setting up a trunk call.

TABLE 1

Trunk Call Charges (3 Minutes)

Distances *Miles*	1915	1925	1936	1945	1957	1958
35 — 50	8d.	1/6	1/3	1/10	1/10	1/9
50 — 75	1/-	2/-	1/6	2/3	2/3	2/3
100 — 125	2/-	3/-	2/-	3/-	3/-	3/-
200 — 250	3/4	5/6	2/6	3/9	3/9	3/6

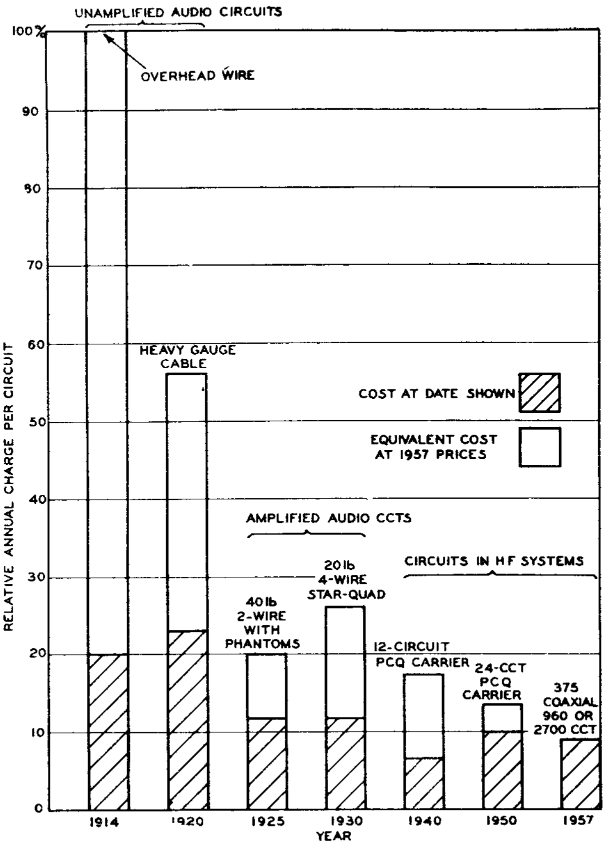


Fig. 2.—Relative Costs of 100 Mile Trunk Circuits (Includes Signalling Costs, Excludes Spare Plant Burden).

2.3. The Present Network

In considering the present network it is useful to know how the cost of providing and maintaining the network is distributed between circuits of various lengths. It is then possible to estimate to what extent cheaper forms of transmission are likely to reduce the overall cost. Fig. **3** shows :

(*a*) the number of circuits (longer than 10 radial miles) in each 5-mile distance step ;

(*b*) the percentage contribution to the total annual charges of all circuits up to any given length.

Note. The analysis has been made on all circuits between 10 and 200 radial miles. (Figures for circuits under 10 miles are not readily available)

One half of the annual cost of providing and maintaining all circuits between 10 and 200 miles length, is due to circuits shorter than 50 miles. This field offers great scope for economies. The proposed short distance carrier systems and the new 2-wire audio repeaters are both intended for this mileage range and it is hoped that substantial savings will be made during the next few years.

During the past ten years, there has been a large increase in the proportion of circuits using h.f. plant, and this trend will continue as it becomes economic to

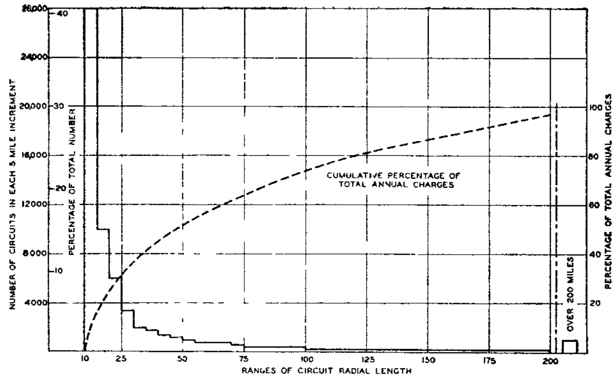


FIG. 3.—DISTRIBUTION OF THE NUMBER OF CIRCUITS (OVER 10 MILES) AND THEIR TOTAL ANNUAL CHARGES.

provide h.f. systems over shorter distances and for smaller rates of growth. Even now, however, only 15 per cent. of the h.f. network is used for circuits less than 100 miles in length. The gradual swing to h.f. working is shown by Table 2 :

TABLE 2

	Proportion of Total Circuit Mileage		*Increase*	
	1950	1956	1950 *to* 1956	
	%	%	%	
Audio ...	59	54	43	Overall increase 57%=7.7% per annum
12/24 Circuit Carrier ...	32	27	32	
Coaxial ...	9	19	230	

The average percentage increase in circuit miles is greater than the corresponding increase in trunk circuits for the following reasons :

(*a*) There has been a larger increase in the number of long distance private wires.

(*b*) Long distance trunk circuits are increasing at a greater rate than short distance circuits. The 1956/57 circuit forecast showed a four-year increase in circuits under 100 miles of 16 per cent., and in circuits over 100 miles of 28 per cent.

(*c*) The greater use of h.f. systems results in an increase in the ratio of route to radial mileage. It is less expensive to use up spare capacity in a carrier or coaxial cable over an indirect route than to provide a cable on the direct route.

2.4. Factors Affecting the Future Growth of Network

2.4.1 *Traffic Growth*

The extent to which the advantages of new h.f. systems can be exploited will be dependent upon the demand for trunk calls and allied services ; a large demand for new services is the best stimulant to new development. Over the past 20 years the number of trunk calls and circuits have increased by approximately 250 per cent., and two extensive television networks have been provided.

The growth of trunk traffic will always reflect the extent of business activity for which, at the present time, the future is a little uncertain. However, it is found that, although business activity and tariff charges affect the number of trunk calls over a short period, the long term expansion has been fairly uniform at approximately 900 circuits per year (now about 4 per cent. of the present number of circuits), but there are new factors which could increase the growth and which should be considered in a little more detail.

2.4.2 *Group Charging*

The increase in traffic following the introduction of Group Charging at the beginning of 1958 to replace point-to-point charging is expected to be more noticeable in some areas than in others, depending on the community of interest between towns previously connected by multi-fee or timed calls which became unit fee. The rapidity with which the public will take advantage of reduced charges is difficult to forecast.

2.4.3 *Subscriber Trunk Dialling*

When this is introduced at an exchange an increase in traffic can be expected simply because subscribers are able to dial their own calls. Also the attraction of being able to obtain short duration calls for less than the three-minute charge, which will be possible under S.T.D., could lead to a large increase in the number of calls but they would have a shorter average duration than at present.

3. ECONOMIC COMPARISON OF THE VARIOUS METHODS OF TRUNK PROVISION

3.1. General

In considering the economics of trunk provision, all factors which may be different for the various methods have to be taken into account. The two main alternatives to be considered are :

(*a*) Audio cable with d.c. signalling and with or without repeaters.

(*b*) H.F. systems (carrier and coaxial cable systems and radio systems) with a.c. signalling.

Each of these methods has its own peculiar cost characteristics which will affect the rate of provision required to meet a given demand.

3.2. Economics of Planning

The assessment of the cost of the alternative methods of provision is based on the normal methods used in the Post Office, in that a comparison is made of the sum of the "present value of annual charges" (P.V. of A.C.) appropriate to each item of plant.

Fig. 4 shows the P.V. of A.C. for audio and h.f. provision of point-to-point circuits for rates of growth of 6 and 24 circuits per year. The different cost characteristics of audio and h.f. systems are evident. The cost of audio provision is approximately proportional to length times the number of circuits required, and the cable and duct account for a large proportion of the overall cost. For circuits longer than 20 miles

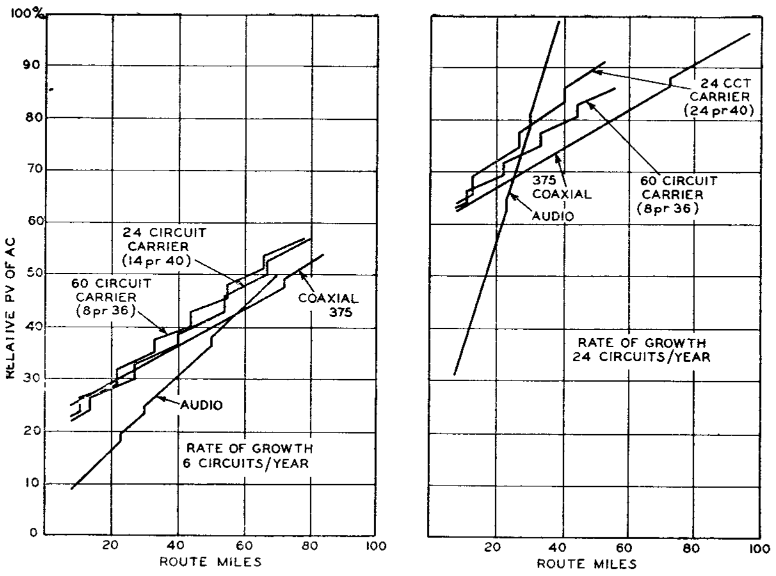


FIG. 4.—RELATIVE P.V. OF A.C. OF THE TOTAL CABLE AND EQUIPMENT COST FOR VARIOUS METHODS OF PROVISION (TWO RATES OF GROWTH).

the signalling and amplifier equipment costs can almost be neglected. On the other hand the terminal costs of an h.f. system are very high; in addition, particularly for a rate of growth of 6 circuits per year (120 in 20 years), the capacity of a coaxial cable system is considerably more than required, but it is still cheaper than an audio cable for distances above 60 miles.

Fig. **5** shows, for various rates of growth, the distance at which h.f. working "proves in" as compared with audio. It also demonstrates that coaxial systems are less expensive than the 24 and 60 circuit carrier systems at all distances where h.f. working is economic.

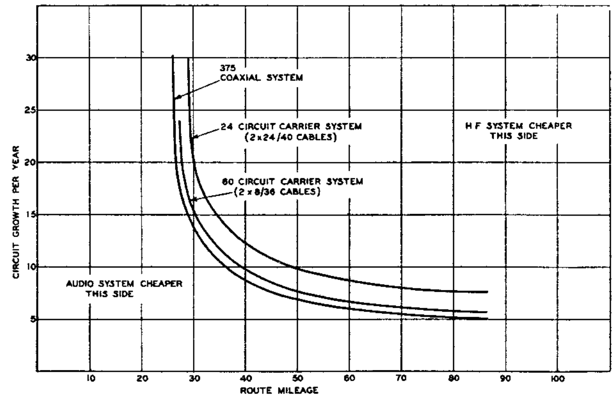


FIG. 5.—EQUAL COST CURVES BETWEEN AUDIO AND H.F. PROVISION OF POINT-TO-POINT CIRCUITS.

3.3. Extensions from the H.F. Network

It is often necessary to determine the least expensive method of providing extensions from an established h.f. network. Here the expensive carrier terminals and a.c. signalling equipment have to be provided irrespective of whether the extension cable is audio or h.f. The comparison is thus between the cost of an audio cable and that of an h.f. line system. The equal cost curves are shown in Fig. **6** and it will be seen that h.f. provision can be justified for very short distances.

Although it may be economic to provide an h.f. system to extend circuits from the main h.f. network, it may still be uneconomic to include short point-to-point circuits in the system in order to use up spare line capacity. If the cost of providing circuits on additional pairs in audio cable is equated to the cost of adding channel equipment to an existing h.f. system (assuming that the line costs nothing as there is spare bandwidth) then it is found that it is cheaper to provide the circuits on audio plant if the distance is less than 18 miles.

The curves in Fig. **6** show that carrier cables may be cheaper than coaxial for short h.f. tie cables and in particular between h.f. distribution frames in different buildings in the same town.

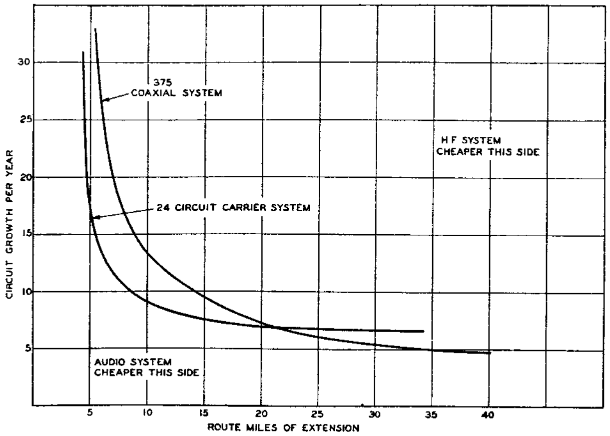


FIG. 6.—EQUAL COST CURVES BETWEEN AUDIO AND H.F. EXTENSION OF CIRCUITS FROM AN H.F. SYSTEM (CIRCUITS AVAILABLE AT GROUP LEVEL).

4. NEW TECHNIQUES

4.1. General

At the present time, transmission equipment is being rapidly and intensively developed by the Engineering Department and by industry. New materials and components, such as ferrites, semiconductor devices, synthetic plastics and new valve types are at the disposal of designers. The techniques of electronic circuit and network design are advancing so that better and less expensive equipment can be produced without wide margins for errors and suited to modern production methods. Much of the impetus for this development comes from the keen competition between manufacturers at home and abroad for foreign markets. In these markets, low capital cost, small size and low power consumption are important selling points and much design effort has been devoted to the development, from the older designs, of equipment of modern types, providing similar or even improved facilities and performance, but better suited to the competitive export markets. Substantial increases in the capacity of carrier line systems have also been achieved, for example, by increasing the frequency band transmitted by the standard $\frac{3}{8}$ in. coaxial cable from 4 Mc/s to 12 Mc/s, or more and, by the development of a small-diameter $\frac{1}{6}$ in. coaxial cable system with transistor repeaters to replace the 24- and 60-circuit carrier systems.

Many of the new developments are capable of immediate application within the U.K. network ; where the export equipments can be used for B.P.O. requirements there are substantial economies in equipment capital cost resulting from the large-scale manufacture of a competitive design. But sometimes the type of telephone development and the administrative and the operational framework may be different in foreign markets from those in the U.K., fully-engineered proprietary systems may incorporate features (such as non-preferred valves) or may be based on compromises which are unacceptable to the B.P.O., particularly where individual items and not complete systems are to be bought. Sometimes, a minor variation from an export design may be practicable without excessive development or undue increase in manufacturing costs.

It will be clear from the above that B.P.O. interests in the purchase of transmission equipment are best served by a careful and objective analysis of the requirements of the B.P.O. network, carried out in the light of current developments of proprietary equipment for export ; discussions with contractors at an early stage of their development work may usefully guide designers' compromises in a favourable direction but for obvious reasons such opportunities are not common.

4.2. New Constructional Techniques

51-type construction is now fairly familiar having been adopted as a B.P.O. standard method of construction for new equipment design for several years. It is a highly organized and codified assembly and piece-part system which comprises a pressed-steel rackside with ready replaceable panel assemblies made from standardized pressed-steel or die-cast piece-parts. Connexion with the rack wiring is via flat-bladed or coaxial U-links having access points for level and voltage measurements. Each panel is built-up in three-dimensions, some components, especially functional units, being assembled on wafers inside enclosed (not necessarily sealed) cans. Components are jointed between convenient tags and there is a minimum of formed panel wiring. This type of construction, although employing some expensive piece-parts, has been found very convenient and satisfactory for all applications where flexibility in 2-unit panels ($3\frac{1}{2}$ in.) or larger is convenient. However, advances in electrical circuit design have rapidly reduced the physical size of such natural units as a complete channel modem panel or an audio amplifier so that several can be accommodated in the space occupied by a 2-unit panel. Consequently a smaller constructional unit, having plug-in facilities, is required. This has been achieved and some of the more expensive piece-parts of 51-type construction abandoned with the introduction of the variant known as 56-type construction. In the new form of construction, the existing 51-type rackside is retained and a rackside can be equipped partly with 51-type and partly with 56-type equipment.

The panel, formerly the smallest unit, has been broken down into smaller units disposed horizontally across the panel width. Connexions to the units are made using U-links and connexion blocks at the horizontal and vertical edges of the units, which are in cans located by clips on to the shelves and can be easily removed. The new racks have extra drillings to accommodate a greater range of unit heights ; the separation of the shelves can be made in multiples of $\frac{7}{16}$ in., which is one-quarter of the old "unit" of $1\frac{3}{4}$ in. Fig. **7** shows a channel unit constructed in this new form.

Cabling on the new equipment may be run down either the sides or the centre of the rack.

The through-level test facility provided on the 51-type U-links cannot be fitted on the smaller links of the flat-bladed type used on the 56-type construction, any through-level test points will be provided within the functional unit itself. Coaxial U-links, however, are substantially the same in both 51- and 56-type form. The facility of solder-strapping across the U-link connexions has not been continued in 56-type equipment. This facility was available in 51-type equipment but it has not been found necessary to suspect the reliability of the flat-bladed connector. With advances in the reliability and life of equipment, particularly if the hoped-for service from transistor equipment is achieved, it would be possible to dispense with U-link connectors for equipment affecting only single-channels and to substitute simpler and cheaper wire strapping. This possibility is being considered for future audio equipment.

4.3. New Components

Most of the component developments foreshadowed in Mr. R. J. Halsey's 1949[1] paper have now passed into general use. These include ferrite inductor and transformer cores, germanium diode modulators and polystyrene film capacitors. A marked advance in valves for wide-band amplifiers has been achieved with the development by the Bell Telephone Laboratories of their types 435A, 436A and 437A and their subsequent incorporation in the L3 coaxial line system. Similar valve types are now made in this country and types equivalent to the 435A and 437A have been given the codes CV 3998 and CV 5112. These valves form the amplifying and output stages of the 12 Mc/s line amplifier and will have other applications.

Perhaps the most significant current development, however, is that of the transistor. Some low-frequency transistors are already standardized by the Services and the B.P.O. and have been incorporated in audio-frequency equipment. High-frequency transistors are now available commercially although not yet standardized, and nearly all new transmission equipment development for frequencies up to about 1 Mc/s is based on the expected availability of transistors to replace valves in all low-power applications. Some of these applications will be referred to in subsequent sections. The simplicity and economy of power supplies, the reduced heat dissipation and increased reliability expected of transistorized equipment will profoundly influence future planning. In particular their use will solve the space heating problem which in 1949 Mr. Halsey thought would set a limit to further miniaturization.

5. DEVELOPMENTS IN TERMINAL TRANSLATING EQUIPMENT

5.1. "Medium-distance" Channel Equipment

Detailed breakdown of circuit costs showed many years ago that the cost of conventional channel equipment with 4 kc/s spacing together with the signalling equipment of channels is the major item in the total cost of providing short and medium distance circuits.

The Netherlands Telephone Administration concluded from similar studies that a single-sideband system with 6 kc/s spacing of channels would give worthwhile economies if applied extensively throughout their network ; the additional separation between the channels leads to simplification of the channel band filters and at the same time provides space for an outband signalling channel.

The B.P.O. prepared a general specification for a medium-distance channel equipment based on providing at least 8 channels in the basic group (60—108 kc/s), each channel having built-in continuous-tone signalling equipment using an outband signalling frequency. Field tests of contractors' designs were made.

One of these designs has been developed to meet the requirements of the B.P.O. specification from a proprietary equipment which has been in production for some time and a number of B.P.O. installations are planned following the satisfactory completion of the field trial. This equipment is especially suitable for small stations and for installation by direct labour as it is entirely self-contained, including its own free-running carrier oscillators. However, the relatively poor frequency accuracy of these oscillators may impose limitations upon the use of in-band v.f. signalling equipment and v.f. telegraphy. A typical example of the scope for this type of equipment is given by the solution to the following problem :

> "It is desired to augment certain routes around Truro without the expense of laying new audio cables which would also result in a large duct expenditure. Spare pairs in the Tavistock-Truro 24-circuit carrier cables could be cut into, for example, St. Austell and used to provide Truro-St. Austell circuits, Bodmin-St. Austell circuits etc., provided that :

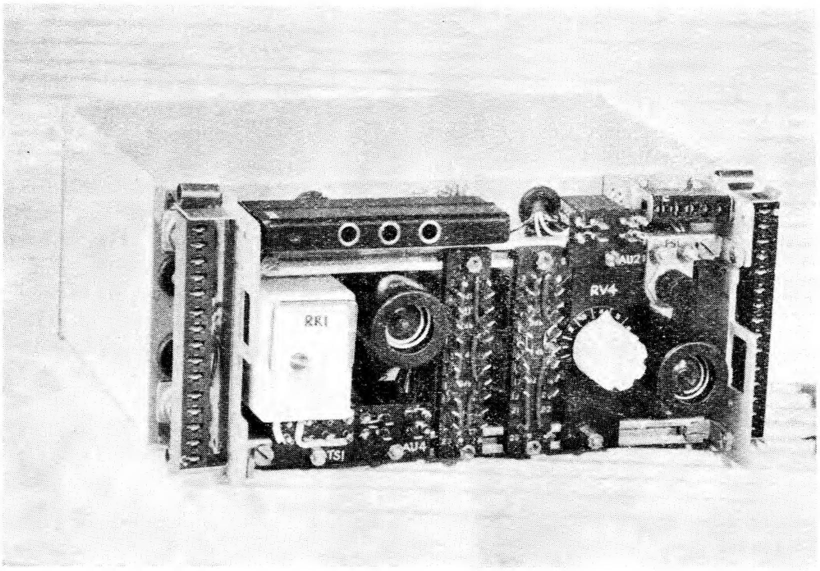


Fig. 7.—56-Type Channel Unit with Outband Signalling.

(i) a self-contained and inexpensive type of group modulating and channel translating equipment were available, suitable for an initial small installation, and

(ii) signalling facilities (including those of subscriber-dialling) similar to those available on the existing audio circuits can be provided on the carrier channels. (The use of Signalling System A.C. No. 1 in this application where direct subscriber-dialling was required would have involved the development of a new form of outgoing relay set giving metering. Additionally problems of accommodation would have arisen.)

One design of 6 kc/s-spaced channel equipment is a double-modulation system, first assembling 8 channels in the range 12-60 kc/s and then translating them to the 60-108 kc/s range. Application of this to 24-circuit carrier cable working is then conveniently made by combining one group in the lower range with a second group after modulation. A special version of the equipment has been arranged for this purpose. The built-in signalling equipment gives all the essential signalling facilities when used with the appropriate exchange relay sets."

This example may be taken as illustrating a useful field of application of this type of channel equipment and at present it is often the only means available of introducing carrier working on the shorter routes while maintaining existing facilities. However, the long-term justification for 6 kc/s-spacing as against the internationally-standardized 4 kc/s-spacing has by no means been established. Indeed, it seems very probable, that mass-production of the standard 4 kc/s-spaced equipment will eliminate the marginal cost advantage of the easier filter design of 6 kc/s-spacing if the market for the latter is limited. It may well be that 6 kc/s-spaced equipment represents merely an interim stage in the development of medium-distance carrier working. At the time of writing, however, the problems of designing a low-distortion signalling channel with an outband signalling frequency of 3825 c/s for 4 kc/s-spaced channels have not yet been overcome and the 6 kc/s designs are the only ones which fully meet the B.P.O. requirements in this respect.

5.2. 4 kc/s-spaced, 56-type, Channel Equipment

Two manufacturers have developed for their export markets entirely new forms of main-line channel translating equipment with 4 kc/s-spacing of channels, meeting the C.C.I.T.T. requirements, and capable of providing outband signalling using the internationally recognised frequency of 3825 c/s. Although electrically dissimilar as the development was carried out quite independently, a common type of mechanical construction, 56-type previously described, has been evolved to suit the more compact functional units. A typical channel unit (with signalling), shown in Fig. **7**, comprises modulator, demodulator, transmit and receive band filters and receive amplifiers, as well as the sending static relay, signalling receiver and combining circuitry in one half of a 3½ in. panel. These units are far smaller than present types of 4 kc/s-spaced channel equipment without signalling, and mount 36 channels on a 51-type rackside. Both these new units use conventional valves (CV 455, double-triodes) which results in a high concentration of heat-dissipating components on an equipped rack (250 watts per rackside without signalling, 450 watts per rackside with signalling). It would not be permissible to have continuous suites of this type of equipment but no doubt considerable dilution with low-power equipment could be achieved in most stations. This problem will vanish when valves are replaced by transistors as has already been achieved at the design stage. A fully-transistorized channel panel (without signalling) is expected shortly to be in production and will be even smaller than the valve type referred to above, 72 channels being accommodated on a 9-foot rackside. The transistorized unit operates from a 21 volt supply which may be a central battery or a mains-driven power unit individual to the rackside.

The drastic reduction in the size of channel equipment which will become general when fully-transistorized equipment is available will bring consequential changes in station layout. One place where there may well be a simplification of station cabling is in the carrier distribution arrangements. In view of the large amount of carrier power required per rackside, the distribution of supplies to the individual channel panels may be effected via distribution networks on the rackside. This may represent a considerable saving in the amount of on-site cabling work and hence a reduction in the time and cost of installation.

The signalling channels on the new designs of equipment were developed primarily for export requirements, e.g., for association with these manufacturers' line and radio systems. While the signalling distortion meets the requirements of particular overseas administrations, it is somewhat greater than can be tolerated for general application in the U.K. network.[2] However, there is good reason to believe that a relatively minor variation from a standard design will meet the desired target.

The introduction of new types of 4 kc/s-spaced channel equipment into the B.P.O. network is expected to proceed as follows. Providing its signalling and transmission performance are found to be satisfactory for B.P.O. use, the 56-type valve-operated equipment could be installed in stations where outband signalling equipment is urgently required. A standard form of transistorized channel equipment is expected to be available within a few years, either with or without outband signalling channels, and suitable for installation in any type of station. A present estimate is that about 15 per cent. of this channel equipment would be required with signalling, the remaining 85 per cent. would be without signalling. If this condition is in fact achieved there may be little or no field of application for present forms of 6 kc/s-spaced equipment.

It is of interest to consider the steps whereby the reduction in channel panel size has been achieved without sacrificing performance. The following factors contributed :

(1) The primary object of the re-design project was reduction in cost and size.

(2) The channel unit, including the associated signalling facilities, was studied as an integrated whole ; this leading to a major simplification of the costly channel band (crystal) filter by easing its requirements (e.g., by using a lower working level at the modulator to reduce unwanted products or by effecting some filtration at audio frequency).

(3) Smaller components were available.

Fig. **8** illustrates the progress in reducing the size of channel units over the period 1938-1958.

As the modulator input level in the new equipment has been lowered, while the group distribution frame level of —37 dbr (transmitting) remains the same, additional transmitting gain is required. In one design, this is effected by a reduction in the channel filter loss alone, and in another, a common group amplifier is provided. In some ways this addition may be regarded with misgivings as introducing an additional fault liability in an active unit common to all channels and so removing one of the advantages of single over double modulation working. However, the presence of spare gain and the improved impedance at the

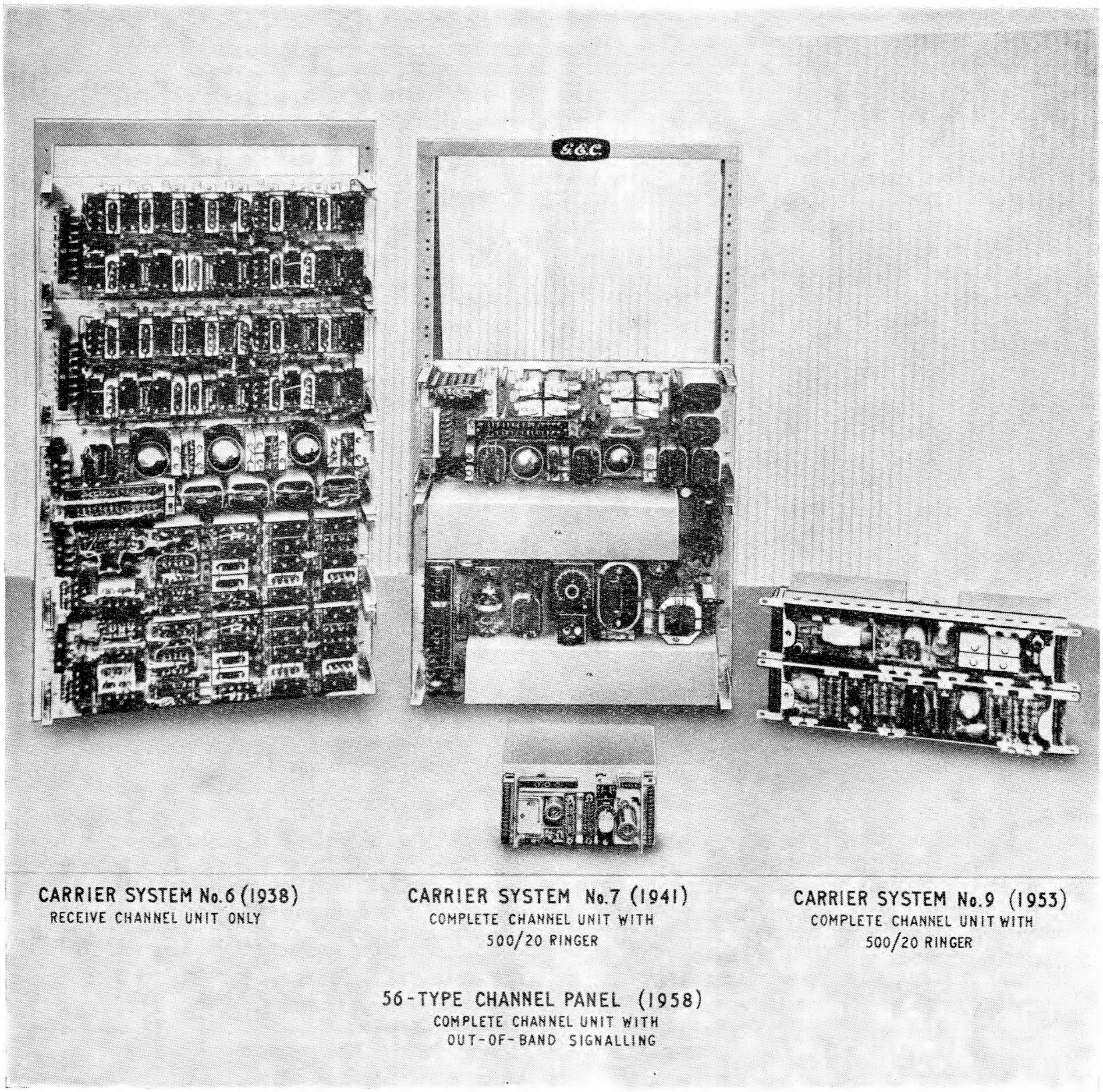


Fig. 8.—Progress in Channel Translating Equipment.

group distribution frame are worthwhile by-products. A block schematic of one type of the new channel equipment is given in Fig. 9.

6. NEW LINE SYSTEMS FOR MAJOR TRUNK ROUTES

6.1. 375 Coaxial Cable Systems

The desirable characteristics of a main trunk system can perhaps be summarized as follows :

(*a*) suitable for telephony or television,

(*b*) provide facilities for main through circuits as well as for short junction circuits along the same route.

(*c*) provide flexibility at low cost compared with the system cost.

For the past 10 years, the standard 375 coaxial cable has been by far the least expensive way of meeting the telephony growth on the main routes (apart from the re-equipment for 24-circuit working of the 12-circuit P.C.Q. carrier cables). However, it is now necessary to consider also the use of radio links for both telephony and television requirements on main routes. Although at present the highest capacity working radio link is the 240-circuit system between Braewynner and Thrumster and Kirkwall, 600-circuit systems are being provided in the U.K., and higher-capacity systems are feasible. The economic comparison of cable and radio provision is appreciably affected by such factors as the terrain, the availability of duct space, the number of broadband channels required in the planning period and the possible need to provide a junction cable in any case to serve intermediate exchanges. Where there is an existing coaxial cable, it may often be economic to increase its capacity by a more advanced design of system.

The 375 coaxial cable system has been standardized internationally for some time and telephony links of 10 and 16 supergroup capacity (nominally 2.6 or 4 Mc/s bandwidth) and with repeaters spaced at about six miles apart, are in use in many countries. In the U.K. most of the coaxial cable links at present working are of 10 supergroup capacity (e.g., C.E.L. No. 2) but the more modern and internationally standardized 4 Mc/s system[3,4], e.g., C.E.L. No. 4 or No. 6, is being extensively brought into use. These 4 Mc/s links can be used alternatively for the transmission of a vestigial-sideband television signal for the British 405-line standard (3 Mc/s video). This feature has been of great value during the present period of rapid television expansion.

Other television standards used abroad require a wider bandwidth. Transmission of the 625-line European standard (5 Mc/s video), requires a line bandwidth of some 6 Mc/s, and coaxial cable links having rather elaborate repeaters at the standard six mile spacing have been installed abroad for this purpose. However, using the most modern valves, it is now possible to design a six mile spaced system which may be used for the transmission of either 625-line television or 16 (or perhaps more) telephony supergroups. Such a line link would be little more elaborate or costly than with the present 4 Mc/s equipment and it is likely that the 6 Mc/s system will become standardized internationally and may supplant the 4 Mc/s system in countries requiring dual-purpose links of this capacity.

The major cost of a coaxial line link is incurred in the cable and duct (the repeater equipment, buildings and power plant accounting for only 30 per cent. of the overall capital cost). Developments have therefore been directed to more efficient use of the cable by increasing the bandwidth at the cost of more frequent repeaters. In the U.S.A., a substantial increase in line capacity has been achieved with the L3 coaxial cable system, of 8 Mc/s bandwidth and with repeaters at four mile spacing.[5] This system was developed by the Bell Telephone Laboratories around three new repeater valves of high performance.[6] A similar range of valves has now been produced in this country and has enabled a contractor to design a three mile spaced system with a bandwidth of 12 Mc/s. The first

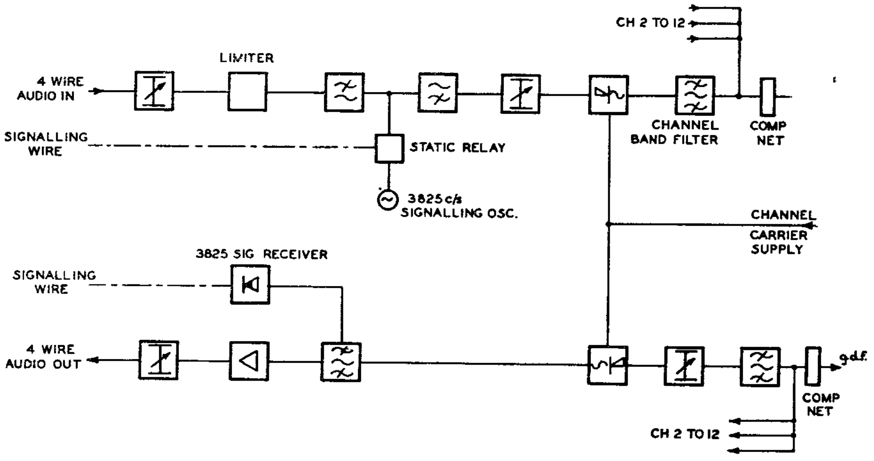


Fig. 9.—Block Schematic of 56-Type Channel Equipment with 3825 c/s Outband Signalling.

installation for the B.P.O. of this new system, coded C.E.L. No. 8A, will begin in 1958 on the London-Oxford-Birmingham route.

Amplifiers. The 12 Mc/s line amplifier has a gain/frequency characteristic designed to match closely the loss of 3.125 miles of 375E cable over the frequency range 300 kc/s—12.5 Mc/s (6.5 to 41.5 db). The portion 60-300 kc/s normally provided on earlier coaxial systems has been abandoned in the new system due to the difficulty in constructing transformers covering the additional $2\frac{1}{2}$ octaves. The amplifier uses the following new valve types :

(1) CV 3998 ≡ E 180F, 5A/170K, Beam tetrode having a slope of 16.5 mA/V, and anode current 13 mA.

(2) CV 5112 ≡ 3A/167M, triode, having a slope of 47 mA/V and anode current 40 mA,

and is in two parts. The first unit has two valves (CV 3998) and is separated by the $\sqrt{f}$ regulating network from the output unit which has one CV 3998 and two CV 5112 valves, the latter being arranged in cascode form. The desired gain/frequency characteristic is achieved by the shaping effect of various networks including the input and output transformers.

The achievement of adequate feedback over this frequency band is of major importance in obtaining low intermodulation and adequate stability against changes in valve characteristics and power supplies. There is reason to believe that with present valves and techniques, the present upper frequency limit could not be substantially raised.

Pilots. The main pilot will control a $\sqrt{f}$ regulator at every intermediate station to compensate for the variation of cable attenuation with temperature. Some difficulty arises in choosing a frequency for this pilot ; it should be near the upper limit of the transmitted frequency band where the change of cable loss is greatest. On the other hand, it must not be placed so near the limit of the band that variations in the amplifier characteristics due to valve ageing, power-supply variations, etc., become significant due to the falling-off in feedback. It is necessary also to consider convenient free spaces in the line frequency spectrum (see following section on "utilization"). The value finally recommended for the main pilot is 4287 kc/s, the exact value (1 kc/s below a multiple of 4 kc/s), being chosen to minimise interference due to discrete modulation products between 4 kc/s-spacing speech channels and this pilot.

Two auxiliary pilots, at 308 and 12,435 kc/s, which will operate regulators only at terminal and perhaps main stations, will be used to correct for the effects of valve ageing and repeater temperature variation upon the gain/frequency characteristics of the line.

Power Supply. The dependent repeater stations will be power-fed over the inner conductors of the coaxial pairs at 1000-0-1000 volts r.m.s., and up to 13 stations can be fed on either side of a power-feeding station, thus giving compatibility with a C.E.L. No. 6A system on the same route. Due to the large number of stations fed from one supply and to the probable sensitivity of the amplifier, in the upper part of the line frequency band at least, to variations in supply voltage, a very high standard of regulation accuracy both short-term and long-term is required. On the initial routes, at least, this requirement will be met by the provision at each dependent station of an automatic voltage regulator (motor-driven variable auto-transformer).

Experience on earlier power-fed coaxial cable systems has shown the need to supplement the normal power-feeding arrangements by an alternative supply which can be brought quickly into use. This is particularly necessary when composite (audio and coaxial) cables are used and when many stations are fed from a common supply. B.P.O. safety regulations require power to be removed from all coaxial pairs in a cable before any work is done on them or on the audio pairs in a composite cable. On C.E.L. No. 8A, each dependent will revert automatically to local power

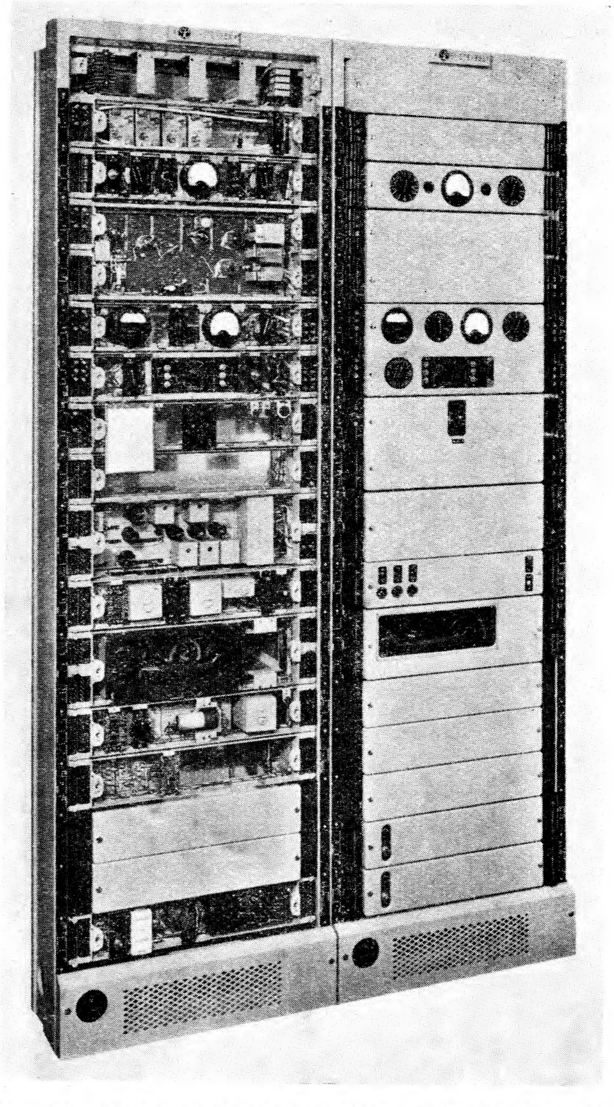


Fig. 10.—12 Mc/s Intermediate Repeater (C.E.L. No. 8A).

when cable power is removed. Furthermore, it is planned to provide a facility for reverse-power-feeding from the dependent at the end of a power-feeding section which can be brought into use if the normal power-feeding arrangements have to be taken off for a lengthy period. The somewhat unwelcome power regulator at each dependent station will play an essential part in compensating for the wide variations in station voltage which will occur at certain stations as the power is drawn from one or other of the alternative sources.

Construction. As shown in Figs. **10** and **11** the C.E.L. No. 8A equipment will be similar to C.E.L. No. 6A in construction and appearance but, due to the greater bulk of the amplifiers and of the power-separating filters, all the high-voltage equipment has been removed from the transmission racks at dependent stations. The power-separating filters will be mounted behind the cable termination box, and the cable power equipment, including the high-voltage transformer, power regulator and all protective switchgear will be mounted in a separate cubicle, with capacity for two such systems. The power-separating filters and cable-terminating box will terminate on the normal sealing ends fitted at the standard height (7 ft. 2½ in.) and the transmission rack will be mounted immediately below, occupying the same floor space as the earlier types of coaxial line equipment. Some effort has been made to ensure that there would be no major installation problems when an existing coaxial route is to be re-equipped with C.E.L. No. 8A.

Utilization of the 12 *Mc/s Line Spectrum*

(i) *Internationally.* Two possible telephony frequency allocations have been provisionally recognized by the C.C.I.T.T., they are as follows (see Fig. **12**):

Allocation "A": 15 supergroups in the range 312 to 4028 kc/s plus 30 supergroups (arranged in two blocks each of three mastergroups) in the range 4332 to 12388 kc/s.

Allocation "B": 45 supergroups in the range 316 to 12388 kc/s (arranged in three blocks each of three mastergroups).

In each case, the mastergroup comprises five supergroups, the basic mastergroup being supergroups **4** to 8, in the range 812-2044 kc/s.

In each allocation there are three large blocks of supergroups, separated by gaps which are sufficiently wide to permit filtration at line frequency. Within the blocks of mastergroups are gaps of 88 kc/s which are adequate to permit the construction of through mastergroup filters in the basic mastergroup frequency range.

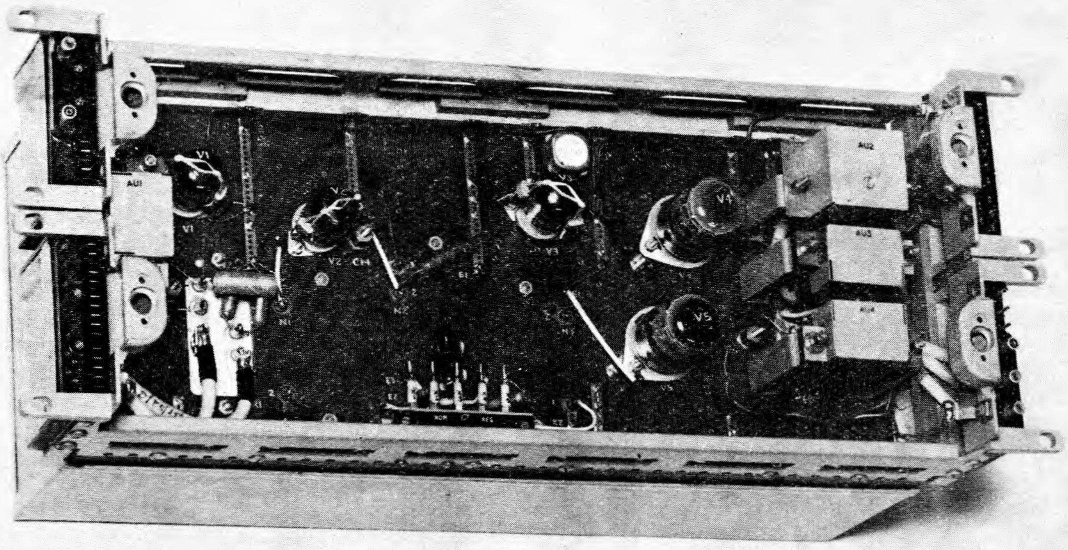


FIG. 11.—12 Mc/s LINE AMPLIFIER.

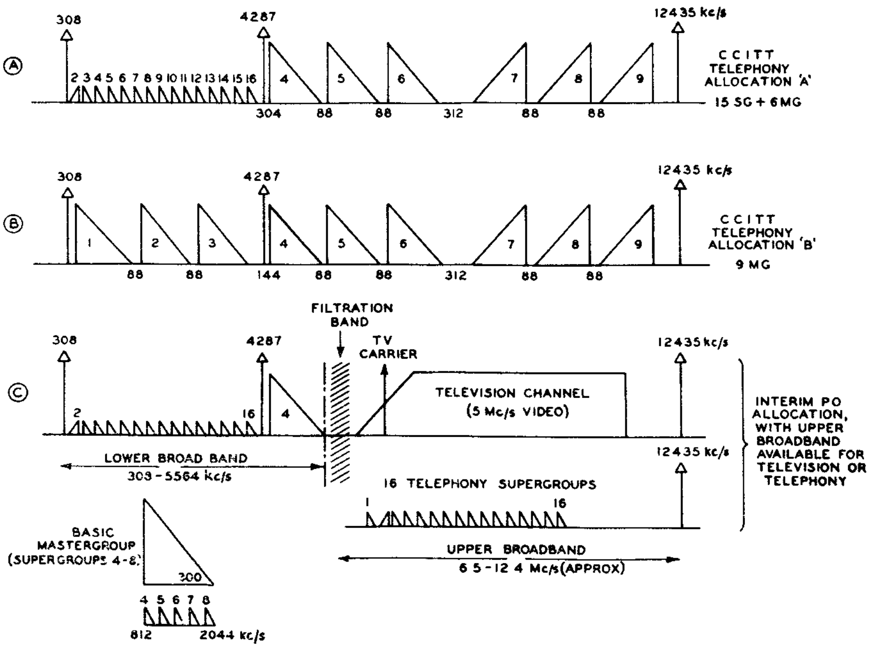


Fig. 12.—Frequency Allocations for 12 Mc/s Coaxial Cable System.

All the carrier frequencies used in mastergroup translations are derived from a base of 440 kc/s which may be obtained from the 124 kc/s master oscillators of high stability.

As an alternative to the top five mastergroups, the line may carry a vestigial sideband television channel (having a low-level carrier at a frequency of 6799 kc/s) giving a 5 Mc/s video band suitable for 625-line television. Although a video band of 3 Mc/s is sufficient for 405-line television, no attempt is being made to restrict this video band to this figure so as to make available space for extra telephony channels.

(ii) *Initial use in the U.K.* The present U.K. coaxial cable layout consists mainly of 2.6 Mc/s, 10-supergroup telephony lines plus an increasing number of 4 Mc/s lines which are suitable either for 16 telephony supergroups or for a 3 Mc/s television channel for 405-line television. It has recently been agreed by the B.P.O. Directorate that provision may be made on the main routes for spare, equipped coaxial lines as a means of ensuring continuity of service, of facilitating maintenance and as a means of meeting urgent demands for new broadband channels. The proposed utilization of the 12 Mc/s line takes account of these facts. It is proposed to follow C.C.I.T.T. allocation A for telephony up as far as Mastergroup No. 4 (5564 kc/s) and above this to form a standby broadband channel which may be used to carry telephony, 10 or 16 supergroups from a 2.6 or 4 Mc/s line translated up into the upper part of the 12 Mc/s line spectrum, or alternatively to carry television. In the latter case, the C.C.I.T.T. 5 Mc/s video channel allocation would be followed (see Fig. **12c**).

An added complication is that in most of the large cities the standby channels and the working 2.6 or 4 Mc/s route terminals are distributed over a number of different repeater stations, often several miles apart. To use the standby channel to any effect will require a network of wideband tie lines connecting together neighbouring stations, such as is indicated in Fig. **13** for London and Birmingham. Furthermore, freedom to switch between working and spare lines, which is necessary if the potential advantages of spare lines are to be achieved, requires that the gain/frequency characteristics of all such lines are held to fairly close limits. These problems have been met and solved in the U.S.A. network, complex adjustable equalizers and display-type measuring equipment being provided to facilitate the maintenance and use of switchable broadband channels.

6.2. Supergroup Derivation and Through-Hypergroup Working

The principal disadvantage often quoted against the coaxial line link as compared with the audio or carrier quad cable is the difficulty of diverting a few circuits from the line to feed a small intermediate exchange on the route. To terminate the line regulating section and to provide supergroup translating equipment for the whole line capacity at the intermediate point would in many cases be disproportionately costly if only a few circuits are to be extracted. Furthermore, the variability of long through circuits would be worsened by the loss of through regulation and by the introduction of amplifiers and modulators which are subject to random changes in their transmission characteristics.

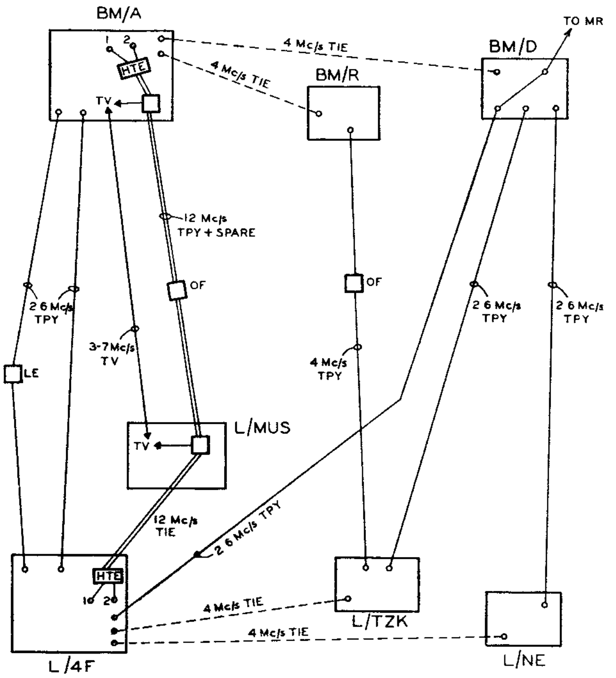


FIG. 13.—LONDON-BIRMINGHAM COAXIAL CABLE LINKS ARRANGED TO SHARE A COMMON SPARE BROADBAND CHANNEL.

To provide the facility of extracting and injecting a few supergroups at the line frequency range within a line regulating section is the function of Supergroup Derivation Equipment. At present, this can only be applied to the regulated type of coaxial line equipment (e.g., C.E.L. No. 6A) and then only if a "main station" exists or can be provided at the required point. This is a station having a "flat" point (where all channels appear at one relative level) and having some 12 db spare gain in each direction of transmission. Fig. **14** shows schematically how Supergroup Derivation Equipment is inserted into a main line to provide full extraction facilities. Essentially, there is a set of complementary bandstop and bandpass filters, together with amplifiers for the branch path and by-pass filters for certain cases where one or other of the line pilots must be taken round the main path filter. The specification for this equipment originally listed a large number of possible filter combinations but in practice it is hoped that the following few cases (see Table 3) only need be considered.

TABLE 3

	Divert in and out of Branch Path	*Pass through Main Line*	*Remarks*
(a)	SG1	SG2 upwards	Note A
(b)	SG2	SG1 & 3 ,,	Note A
(c)	SG1, 2	SG3 ,,	Note A
(d)	SG1, 2, 3	SG4 ,,	Note B
(e)	SG1 to 6	SG7 ,,	Note C
(f)	SG1 to 10	SG12 ,,	Note D

Notes : A. 12 kc/s gap available between Supergroups 1 and 2 and between 2 and 3 and filtration relatively easy.

B. 8 kc/s gap only between SG3 and SG4, hence C1 G1 SG3 or C12 G5 SG4 may be distorted.

C. G1 SG6 would probably be lost in filtration.

D. SG11 would probably be lost in filtration

Several such arrangements are now on order, e.g., type (a) for Inverary on the Glasgow-Oban route; type (d) for Cambridge on the London-Doncaster route; and type (d) at Canterbury on the London-St. Margaret's Bay (2.6 Mc/s) route. Similar facilities will no doubt be required on C.E.L. No. 2 or 4 routes which do not have main stations and use block temperature equalizer switching. Additional development work will be required to make derivation practicable on such routes.

The use of supergroup derivation equipment will undoubtedly increase the difficulty of maintaining a line regulating section because it will not be possible to explore the whole gain/frequency characteristic of the line from one terminal to the other. Consequently, the small changes in characteristic which are often the sign of incipient major defects may not be detected, or if detected may not be capable of location, and it may be difficult, if not impossible, to pursue a consistent policy of providing spare line links. The alternative to derivation, however, of introducing back-to-back line terminals at the dropping point, although it may give easier maintenance of the line sections, is likely to be more costly and to give no better performance overall for the through circuits. The problem of circuit variability will, however, be best overcome by the proper use throughout the network of group and supergroup pilots with deviation alarms or AGC.

Analogous to supergroup derivation, and probably using the same filters, is "through hypergroup working" at line terminal stations (i.e., outside the regulating sections). Blocks of supergroups (the term "hypergroup" is used as a generic term for any block of supergroups which is handled as a switching unit) are passed from one line section to another without the use of translating equipment and through group or supergroup filters. The arrangement is similar to that in Fig. **14** for supergroup derivation but 308 kc/s filters and the 308/60 kc/s convertor are not required. An installation is planned for Carlisle (between the Manchester-Carlisle and Carlisle-Glasgow 4 Mc/s telephony line sections) where, using a pair of filters

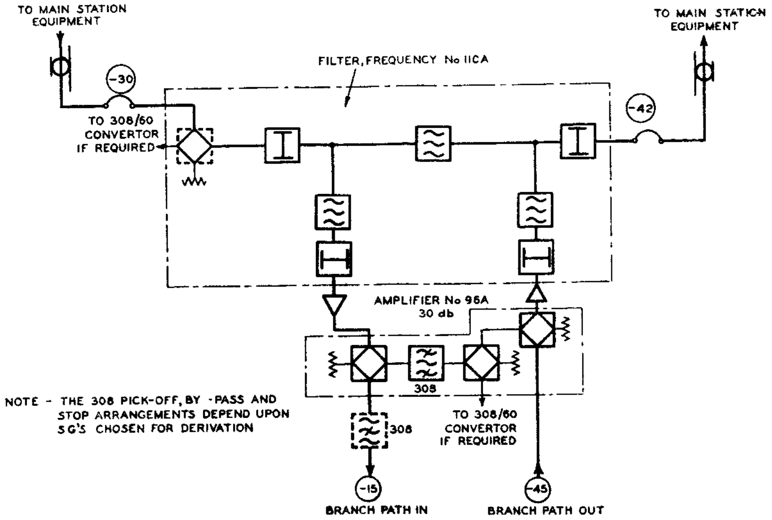


FIG. 14.—SUPERGROUP DERIVATION EQUIPMENT SCHEMATIC.

similar to those proposed for supergroup derivation at Canterbury, SG1 to 5 will be taken off at Carlisle to provide Manchester-Carlisle and Carlisle-Glasgow supergroups whilst SG6 to 16 (part of SG6 being lost) are put straight through as Manchester-Glasgow supergroups.

7. LINE SYSTEMS FOR SUBSIDIARY TRUNK ROUTES

This particular section of the trunk network includes a wide variety of routes of various lengths and traffic rates of growth. It is not easy, therefore, to say categorically whether an h.f. or audio system is the more suitable or the more economic. Generally, the capacity required, even if h.f. provision is justified, is much less than the present 960-circuit coaxial system which is usually the cheapest system to employ except for short distances. Very often only audio cables have been justified on a particular route, but the economies gained by the extension of through circuits on the main h.f. network by a compatible carrier system have to be considered. New carrier line systems for application in this field include 60-circuit working on PCQ carrier cables, small-diameter coaxial cable systems and various schemes for using deloaded audio cables.

7.1. 60-Circuit Line System

Multi-channel carrier working was introduced as the basis of the long-distance network in the form of 12-circuit working with separate carrier quad cables (usually 24 pr/40 lb) for the two directions of transmission. 24-circuit working on the same cables was obtained later by a conversion program. No new main cables of this type have been laid recently because the wideband coaxial cable system has been found to be a less expensive method of providing large blocks of trunk circuits. However, an alternative way of obtaining large circuit capacity which has found much favour with a few foreign administrations is to increase the number of channels carried on each pair of a carrier quad cable to 60 or even 120. This requires an improved type of cable having lower attenuation, achieved by greater separation between the conductors, and maintaining good crosstalk performance up to the higher line frequency used. A 60-circuit cable system has now been introduced into the U.K. network for subsidiary trunk routes and Table 4 shows its essential characteristics which are in accordance with international standards.

TABLE 4

60-Circuit Line System

Cable (C.C.I.T.T. Type II):

36 lb conductor (1.2 mm or 0.0472 in. dia.), 8 or 14 pair.

Mutual capacitance 0.0425 μF/mile.

Impedance 170 ohms (nominal).

Attenuation 4.7 db/mile at 250 kc/s.

Far-end crosstalk (S/N) 70 db per repeater section (worst combination).

Repeaters:

12-252 kc/s line bandwidth spacing, 11.9 miles.
Normal maximum spacing, 11.9 miles (56 db).
Occasional maximum spacing 13 miles (61 db).

Regulating Pilot:

256 kc/s.

Supergroup modulating equipment is required to convert from the basic supergroup range (312-552 kc/s) to the line frequency range (12-252 kc/s) and is connected between the S.D.F. and the H.F.R.D.F. For convenience in co-ordinating 24-circuit and 60-circuit cables, a common H.F.R.D.F. is used, where the impedance for both systems is 140 ohms ; the 60-circuit line level at the H.F.R.D.F. is, however, 0 dbr whereas the 24-circuit level is +5 dbr.

On all but the shortest cable links the variation in cable attenuation with frequency will be automatically compensated by means of regulators controlled by the level of the 256 kc/s pilot and which introduce the necessary shaped equalization characteristic. These regulators will normally be fitted at line terminal stations and also at selected intermediate stations on long sections (e.g., over 50 miles). Initial installations of these manufacturers' designs have been ordered for the Derby-Leeds, Leeds-Middlesbrough and Birmingham-Coventry routes and a few more are programmed. In all cases it is planned to use the phantom circuits to provide program channels as is done with 24-circuit working.

In one installation (Leeds-Middlesbrough), opportunity has been taken for a trial of power-feeding of intermediate repeaters (both carrier and program amplifiers) by means of the double-phantom circuits in the two cables, using an a.c. supply of 375-0-375 volts r.m.s. There are serious difficulties involved in power-feeding over more or less conventional paper core cables. The protection of cable jointers and cable testing staff against accidental contact with the lethal power voltage is of first importance. Power-fed paper-core cables are at present unknown in the U.K. and it has been thought necessary to give a positive indication to the jointer by providing a warning paper lapping immediately beneath the lead sheath of the power-carrying carrier quad cable. It is necessary to provide means for removing automatically the power from a wet section of cable, otherwise the paper insulation would be permanently damaged. Furthermore, it is unlikely that phantom program circuits could be maintained to an entirely satisfactory performance standard when the double phantoms are carrying a.c. power.

The future scope for 60-circuit carrier working in its present form is thought to be small. Its principal advantage over a coaxial cable system is that its capacity is spread over a number of pairs which may be interconnected at H.F.R.D.F. points to give flexibility in supergroup units. In the U.K. the basic long-distance medium is now the $\frac{3}{8}$in. coaxial cable and only on the spur routes is there likely to be a place for a different type of cable. The main disadvantage of 60-circuit working are that two separate cables are required (which cannot satisfactorily be combined with audio pairs in the same sheath) and that, in the absence of power-feeding, a complete main and standby power plant is required at each repeater station, i.e., at about 11 mile intervals. Both these factors add greatly to the cost of the present form of 60-circuit system and it can only compete with conventional coaxial cable systems in very special circumstances. Buried transistor-type repeaters could, however, radically change the economic outlook for this system.

7.2. Supergroup Tie Lines

A useful variant of 60-circuit working using the same cable provides tie circuits in the basic supergroup range (312-552 kc/s) between supergroup distribution frames in neighbouring stations without modulating equipment being required. This is limited to short-distances, as the cable crosstalk is naturally worse than it is in the normal frequency range (12-252 kc/s). Installation of this kind, which will use existing types of supergroup and coaxial line terminal amplifiers, are planned for London/Faraday—Kingsway and Leeds/Burley Street—Rothwell Haigh.

7.3. Small-diameter Coaxial Cable Systems

With the extension of the 375 coaxial cable on main routes throughout the country (from Plymouth to Wick) there is an increasing need for a small-capacity multi-channel system to provide spur and short-distance routes. With the disadvantages of pair-type cables in mind, suggestions have frequently been made for the use of smaller-diameter coaxial cables, e.g., one of $\frac{1}{8}$ in. diameter, which would replace any single quad in an audio cable and would carry one supergroup with conventional repeaters at about six miles spacing. However, study showed that the cable itself would be costly and a much larger circuit capacity, e.g., three to five supergroups would be needed to absorb the cable cost and as the repeater spacing would have to be reduced accordingly the cost of repeater, buildings, etc., becomes prohibitive. Such proposals have previously been abandoned, but transistors suitable for carrier line amplifiers are becoming available and this has greatly altered the case for small coaxial cables.

A contractor has recently proposed a fully-transistorized line system for use with a small coaxial cable, shown in Fig. **15**, and having the following electrical characteristics :

Internal diameter .	0.163 in.
Z_0 at 1 Mc/s . . .	67 ohms
Attenuation at 1 Mc/s	10 db/mile
Dielectric . . .	cellular polythene

Transistor type repeaters are planned to be spaced at 4000 ± 220 yard intervals (to be compatible with loading-coil manhole spacing) and the capacity of the system will be five supergroups or one mastergroup (60-1300 kc/s) with a line regulating pilot at 1054 kc/s. The intermediate repeaters will be power-fed by a constant-current series feeding scheme and will be housed in buried chambers. A sealed chamber (shown in Fig. **16**) has been developed for roadside mounting and it will possibly be used in the first installation now being planned. The original proposal was for these chambers to be partly above ground but in this country there are many objections to the wide use of above-ground structures and where this type of chamber is used, it will be installed wholly below ground level, probably through the floor of a footway jointing box. The repeaters are carried in a cradle which normally rests at the bottom of the chamber and can be pulled up to the surface for maintenance.

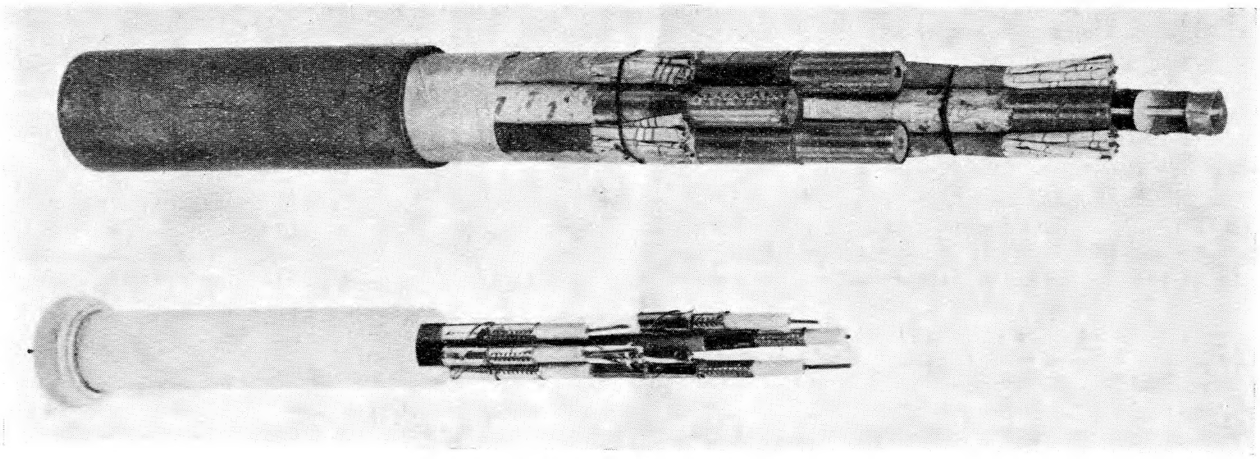


FIG. 15.—375E AND 163A COAXIAL CABLES.

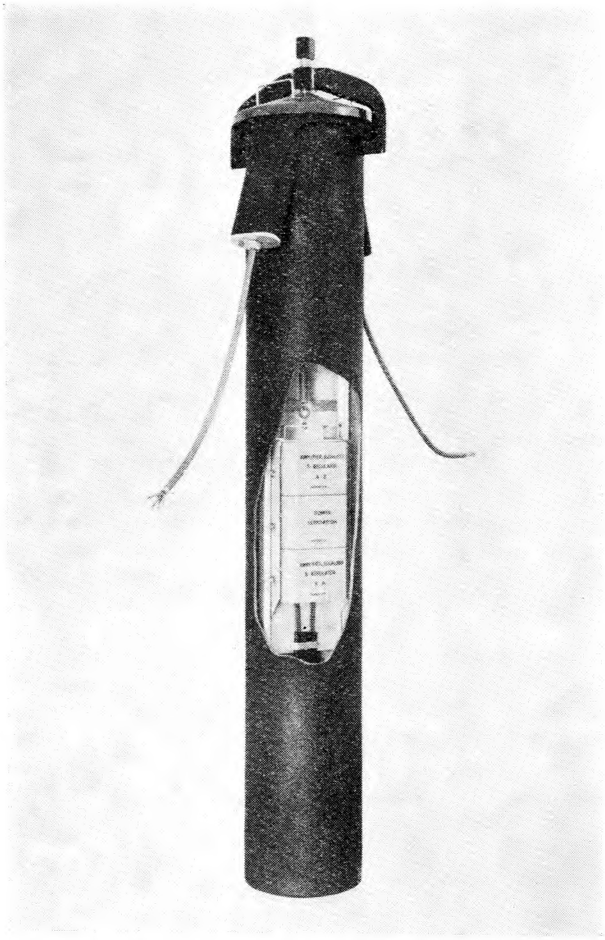


FIG. 16.—HOUSING FOR BURIED 300-CIRCUIT REPEATER (163A COAXIAL CABLE SYSTEM).

As a result, the variations of ambient temperature to which the repeater is subjected are kept quite small. Experience will show whether these precautions are, in fact, necessary but it is undoubtedly wise in an initial installation to minimize the external influences as far as is possible.

Power Feeding. Although shunt or "constant voltage" power-feeding is used on all main coaxial systems in this country, it has long been realized that "series" or "constant current" power-feeding has many advantages. With the advent of transistors, d.c. constant current power-feeding is the natural choice because transistors are naturally stabilized in terms of current and require relatively small operating voltages. The power-feeding arrangements for the transistorized coaxial cable system will provide balanced power-feeding, at about 50 mA d.c. per conductor, derived from a current-stabilized mains power unit.

Supervisory arrangements. In the first installations the small-diameter coaxial cables will have interstice pairs available as follows :

	4-*Tube Cable*	6-*Tube Cable*
Alarm circuit	2 pairs, 6½lb	3 pairs, 10lb
Speaker circuit	1 or 2 pairs, 6½lb	1 or 2 pairs, 10lb

The alarm circuits will be used to extend to the terminal a pilot deviation alarm from repeaters fitted with regulators. Each repeater will have a level access point so that a simple check, e.g., of pilot level, can be made *in situ*. A portable amplifier-speaker will be provided for connexion to the speaker circuit at any repeater.

An initial installation of such a system is planned for the Eastbourne-Hastings route, where it is desired to extend through supergroups from the London-Eastbourne 2.6 Mc/s coaxial cable link to provide through circuits from London and Tunbridge Wells to Hastings. Incidentally, this is a case where sufficient spare line capacity is available initially for 6 kc/s-spaced channel equipment to be the obvious choice, the outband signalling channel giving the direct dialling facility required into London.

The small-diameter coaxial cable system outlined above does not necessarily represent the optimum type of system for future standardisation in the U.K. It has already been pointed out that a spur system, carrying one or two supergroups only, seems more suited to many B.P.O. requirements. The cost of the cable could perhaps be reduced if the lower limit of the line frequency range were raised, perhaps to 0.3 Mc/s, so that the thickness of copper in the outer conductor could be reduced whilst maintaining acceptable crosstalk attenuation. It might be possible by this means to produce a small coaxial cable system which is economical for one or two supergroups.

However, for the 163A cable a capacity of five supergroups appears reasonable and this capacity could be formed from the "mastergroup", the five-supergroup unit planned for the 12 Mc/s cable system. It is likely that radio systems may also be developed for one or more mastergroups and an interconnected h.f. network on this common basis can be envisaged. Mastergroup No. 1 in the 12 Mc/s system begins at 316 kc/s and it may yet be found desirable to begin the working band of a small-diameter coaxial cable at this figure to ease the crosstalk requirements. The close repeater spacing proposed (4,000 yards, 24 db at 1.3 Mc/s) is suited to present types of transistor amplifier which are restricted to low output powers. A reduction in the number of intermediate repeaters can be expected as transistors develop, and repeaters having the performance of present valve-types at about four-miles spacing or more may be envisaged. However, the optimum system design has to take account of power-feeding also and this may limit the scope for increasing the gain (and hence the power-handling capacity) of intermediate repeaters.

Many new problems will arise in the supervision and maintenance of a line system using underground power-fed repeaters. The present practice with 375 cable systems of switching-over to local power to free cable sections for joining operations on coaxial or audio pairs in the cable cannot be adopted with the new systems. The need for this precaution may be avoided if the power-feeding system is suitably designed. The use of a constant-current arrangement limited to a line current of 50 mA with the open-circuit voltage limited to 250 appears to meet these requirements and power could be left on all pairs except the one to be opened.

Although various other schemes have been put forward, the ultimate design of an intermediate repeater in a transistorized line system must be suitable for mounting in any existing manhole or jointing box. The use of cabinets or pillars for mounting repeaters would certainly simplify access for maintenance and would not require the repeater to be pressure-sealed, but the difficulty of ensuring that an existing duct track and jointing chambers can be used and that wayleaves and sites could be obtained precludes reliance on these methods. A footway box would give easy access and would be chosen where possible, but a realistic assessment of future cable possibilities shows that the problem of fitting and maintaining repeaters in existing manholes needs to be solved sooner or later.

With an underground repeater system, maintenance of the cable and the repeaters must be considered together, fault location and clearance throughout being carried out by one organization. With a reliable transistor repeater system (and no other can be contemplated for underground installation) routine preventive maintenance of the repeaters will be unnecessary and cable faults would predominate over equipment faults. The following principles are therefore proposed :

(*a*) A faulty repeater will be replaced complete and a sealed unit will not be opened except in a proper repair centre.

(*b*) Means will be provided outside the sealed repeater unit for testing pilot level, power supply and for obtaining access to an omnibus speaker circuit connecting all repeaters to the terminals.

(*c*) Means will be provided for locating faults from the terminals. These may include pilot deviation alarms from repeaters equipped with regulators (possibly power-fail alarms from all repeaters) relayed to the terminals, or means for effecting precision location tests from the terminals by conventional conductor-resistance or capacitance measurements on the unenergised coaxial pairs. This latter facility would require the power-feeding circuit to be suitably arranged and its characteristics controlled in the design and manufacture of each repeater.

(*d*) However attractive a comprehensive supervisory system may appear it must not be allowed to complicate an underground repeater. Simplicity is the best approach to reliability.

(*e*) A fault located in a line section having underground repeaters would be dealt with entirely by external staff via the appropriate precision cable testing officer who would be responsible for final location and clearing of the fault whether in the cable or a repeater. Repeater faults would be cleared so far as he is concerned by complete replacement.

7.4. Use of Existing Low-Frequency Cables

Cost studies show that the shortest economic distance for multi-channel carrier working is steadily falling and it is becoming increasingly worthwhile to introduce carrier working on routes which at present are served only by audio cables. This is particularly so on spur routes from the main h.f. network, or where a few additional circuits only are required on an audio route. It is natural, therefore, to consider the application of carrier working to deloaded audio cables for providing quickly and inexpensively a small increase in the capacity of a cable and so deferring the provision of a full-scale relief scheme.

The difficulties in the use of deloaded audio cables for carrier working are :

(i) High loss at carrier frequencies, requiring close repeater spacing.

(ii) Poor crosstalk performance, both direct and indirect via through circuits at repeater points.

(iii) Only one cable is available, usually, for both directions of transmission.

(iv) High noise level over the whole carrier frequency band due to d.c. dialling and signalling circuits in the cable.

The classic way of using deloaded audio cables is undoubtedly the Bell Laboratories N1 System[7] in which the transmission limitations of audio cables are overcome in a radical and certain manner by the use of double-sideband transmission with channel compandors and frequency-frogging repeaters. With this short-haul system no special tests or selection of cable pairs is required and there is no limitation on the proportion of pairs in a cable which may be equipped. Such a system is simple of installation, gives circuits in convenient units of 12 and can give a small or large increase in the capacity of a cable as desired. No equivalent system has yet been marketed commercially in this country and it has not achieved much popularity outside the Bell System in U.S.A. where it is mass-produced on a vast scale ; this may be an important factor in reducing its cost and making its use economic.

A system of this type has recently been developed by the Engineering Department and a field trial installation between Bedford and Hendon has recently been described in the Journal.[8,9].

These short-haul systems are essentially audio-to-audio or point-to-point systems because the line frequency spectrum of each channel is not compatible with main line systems. Consequently, extensions from the main h.f. network cannot be made on a through-group basis, and connexion via two sets of channel equipment is necessary ; this is expensive.

There would therefore appear to be scope for a line system for deloaded cables which would use standard groups or supergroups.

One such system is already recognised internationally and has been fairly widely used abroad.[10] It transmits 12 channels in the two bands 6-54 and 60-108 kc/s, both directions of transmission being carried on a single pair. Most manufacturers of transmission equipment offer this system in one form or another but due to its need of closely-spaced repeater stations and to its dependence upon a reasonably good cross-talk and noise performance from the cable, it has not been found attractive. However, at least one transistorized version of this system is now offered (though at present it still requires intermediate buildings, each with a power supply) and the cable limitations may be removed by adopting some of the characteristics of true short-haul systems, such as frequency-frogging and channel compandors. The "12 + 12" system now appears to be quite promising, although for extensive application power-feeding is necessary and the need for standard buildings must be removed.

An alternative approach to the compatible line system becomes possible with the development of transistor amplifiers for the higher carrier frequencies. This is to exploit one or perhaps two pairs only in an audio cable for a very large number of channels, e.g. 60, 120 or more channels, using closely-spaced low-gain transistor-type repeaters.[11] The use of low-gain repeaters minimizes the effects of noise and indirect crosstalk while system-to-system crosstalk does not arise if only one pair in a cable is equipped. The wider-band line system would be expected to be the more economical, other things being equal, but of course this economy would not be obtained if translating equipment costs predominate or if the circuit capacity obtained cannot be used to the full.

The time is not yet ripe to standardize any of the several possible ways of using deloaded cables. A successful scheme must be readily applicable to existing cables without major modifications and without the need for buildings. Successful development of simple and reliable repeaters suitable for accommodation in a manhole or footway jointing box with a simple and safe power-feeding scheme appears to be the first essential and now appears possible with transistor amplifiers of the future.

8. AUDIO CIRCUIT DEVELOPMENTS

Although the progress in multi-channel carrier working attracts most attention, the importance of the audio circuit has not diminished as circuits less than 35 miles almost invariably use audio cable pairs and, within the range 15 to 35 miles, 70 per cent. use 4-wire repeaters. Many of these 4-wire circuits could be converted to 2-wire working. Useful progress in simplifying the 4-wire repeatered circuit and in introducing new and simplified techniques for 2-wire repeatered working has been achieved.

8.1. 4-Wire Repeaters

Work has been proceeding for some considerable time in the Engineering Department on the replacement of the Amplifier No. 32 and the associated Transformer and Line Corrector Equipment by a more compact and up-to-date design. Finality in this field has not yet been reached due to the rapid advance in transistors and in constructional methods. The present stage is represented by the Panel, Audio, No. 1A. In this arrangement, which is in 51-type construction, four line transformers, two equalisers and attenuators and two amplifier units (Amplifier No. 80A) are mounted within a 2-unit (3½ in.) 51-type panel. Twenty-four such panels may be mounted upon a 9-foot rackside which is then cabled away to the M.D.F. Any of these through repeaters may be converted into a terminal repeater by replacing one pair of line transformers with a similar unit which forms a 4/2 wire terminating set.

An experimental installation of Equipments, Audio, No. 1A has been put in at Reading. Equipment of this type has also been used to meet special requirements at Oban and Lochearnhead in Scotland.

Further development can now be foreseen, in the direction of simplified and less expensive constructional techniques, and of course, in complete replacement of the valve amplifiers by a transistor version. Several models of transistor amplifier have already been made and the Reading installation of Equipments, Audio, No. 1A will include a few models of current designs of transistor audio amplifier of Research Branch design (e.g. Amplifier No. 121A shown in Fig. **17**) which in performance are exact replacements for the Amplifier No. 32.

The new constructional techniques will certainly incorporate 56-type practices but one point which is not yet decided is whether the cost of providing individual U-link type connexions to the units is justified in view of the very low fault rate per circuit of audio equipment. It may be that adequate maintenance facilities are obtained with simple soldered-strap connexions. It is, perhaps, going too far at present, to forecast abandonment of the M.D.F. terminating blocks and jumper field, but many examples can be imagined where negligible loss of flexibility would result if the main cable were cabled to the repeater equipment racks without a jumper field.

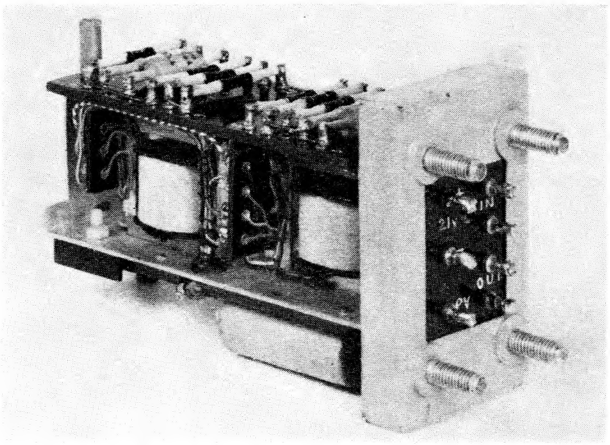


FIG. 17.—TRANSISTOR AUDIO AMPLIFIER (AMPLIFIER NO. 121A).

8.2. 2-Wire Repeaters

The 2-wire unrepeatered circuit is undoubtedly the least expensive way of providing short-distance circuits. If a range of circuits of increasing length is considered, a satisfactory overall loss may be achieved for the shortest distances with unloaded cable, then with cable loaded 88 mH at 2,000 yards, first of 10 lb then 20 and finally 40 lb. The maximum length of 40/88/1.136 cable which will give 3 db loss at 1,600 c/s is 15.8 miles, beyond this distance it is present practice to provide a 4-wire amplified circuit. Examination of circuit records shows that there are many 4-wire amplified circuits in which the cable loss is only a few decibels beyond the acceptable limit for the class of circuit; the cost, in cable plant of the few decibels improvements is very heavy indeed. The changeover from 4-wire working to 2-wire would result in a saving of one audio pair with the possible small increase in the signalling cost; the annual charges of a 23 mile circuit would be reduced by approximately 30 per cent.

However, it is not for new cable provision that the 2-wire repeaters will be used initially; spectacular capital savings can be made when they are applied to existing audio cables and this is particularly important in these days of capital restriction. On many routes of small traffic growth the cost per circuit of a new cable is very high, particularly if duct has to be provided. The economies that are possible by avoiding cable provision by the use of the 2-wire repeaters are such that exceptional measures should be made to overcome signalling and accommodation difficulties where they exist. To give a guide to the relative economics of new provision, either by new audio cable or using 2-wire repeaters with a change of signalling from loop dialling to Signalling System D.C. No. 2 (Long distance D.C.) the comparative capital costs and annual charges per additional circuit have been studied. Without taking account of the credit value for the 4-wire amplifier equipment and loop dialling relay set that would be released (which in most cases could be used for other circuits), the study shows that a saving in capital expenditure of over 60 per cent. is possible on circuits of 20 mile length. Even so, this does not reflect adequately the savings that are possible by avoiding new cable provision. The 2-wire amplifiers and new signalling relay sets have only to be provided initially to meet possibly a three year growth, whereas if a new cable were laid, additional pairs would be included so that it would meet the growth for up to 10 years; some of the capital expenditure is thus deferred.

The re-introduction of 2-wire repeatered working may seem to be a retrograde step when the old type of 2-wire repeater is recalled and the general relief that was felt when 4-wire working was standardized. However, the present proposal limits the application of 2-wire repeaters to quite modest distances where only one repeater is required, and to modern cables with standard loading (88/1.136). Furthermore, as a consequence of these limitations, setting-up of the repeater will be simple because pre-determined balance network suitable for the standard loading will be used. Typical applications are to reduce a cable loss of 12 db (e.g., 30 miles of 20/88/1.136 cable) to 3 db by using one intermediate repeater in the circuit. A terminal repeater could be used if the cable loss did not exceed 9 db.

Two forms of 2-wire repeater have been developed by the Engineering Department and are now undergoing field trial:

8.2.1 *Conventional 2-Wire Repeater*

The Panel, Audio, No. 2A is a conventional 2-wire repeater and comprises two line transformers, two hybrids, two amplifier units, two balance networks and signalling and transmission path filters. Particular attention has been paid to the need for the minimum extra resistance to be introduced into the signalling path; the actual value, 80 ohms is reasonably low. The panel is made in 51-type, 2-unit (3½ in.) construction. The amplifier used in this version is the Amplifier No. 80A previously mentioned; however, it will in due course be replaced by a transistor version.

The balancing networks for standard loading have five elements and are a slight simplification of the network used by the Cable Test Section of I Branch during acceptance testing of this type of cable. The only adjustment provided on the network is variation of one capacitor, obtained by strapping, to suit the particular length of end-section.

The commissioning of the new 2-wire repeaters should present little difficulty if the cable is free from faults, such as faulty or missing loading coils. It would possibly be desirable for the impedance/frequency characteristic of the cable (perhaps as a return loss against the network) to be checked before 2-wire repeatered working is introduced on a cable for the first time.

The adjustable balance capacitors will be set to the value appropriate to the particular end-section and the attenuators adjusted to the value giving the required circuit loss (e.g. 3 db) which should be achieved with at least zero stability with the ends of the circuit open or short-circuited.

Fig. **18** gives loss/frequency curves for a typical circuit with and without a 2-wire repeater of this type. Equipment is being obtained for installation later this year on a few junction routes in London (e.g., London-Watford) and to provide relief on suitable junction routes throughout the country if this becomes necessary as a result of the introduction of Group Charging.

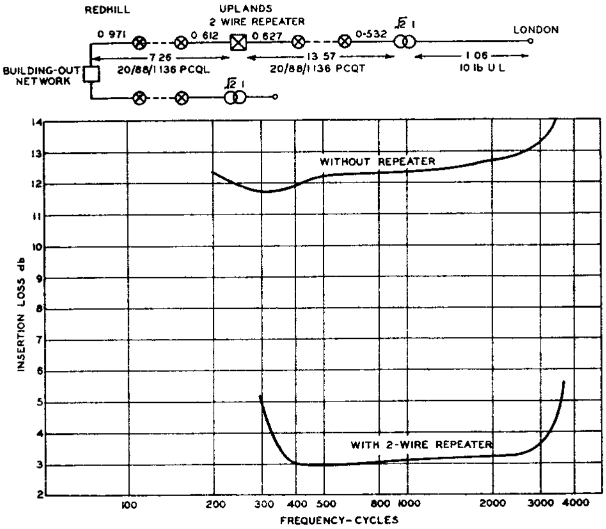


Fig. **18**.—Typical Characteristic of Circuit with Conventional 2-Wire Repeater.

8.2.2 *Negative-Impedance Repeaters*

A form of 2-wire repeater which is alternative to the conventional types is the "negative-impedance" repeater.[12] In early forms of this repeater, a two-terminal negative impedance was introduced in series or in shunt with the line hence reducing the line loss. The insertion of this element acted as a severe impedance discontinuity giving rise to objectionable reflections. A more satisfactory arrangement is to arrange series and shunt negative impedance elements to form a four-terminal network whose image impedance is positive and nominally equal to the line impedance, i.e. a pad with negative loss. Fig. **19** shows a practicable arrangement of this kind and Fig. **20** shows the construction of such a repeater. The active elements employ transistors and operate from a 21 volt d.c. supply. The impedance networks are fixed and, except for a transformer tapping in each network which is used to vary the gain, no adjustments are required when setting up. The repeater requires no line transformers and introduces only a few ohms resistance into the signalling path. The limit of application of this type of repeater depends, as does the conventional type of 2-wire repeater, upon the accuracy with which cable and network impedances are matched. So far, only standard loading (88 mH, 1.136 miles) has been considered and it is quite practicable to reduce 9 db cable loss (22 miles of 20/88/1.136 cable) to 3 db (with zero open or short-circuit stability) as shown in Fig. **21.** There is no restriction on the location of the repeater; it may be at either end of the circuit, or at some intermediate point.

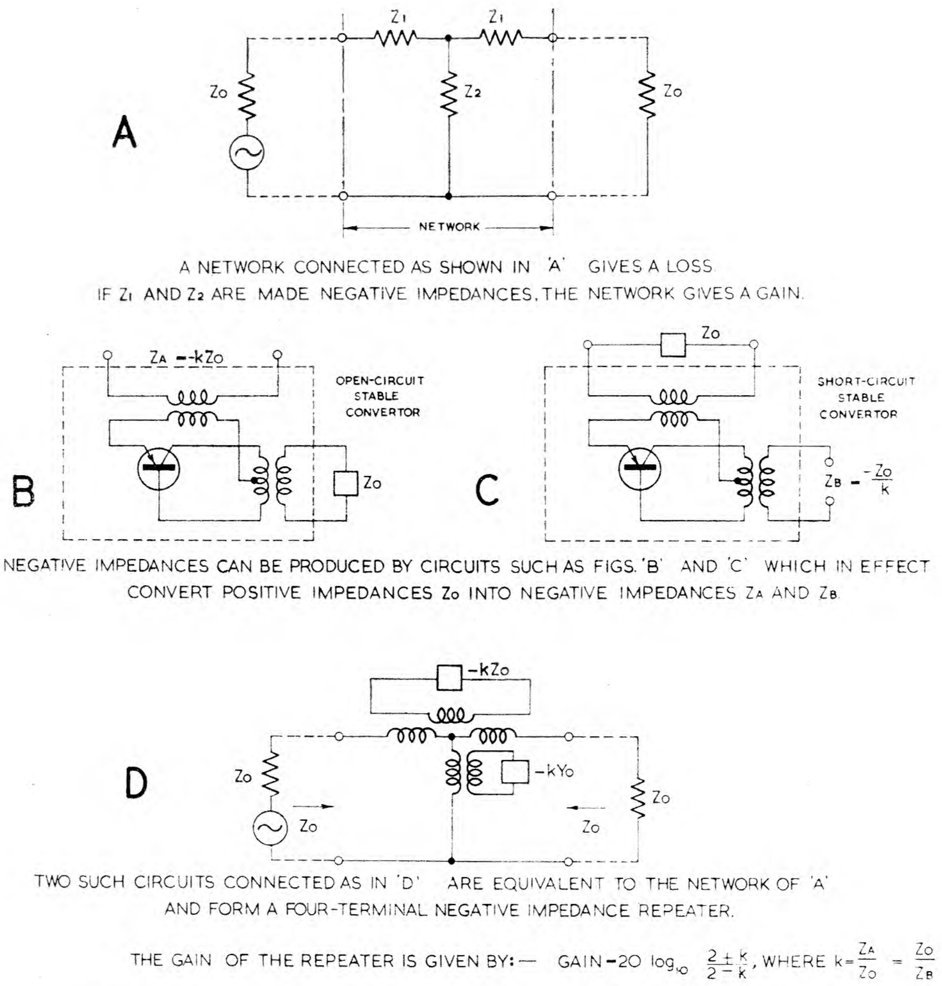
A first installation using laboratory models of this repeater has been made on the Elgin and Buckie route and has enabled traffic relief to be given by converting the necessary number of circuits from 4-wire to 2-wire.

One slight advantage of the negative-impedance repeaters as compared with the conventional type is that a power failure only results in loss of the gain so that on most calls in progress conversation will still be possible. The real advantages are, however, lower cost, smaller size and lower signalling resistance.

8.3. Program Circuits

For many years, the provision of program circuits has kept in step with the expansion of the trunk network by using phantom circuits on PCQ carrier cables and screened pairs in audio cables. The coaxial cable has now supplemented the audio and PCQ carrier cables on the main routes and there will soon be an insufficient reserve of program-type plant to meet future demands for long-distance program circuits. For shorter distance program circuits, screened pairs are sometimes laid with coaxial cables on specific schemes and very favourable results have been achieved by 500 yard 22 mH loading of 20 lb PCQT cables.[14]

It is necessary, therefore, to look to an h.f. method of providing main-line program circuits. International agreement exists for the use of the band 84 to 96 kc/s in the basic 12-channel group (channels 4, 5 and 6) as a single-sideband program channel giving a program band of 50 to 10,000 c/s. Proprietary designs of



A NETWORK CONNECTED AS SHOWN IN 'A' GIVES A LOSS.
IF Z_1 AND Z_2 ARE MADE NEGATIVE IMPEDANCES, THE NETWORK GIVES A GAIN.

NEGATIVE IMPEDANCES CAN BE PRODUCED BY CIRCUITS SUCH AS FIGS. 'B' AND 'C' WHICH IN EFFECT CONVERT POSITIVE IMPEDANCES Z_0 INTO NEGATIVE IMPEDANCES Z_A AND Z_B.

TWO SUCH CIRCUITS CONNECTED AS IN 'D' ARE EQUIVALENT TO THE NETWORK OF 'A' AND FORM A FOUR-TERMINAL NEGATIVE IMPEDANCE REPEATER.

THE GAIN OF THE REPEATER IS GIVEN BY:— $\text{GAIN} = 20 \log_{10} \frac{2 \pm k}{2 - k}$, WHERE $k = \frac{Z_A}{Z_0} = \frac{Z_0}{Z_B}$

FIG. 19.—A FOUR-TERMINAL (SERIES-SHUNT) NEGATIVE-IMPEDANCE REPEATER USING TRANSISTORS.

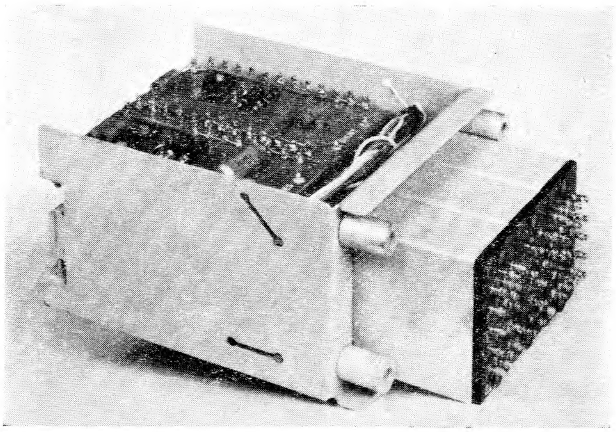


FIG. 20.—NEGATIVE-IMPEDANCE TYPE 2-WIRE REPEATER.

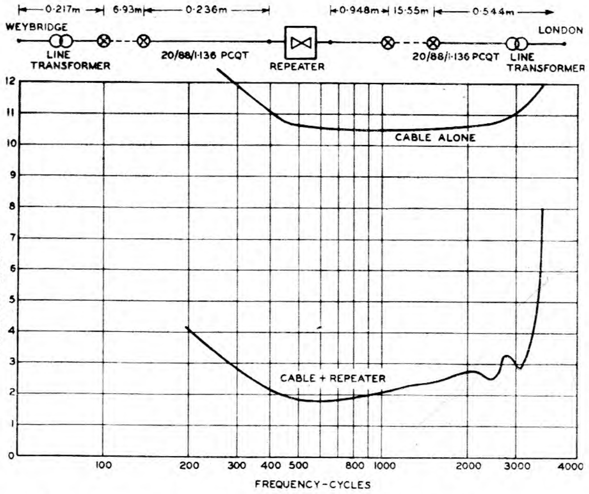


FIG. 21.—TYPICAL CHARACTERISTIC OF CIRCUIT WITH NEGATIVE-IMPEDANCE REPEATER.

program channel translating equipment (often known as "music-in-band" equipment) already exist and have been used in the U.K. and abroad to provide program circuits over submarine cable and radio systems.[13] Work is now proceeding on a standard type of this system for B.P.O. use.

A study of the performance of the present h.f. network shows, however, that it may not be possible to permit unrestricted choice of carrier groups for program working, because the standards of cross-talk and noise required for program circuits are much more severe than the corresponding standards for telephony. Satisfactory performance may be achieved without much difficulty on selected routes, but it may be necessary to call upon compandors to improve the signal/noise ratio on many existing h.f. routes to give satisfactory program quality. The reaction of renters, e.g., B.B.C. and I.T.A. to the introduction of compandored circuits as a general feature has yet to be tested.

So far as audio plant is concerned, the use of the Amplifier No. 35 and associated equalizers has been standard for many years although it has long been realised that this has limited the performance of the longest circuits. Two particular deficiencies affect the low-frequency end of the band ; the delay distortion amounts to some 8 millisecs per 100 miles, and the steady-state gain/frequency characteristic varies appreciably with level. Both these effects arise mainly from the amplifier transformers.

A new design of amplifier, the Amplifier No. 68A, has been available for some time, primarily for 51-type installations. It mounts on a 2-unit panel with its associated line transformers and equalizers in the same way as the Panel, Audio, No. 1A, and attention has been paid in its design to the shortcomings of the earlier amplifier. A few models of the new design have been produced but no large-scale purchase is planned because this development has been overtaken by that of transistors. A new design of program amplifier, using transistors, is in hand. The new design will have similar construction to the Amplifier No. 68A so that it may mount on the same combined panel but will have somewhat lower gain than present designs and will probably have a low-impedance output circuit. The low-impedance output will simplify the equalization of unloaded cable circuits and additionally reduce the low-frequency delay distortion. The use of transistors greatly simplifies the task of securing a reliable power-supply for small installations often in telephone exchanges. This in turn will influence the planning and provision of program circuits by removing the restrictions imposed by inflexible installation requirements of program equipment, and, for example, permits improvement in signal/noise ratio in difficult cases to be achieved by using frequent low-gain repeaters. This scheme could be significant in widening the scope for using lightly-loaded (22 mH at 500 yards) PCQT cable pairs to provide permanent program circuits.

9. SIGNALLING

It is outside the scope of the paper to consider signalling except in so far as trunk and junction circuit signalling is related to the transmission systems used to provide such circuits. On the main (zone-to-zone) routes operator-dialling facilities have long been given by the speech-path 2 V.F. system (Signalling System A.C. No. 1). Apart from the rather high level (by modern standards) of the signalling energy transmitted, this system makes no special demands upon the transmission path and permits free interconnexion of audio and any type of carrier channel.

Difficulties are, however, arising on routes where d.c. signalling is used when it is desired to introduce a new form of transmission system which will not permit the existing d.c. signalling arrangements being used.

One such difficulty arises when 4-wire audio circuits are converted to 2-wire working since the signalling path resistance is then doubled. In some instances, a conversion to Signalling System D.C. No. 2 will restore the existing facilities over the higher resistance path but present equipment design will not enable this system to meet the discriminatory and operator-control requirements of UAX and some remote non-director exchange junctions.

Similarly, a conversion from audio to carrier working, or the introduction of new carrier circuits on a route which hitherto has had only audio circuits, could lead to the loss of signalling facilities. Often, a solution would be the installation of Signalling System A.C. No. 1 but for the cost and the difficulty of obtaining accommodation. In other cases, this system as at present designed would not provide the necessary facilities, e.g., those required on junctions terminating at C.B. manual exchanges, U.A.X's, and remote non-director exchanges.

The use of carrier channel equipment having associated outband signalling goes some way towards solving this problem and on many routes could provide a complete solution. For simple arrangements the signalling conditions with the outband technique are usually limited to the transmission of an "on" or "off" condition in each direction of transmission. Provision of additional signalling conditions by adopting a pulse technique would enable full facilities to be given, but expensive and more complex relay sets would be needed.

A common answer to these problems arising from changing the transmission system is obviously desirable but cannot at present be foreseen. One solution would perhaps be the introduction of a simple and versatile, yet inexpensive speech-path voice frequency signalling system which could be made to give all desired signalling facilities, irrespective of the type of line plant. At the present time this solution appears unlikely to be realised.

The difficulty of obtaining an outband signalling channel with sufficiently low dialling distortion has been referred to earlier in the paper. In some countries this problem may not arise as use can be made of outband signalling channels for supervisory signals only, the transmission of the numerical information being at high speed over the speech path between registers. It has also been pointed out that the characteristics of some "export-type" outband signalling equipment, although meeting the requirements of foreign administrations, may not suit the

B.P.O. network. For use in the U.K., an outband signalling channel must be suitable for forming part of a composite circuit routing. Having regard to the present practice of often providing widely-separated buildings for repeater station and exchange, a typical composite circuit might comprise two separate outband signalling channels, connected with d.c. pulse repetition via an intermediate audio tie circuit and with audio extensions at each end. The pulse distortion for each outband signalling section is then required to be quite small.

10. CONCLUSION

In this paper, it has been possible only briefly to review the transmission field. However, sufficient has been written to indicate the wide range of new equipment and new systems which are being developed. The emphasis in the paper has been put on the application and on the economic basis of the new systems, as well as upon their place in the network. At the present time, one existing trunk system based upon well-established principles is being expanded using the most modern and efficient means that are available. Dramatic improvements in technical performance are not looked for now, but new equipment is expected to be more reliable, less costly, and capable of meeting any foreseeable changes in the pattern of trunk working. Such changes which are being borne in mind are, of course, the extension of dialling range to cover the country and the requirements of any new transmission plan, with its implications upon the method of circuit switching. Electronic trunk and local exchanges, too, will influence the new trunk network.

It has already been pointed out that there has been no technical advance in the method of providing junction circuits since open-wire working was replaced by the loaded cable. The annual capital expenditure on junction plant was, a few years ago, about 45 per cent. of the total trunk and junction outlay ; for the forthcoming financial year it is expected to be 55 per cent. and for the following year it is expected to be an even larger fraction of the total. The tendency for the junction plant expenditure to rise faster than that for trunk plant, reflects the relative lack of success in reducing the junction circuit costs. Present forms of frequency-division multiplex telephony and associated signalling devices are too costly for junction use and it may be that an entirely new field is ripe for study.

Little has been said in the paper on television but the general principle stands that both services, telephony and television, benefit by integration into a common main-line network.

Radio systems, too, have only briefly been touched upon. A detailed survey of the relative places of radio and cable transmission systems in the trunk network will undoubtedly provide much material for study for many years to come.

In conclusion, the authors would like to express their thanks to their colleagues in the Transmission and Main Lines Branch and in the Research Branch for assistance in preparing the paper, and especially to Mr. G. E. Turner for the economic studies on which the first part of the paper was based. Acknowledgement is made to Messrs. Standard Telephones and Cables Ltd., The General Electric Co. Ltd., The Automatic Telephone and Electric Co. Ltd., and The Telephone Manufacturing Co. Ltd., for the loan of models and photographs of their newly-developed equipment.

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