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The Institution of Post Office Electrical Engineers.

Twelve-Circuit Carrier Telephone Systems

G. J. S. LITTLE, B.Sc., A.M.I.E.E.

A Paper read before the London Centre of the Institution on the 10th May, 1938

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Introduction.

The subject of this paper is, broadly, the application of 12-circuit carrier systems to the Post Office Trunk network, but first it will be useful to recall some of the characteristics of carrier operation.

Firstly—when speech is transmitted by carrier telephony (whether over wires or by radio) the speech currents undergo a change of frequency. In modern systems one sideband only is transmitted and the difference between the highest and lowest frequencies (in cycles per second) in telephone speech is the same as the difference between the highest and lowest frequencies in the carrier transmission. The diagram (Fig. 1) illustrates the translation from the speech to the carrier range of frequencies.

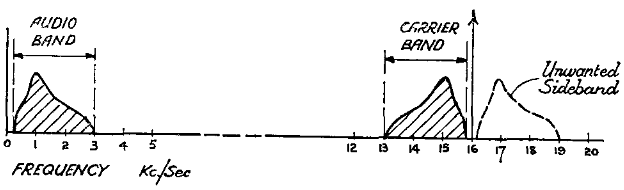

Fig. 1.

Secondly—a number of carrier bands are transmitted simultaneously over a pair of wires. Filters are provided:

(*a*) To enable the currents of the various channels to enter and to leave the main transmission path without mutual interference and reflections producing uneven transmission of frequencies within individual channels.

(*b*) To suppress, to varying degrees, the unwanted sideband and other currents whose frequencies are outside the band to be transmitted.

This use of the channel filters is, perhaps, not so fundamental as that which enables channels to combine and separate from the main transmission path.

Thirdly—having provided the means for translating individual speech bands into the carrier range (and back again) and the necessary filters to enable them to share a common transmission path the channels so formed can be interconnected at their ends to form the equivalent of 4-wire circuits in much the same way as the go and return channels (comprising lines and repeaters) of normal 4-wire circuits. The channels used can be carrier channels on the same or different pairs of wires and, this is the important point, each carrier channel can be considered as equivalent to a pair of wires.

By providing differential transformers and impedance balances it is possible to obtain the equivalent of 2-wire operation (using the same carrier band for the two directions of transmission). However, the disadvantages of 2-wire operation of audio circuits are, in general, intensified in carrier operation, and 4-wire operation is practically universal in carrier systems for underground cables. Fig. 2 illustrates the comparison between 4-wire audio and 4-wire carrier circuits.

The greatest single influence amongst the many technical advances which have enabled multi-channel carrier operation of underground cable circuits to become a practical and economical means for long

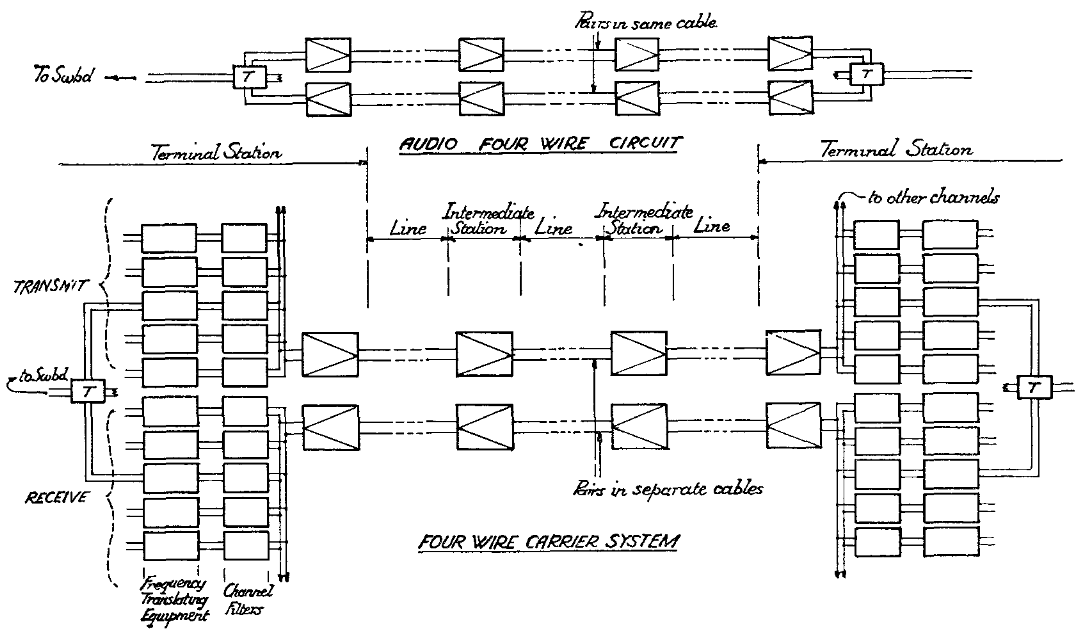

Fig. 2.

distance telephony is the development of the negative feedback amplifier.

The outstanding characteristics which have given it, as it were, this key position are: —

(*a*) The reverse feedback reduces harmonics and other non-linear products to such a degree that when a number of channels are amplified together the interference between channels is at so low a level as to be negligible. This remains true right up to the practical overload point after which increase in input results in little or no increase in output. To obtain comparable results without negative feedback it would be necessary to increase the maximum power-handling capacity of the amplifier many-fold, as the practical overload point could not be approached without excessive noise due to interference between channels in the amplifier.

(*b*) Extraordinary stability. — It is a remarkable and most valuable property of these amplifiers that amplification is practically independent of even considerable changes of voltage in anode and filament supplies and also of changes in valve characteristics.

(*c*) It is practicable to construct and operate repeaters having very high gains, at least, gains much higher than previously used in practical systems. This advantage is perhaps hardly separable from that of gain stability.

Flowing more or less directly from these characteristics are the economical simultaneous amplification of a number of circuits in a single amplifier and the use of a large number of repeaters in tandem (each having a high amplification) without jeopardising circuit stability by variations in amplification.

In normal systems of audio transmission in cables, the amount of amplification that can be introduced at each amplifying point is definitely limited by the crosstalk attenuation between opposite-going directions of transmission, that is to say by near-end crosstalk. A gain of 60 db. is readily provided by a 3-stage negative feedback amplifier, but even at audio frequencies such an amplification is out of the question on account of near-end crosstalk, if the wires for both go and return directions of transmission are in the same cable. Crosstalk is worse in the higher frequency range occupied by carrier systems and this difficulty has been overcome by providing separate cables for go and return channels, so practically disposing of near-end crosstalk altogether.

Far-end crosstalk remains, however, but, unlike near-end crosstalk, this type of crosstalk does not limit the amount of amplification that can be used. Even so, at the comparatively high frequencies involved in multi-channel carrier operation, the attainment of the necessary freedom from crosstalk would be difficult if it depended only on the care and regularity of manufacture of the cables and the selection of wires for jointing during installation. Fortunately, however, all the currents contributing to far-end crosstalk undergo the same changes of phase and far-end crosstalk can be considerably improved by the adjustment of small condensers connected between the wires.

As compared with audio operation, in which each channel of communication has its own pair of wires and requires separate amplification, multi-channel carrier scores by sharing a pair of wires among a number of channels and amplifying the channels in a single amplifier. The amplifiers are, however, more costly, and in spite of their high gain and closer spacing as compared with audio operation, the 12-channel cables provided by the Post Office have 40 lb. conductors as against the 20 or 25 lb. conductors that are normal for loaded audio cables.

On the other hand the cost of loading is saved and the complication of constructing manholes for loading coils at precise intervals, a special difficulty in towns, is avoided.

The net saving in cost per circuit mile has to make up for the additional expenditure on equipment at the terminals. Economic studies have indicated that 12-circuit equipment, at present prices, provides circuits more cheaply than is possible by audio methods, for distances over 80 or 100 miles.

Bristol-Plymouth Experiment.

Inspired by advances made by the Bell Laboratories in U.S.A. in the experimental application of multi-channel carrier telephony to underground cables, the Post Office decided, early in 1935, to commission Messrs. Standard Telephones & Cables, Ltd., to design and instal a 12-circuit carrier system between Bristol and Plymouth. The conviction that carrier telephony was destined to play a major role in the expansion of the British trunk network was firmly held, but the decision to go forward with a full scale experiment at that time was not without risk. But this decision has now been amply justified inasmuch as it has enabled full advantage to be taken of the new system of transmission in providing less costly trunk circuits needed during a period of rapid expansion in the trunk service.

The development of the 12-circuit system for the Bristol-Plymouth route was carried out under the urge of providing working circuits. This no doubt acted as a powerful stimulus, but at the same time must have been a considerable strain on those responsible for its development and manufacture. Service was given in December, 1936.

Cables.

In the Bristol-Plymouth system separate cables were provided for go and return directions of transmission, each cable consisting of 19 paper insulated 40 lb. pairs. The design was a break-away from normal trunk cable practice in that pairs were not twisted together to form quads—it was a ' pair ' cable. This construction had the advantage of a simplification of balancing work in the field due to the absence of the usual within quad balancing. Repeater stations have been provided at intervals up to 22 miles apart and this standard has been adopted on subsequent schemes though in a few routes the 22 miles has been slightly exceeded.

For carrier schemes subsequent to Bristol-Plymouth the ' pair ' design of cable has been replaced with a cable of star-quad formation. Retaining the same

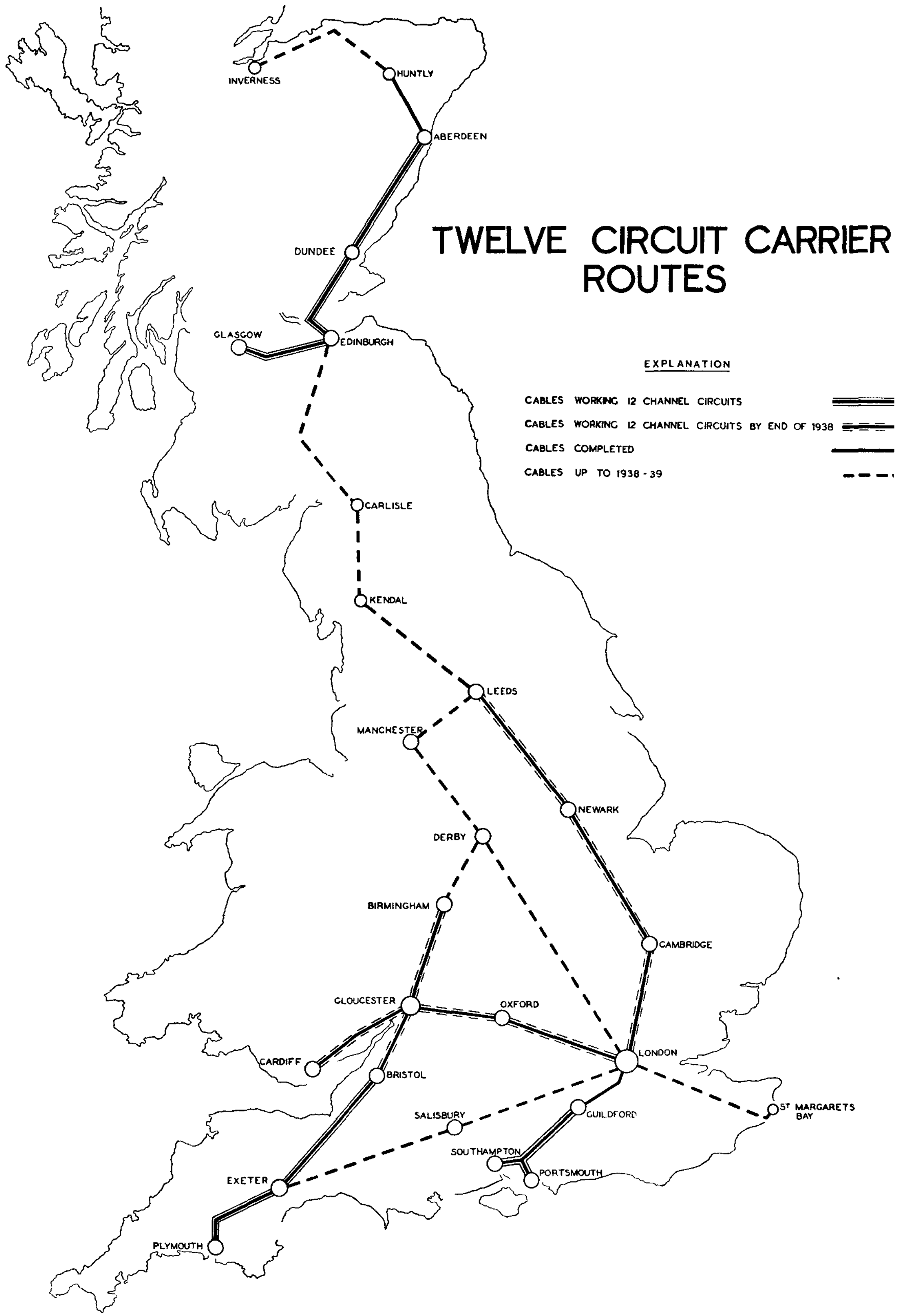
TWELVE CIRCUIT CARRIER ROUTES
EXPLANATION
CABLES WORKING 12 CHANNEL CIRCUITS
CABLES WORKING 12 CHANNEL CIRCUITS BY END OF 1938
CABLES COMPLETED
CABLES UP TO 1938 - 39
INVERNESS
HUNTLY
ABERDEEN
DUNDEE
GLASGOW
EDINBURGH
CARLISLE
KENDAL
LEEDS
MANCHESTER
NEWARK
DERBY
BIRMINGHAM
CAMBRIDGE
GLOUCESTER
OXFORD
CARDIFF
LONDON
BRISTOL
SALISBURY
GUILDFORD
ST MARGARETS BAY
SOUTHAMPTON
PORTSMOUTH
EXETER
PLYMOUTH

Fig. 3.

overall diameter it has been possible at the expense of a slight increase in the attenuation per mile to increase the number of pairs to 24. The inherent symmetry of the star-quad formation has, on the whole, been found to compensate for the advantages of the ' pair ' cable.

The star-quad carrier cables (40 lb. conductors) have a lower capacity per mile than normal trunk cables, the 24 pairs occupying the same space as 38 pairs in the ordinary quad cable. The attenuation of a 22 mile repeater section is about 60 db. at 60 kc/s., the highest frequency transmitted. Far-end crosstalk balancing networks are necessary but by care in manufacture and balancing operations in the field, the degree of freedom from crosstalk attained before the networks are connected has enabled the Post Office to abandon, on future schemes, the use of the balancing huts near the mid-points of repeater sections. The networks will still be required, but will be installed at the receiving end of each repeater section, along with the terminal equipment. That this has been possible is due to the co-operation with the Post Office of the four firms who supply trunk cables and to a friendly rivalry amongst them in the matter of reduction of crosstalk.

The far-end balancing units have been referred to as networks, but in actual fact they consist of condensers connected between the appropriate wires of pairs between which the crosstalk is to be annulled.

The present stage in the evolution of a network of 12-circuit carrier cables is shown by the full lines in Fig. **3**. The cables to be provided in the current programme are indicated by the broken lines. Each line apart from Bristol-Plymouth represents two 24-pair cables with a potentiality of 12 × 24 = 288 telephone circuits.

Equipment.

As to equipment, that provided for Bristol-Plymouth and others of the earlier schemes differ from that now being manufactured by Messrs. Standard Telephones & Cables, Ltd., in the arrangement of equipment on the bays. For those schemes (Bristol-Plymouth, Aberdeen-Edinburgh and Guildford-Southampton-Portsmouth) the terminal equipment for each 12-circuit group was constructed as a self-contained unit. The equipment at a terminal station for one go pair and one return pair was mounted on two adjacent bays, equipped both sides.

Flexibility. With the adoption of the 12-circuit carrier system as standard for circuits over about 80 miles in length it became clear that as a network of carrier cables grew, flexibility in interconnecting and extending 12-circuit groups would become of increasing importance.

From the point of view of flexibility alone the easiest way of interconnecting groups of circuits would be to bring circuits down to voice frequency wherever switching was likely to be required. The objection to this is two-fold.

Firstly, the economics of carrier operation are intimately bound up with length of circuit. If 80 miles is taken as the minimum economic limit, to join together two complete circuits, each 80 miles in length, to form one 160-mile circuit would be just economic, but a 160-mile circuit with terminal equipment at the two ends only would represent a saving of one complete set of demodulating, modulating and filter equipment, the most important saving which could be made on relatively short circuits.

Secondly, the band of audio frequencies transmitted is limited by the terminal equipment and more particularly by the channel filters. The band transmitted cannot be absolutely sharply determined and an additional set of terminal equipment in circuit causes additional loss at frequencies near the edges of the band, that is the band of frequencies effectively transmitted is reduced. This is illustrated in Fig. **4**.

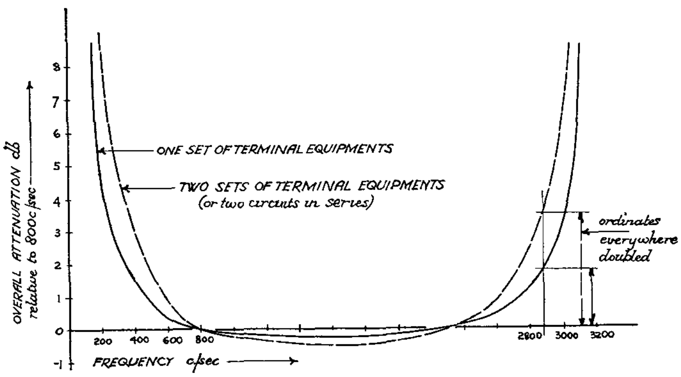

Fig. **4**.

To meet the necessity for flexibility in extending 12-circuit groups as the carrier network increases and to provide for changes in routing to meet changing traffic needs an arrangement which has come to be known as " the flexible system " has been devised. This scheme is shown in diagrammatic fashion in Fig. **5**. The receiving amplifiers at the terminals and

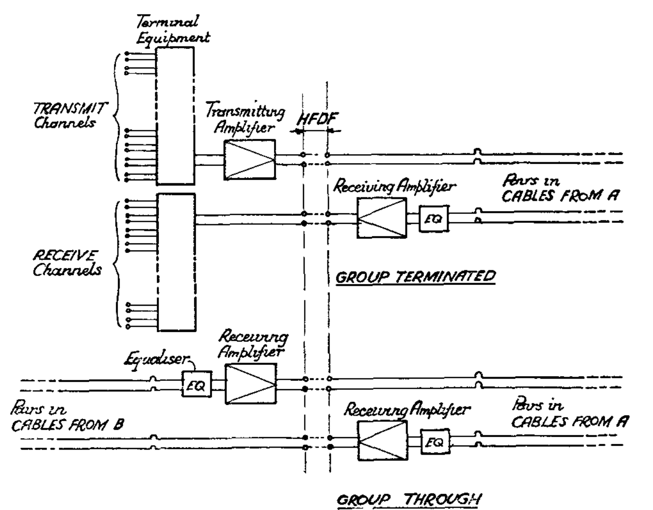

Fig. **5**.

the amplifiers at the intermediate stations (together with the line equalisers) are regarded as one with the cable pairs to which they are connected. To complete the equipment at a terminal station, to bring circuit groups down to voice frequency, it is necessary to add filter and modulating and demodulating equipment and also a transmitting amplifier.

The high-frequency distributing frame indicated in the diagram presented a formidable problem, but the goodwill and perseverance of the two firms (Messrs. Standard Telephones & Cables, Ltd., and Messrs. General Electric Co., Ltd.) who are supplying 12-circuit equipment to the Post Office, coupled with the careful employment of screened wiring, has enabled the problem to be solved. The connections necessary to join terminal equipment to a pair of go and return lines are shown in the diagram. The through connection of a circuit group is also shown.

Careful workmanship in the earthing of screens and making of connections on the high-frequency distribution frame will be necessary, but one may perhaps suppose that the transfer of a 12-circuit group may take no longer than the jumpering of 12 audio circuits.

The introduction of the flexible system has enabled a somewhat freer interpretation of the economic limit of 80 to 100 miles to be taken. By adopting 12-circuit carrier as standard for Zone to Zone links it is economically sound to use the system for links which individually are shorter than 80 miles because of the longer circuits of which such a section forms a part only. By adopting the system for all Zone to Zone links great flexibility is attained and this of itself will be a valuable feature.

Specifications.

The decision to adopt the 12-circuit system for the provision of trunk circuits over 80 miles in length was taken at too early a stage for the Post Office to require standardisation of equipment when Messrs. General Electric Company entered the 12-circuit carrier field. The Post Office specification for equipment lays down, as it were, a technical framework, with which suppliers must conform, a framework to ensure that equipment provided by different suppliers shall function together in such a way as to result in satisfactory circuits.

Fig. 6 is a block diagram representing the essentials of a 12-circuit terminal.

The fundamental characteristics laid down in the specification are outlined below.

1. The bands of frequencies of the various channels must be transmitted over the line in positions within adjacent 4 kc/s. bands (as indicated at the bottom of Fig. 7).

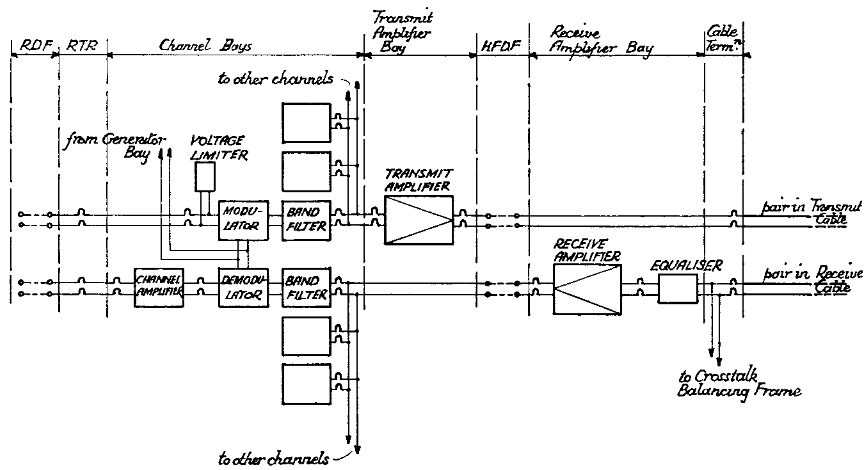

FIG. 6.

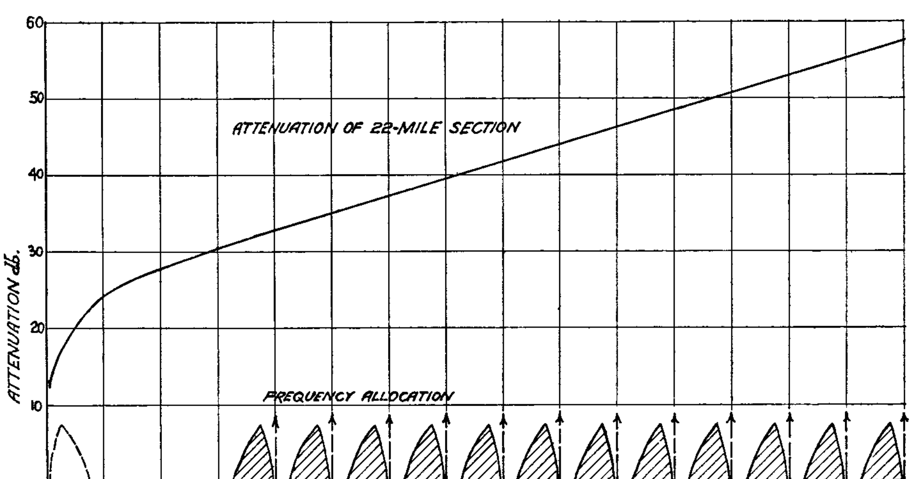

FIG. 7.

2. The bands must be the lower sidebands, or equivalent to the lower sidebands, of carrier frequencies of 16, 20, 24 . . . 60 kc/s.
3. The level difference between audio frequency input to the modulating equipment and the corresponding carrier output from the transmitting repeater must be within the limits shown in Fig. **8**.

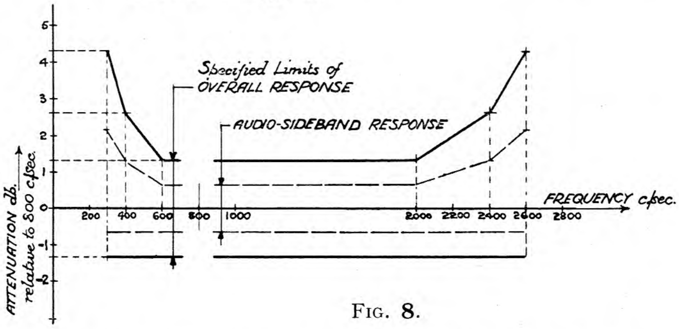

Fig. **8**.

A similar requirement holds in relation to the reconversion at the receiving end from carrier sideband frequencies to the corresponding audio frequencies.

These requirements as to audio-sideband responses were necessary to ensure that two contractors' terminal equipment at either end of a line should give together circuits within the limits laid down by the C.C.I.F. for international 4-wire circuits.

The specification requirements which have been noted derive directly from the Bristol-Plymouth installation. The choice of the 4 kc/s. spacing leaves room for improvement in frequency response by improved technique and should be adequate for a reasonably long period. The choice of twelve as the number of channels is more difficult to defend. One has noted statements that the number might just as well have been ten, but this and the choice of the frequency band extending from 12 to 60 kc/s. probably derives from the crystal filter technique of the Bell Telephone Laboratories.

The omission of a band of frequencies, 0 to 12 kc/s., adequate for a further three channels is to be explained as being bound up with the increasing difficulty of design of a negative feedback repeater (or perhaps to some extent, any type of repeater, with a strictly limited number of valves) as the ratio of highest to lowest transmitted frequency is increased.

A contributory factor is the increased difficulty of attenuation equalisation if the band were lowered.

Messrs. Standard Telephones & Cables, Ltd. System.

Fig. **6**, which was shown as a typical block schematic of a 12-circuit terminal, is applicable to Messrs. S.T.C.'s system. The modulators and demodulators comprise copper-oxide rectifiers and transformers arranged in one of the many possible forms of the ring modulator. In carrier technique, for all except comparatively high frequencies, the copper-oxide rectifier seems to have replaced the valve as a modulating element as completely as the negative feedback amplifier has ousted the amplifier without feedback where more than one channel has to be amplified at a time. The channel filters are built up from carefully adjusted pairs, each comprising an inductance coil and a condenser, mounted in metal pots. These filters represent an extension of the earlier technique of filter manufacture and have enabled the overall channel frequency response curves shown in Fig. **9** to be obtained.

The frequency generating equipment is shown in Fig. **10**. A master oscillator generates 4 kc/s. which

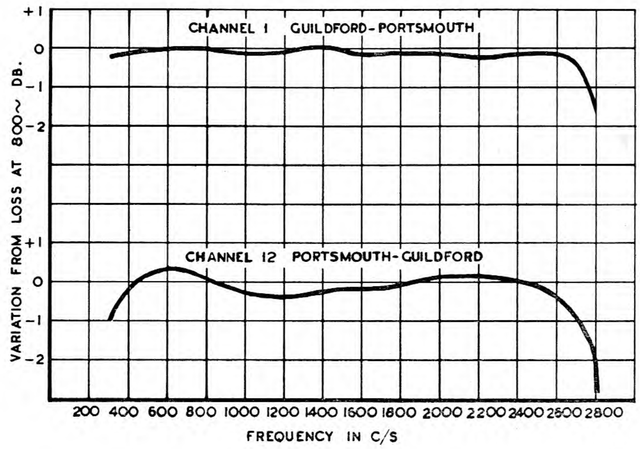

Fig. **9**.

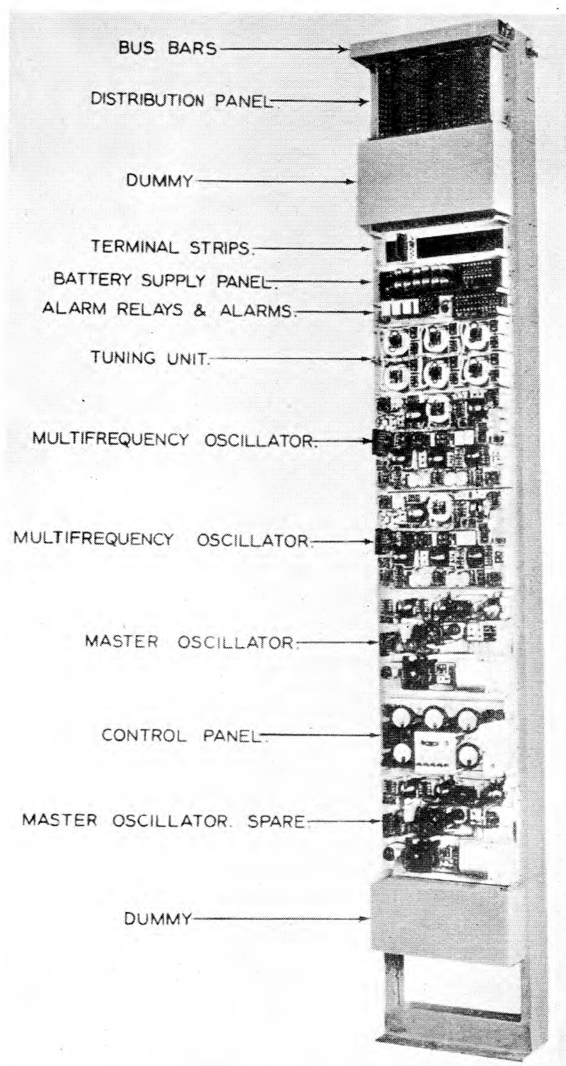

Fig. **10**.—Oscillator Bay. Covers off.

is supplied to four other oscillators each of which provide three of the twelve carrier frequencies that are required. One of the oscillators is tuned to 20 kc/s. and a supply having a frequency of 4 kc/s., from the master oscillator, is injected into the grid circuit, keeps the natural oscillation exactly in step, and modulates the 20 kc/s. giving sidebands 20 – 4 and 20 + 4 (that is to say 16 and 24 kc/s.) as well as 20 kc/s. in the output. As an insurance against interruption of carrier supply the specification requires the frequency generating equipment to be duplicated.

The bay of feedback amplifiers shown in Fig. **11** is such as is installed at intermediate stations. Each side of the bay mounts four amplifiers and line equalisers. Similar bays are required at terminal stations on the receiving side. On the transmitting side the amplifiers are similar but line equalisers are not required.

Messrs. General Electric Co., Ltd. System.

The G.E.C. system has been developed within the framework laid down in the Post Office specification and the solutions to the problems involved differ in varying degrees from those on which the S.T.C. equipment has been based. In the terminal equipment, a way around the rather precise adjustment of filter components has been found by lightening the attenuation discrimination required of the channel filters. This has been accomplished by performing modulation (and demodulation) in two stages. In the transmitting portion of the terminal the voice band of each channel is made to modulate a 6 kc/s. carrier, giving rise to sidebands on either side of 6 kc/s. as represented in Fig. **12**. The lower sideband is cut off by a filter. For the lowest channel, the second modulation is with a carrier frequency of

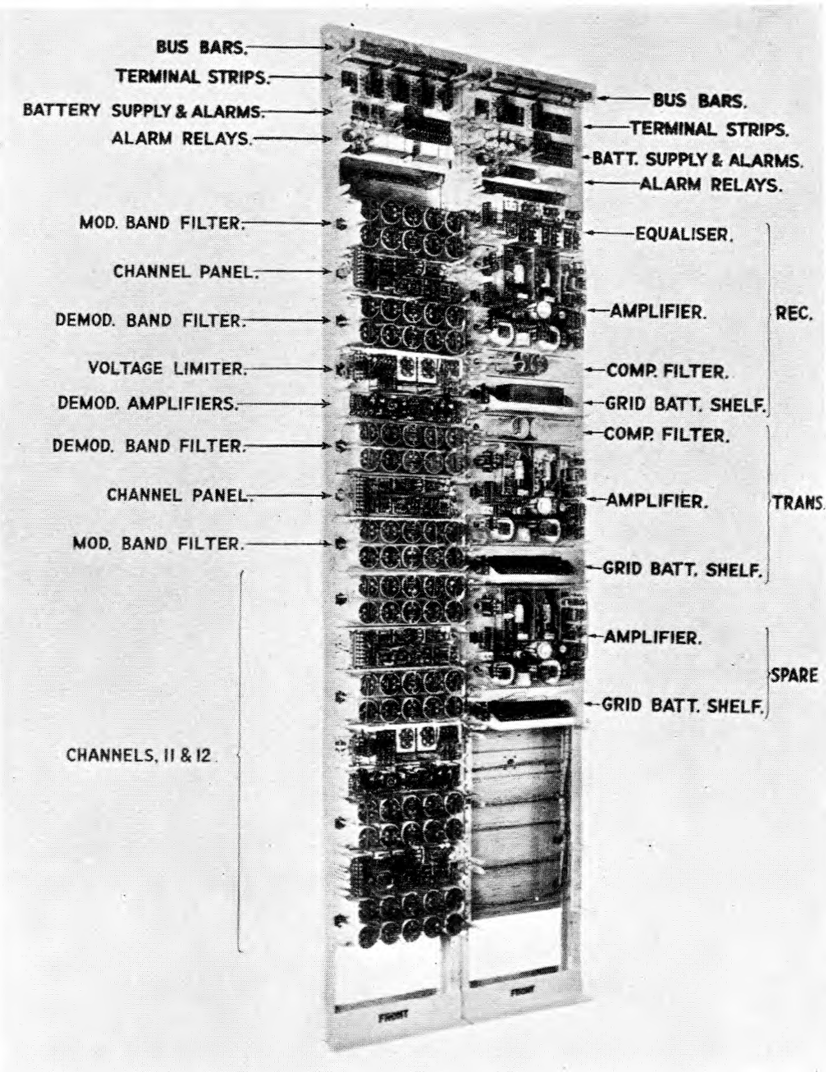

FIG. **11**.—CHANNEL AND AMPLIFIER BAYS. COVERS OFF.

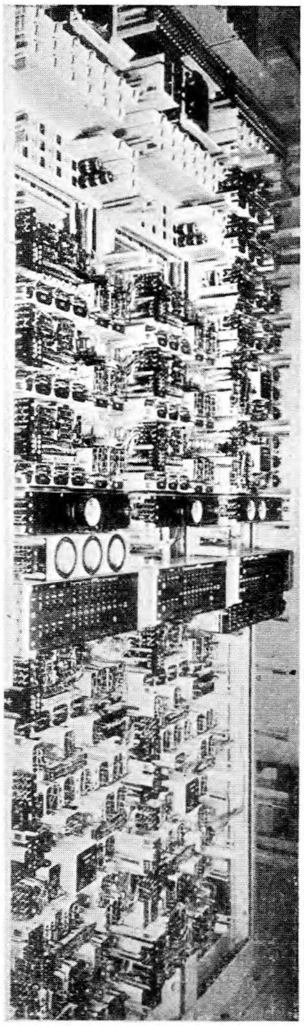

FIG. 15.—DUPLICATE GENERATOR BAYS AND PILOT. FRONT VIEW—COVERS REMOVED.

London - Cambridge.) Overall response curves measured in tests at the G.E.C. Works are given in Figs. **16** and **17**.

The length of single circuits provided by means of 12-circuit cable and equipment at the present time amounts to more than 15,000 miles. Within a few months a further 50,000 miles of single circuit will have been equipped and by the end of this year the total will have risen to close on 100,000 miles.

American System.

The 12-channel system developed by the American Telephone and Telegraph Company has been described recently in the Bell System Technical Journal[1]. The American System has been based on crystal filters, that is to say, on filters in which crystalline quartz plates[2] are used to give the effect of tuned inductances with remarkably low resistance. The sizes of the crystal plates have fixed 60 kc/s. upwards as the practical range for crystal filters. The voice frequencies of each channel are translated into the range 60-108 kc/s. by a single modulation, being led through the channel filters to a group modulator which lowers the 12-channel group as a whole into the range 12 to 60 kc/s., the same range as that standardised in this country. There is this important difference, however, that in the American system the individual bands of frequencies, as transmitted over the line, are not inverted. They are in fact equivalent to upper sidebands. In demodulation, the group is raised into the crystal filter range before individual channels are demodulated. Fig. **18** has been drawn to illustrate the frequency conversions and to contrast the bands transmitted with those of the 12-circuit system in this country.

Future Developments.

It has been decided to proceed with tests to determine whether it will be practicable to increase the circuit capacity of carrier cables by transmitting two or even perhaps three groups of 12 channels over each pair. This will involve the group modulation of the second and third groups into their final positions, that is unless a crystal-filter technique is used in which case one group of 12 channels would be modulated downwards and the other group upwards. The middle group would remain in the normal 60-108 kc/s. range of the crystal filters. A new 12-156 kc/s. amplifier would be needed to replace the existing 12-channel amplifiers. The Post Office Engineering Department Research Branch have made very substantial progress in the matter, but for satisfactory application a number of practical problems have to be solved. To mention but one, groups of 36 circuits instead of 12 may prove to be too large for general purposes, and for this reason, and due to

[1] Bell System Technical Journal. January, 1938.

[2] A. H. Mumford, B.Sc., A.M.I.E.E. — "The London-Birmingham High-Frequency Carrier System." May, 1937. I.P.O.E.E. Paper No. 164.

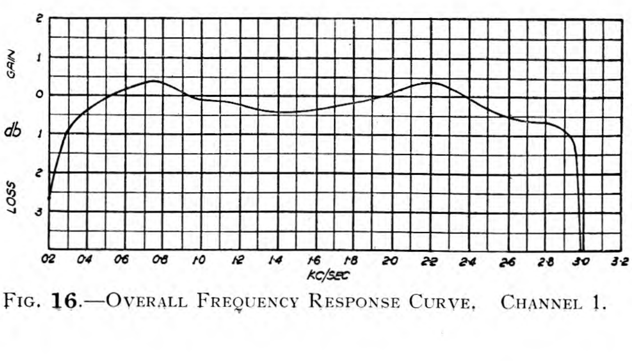

FIG. **16**.—OVERALL FREQUENCY RESPONSE CURVE. CHANNEL 1.

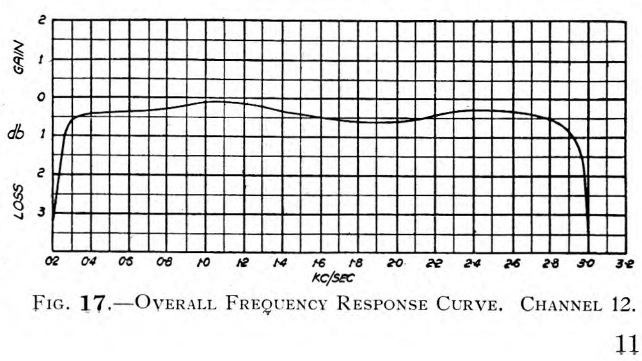

FIG. **17**.—OVERALL FREQUENCY RESPONSE CURVE. CHANNEL 12.

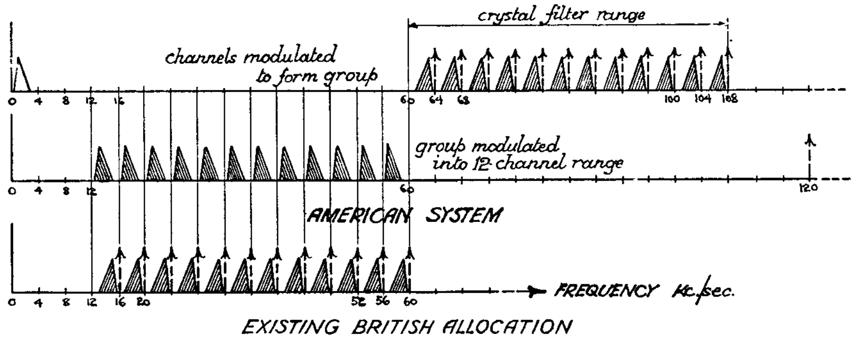

FIG. 18.—EXISTING BRITISH ALLOCATION.

difficulties associated with the higher frequencies involved, it may be necessary to bring all groups to the present 12-60 kc/s. range when taken through the high frequency distribution frames.

The present application of the 12-circuit system in the U.S.A. is to existing cables. In this country there is not a large number of routes on which two suitable cables exist side by side, but in the first instance the practicability of applying the system to existing 40 lb. multiple twin cables between Derby and Leeds is being investigated.

Standardisation.

Although the circumstances under which the 12-circuit system first entered the Post Office Trunk network made it desirable, if not essential, to leave latitude to the different suppliers, a time must be envisaged when such equipment is supplied to standardised designs. How near we may be to that time it is difficult to form an opinion though it is clear that the building-up of a standardised system must itself be a lengthy process.

The question of standardisation here, as in many other cases, resolves itself into two clearly defined parts:—

First—It will be necessary to decide on the essential basic circuits. Frequency translation, which is the core of the system, affords three main possibilities:

Single modulation, double modulation, or crystal filters with group modulation.

The crystal filter technique is capable of giving a considerably wider transmitted band than the other or " straight " system. Messrs. S.T.C., by careful attention to tolerances and manufacturing technique have probably pushed such a system near to its practical limit. Messrs. G.E.C. on the other hand have used the double modulation system to enable them to manufacture equipment with an adequate frequency response while retaining more normal manufacturing tolerances. A combination of the G.E.C. technique with the close tolerances of the S.T.C. would probably give a performance of the same quality as the crystal-filter technique. This is presumably, in effect, the technique that has led the German Post Office to advocate a 3 kc/s. channel spacing as adequate for the realisation of the existing C.C.I.F. requirements for overall frequency response of international circuits. The increased efficiency of new designs of telephone transmitters and receivers, however, makes it necessary to look forward to a general extension of the upper limit of transmitted frequencies on new circuits.

As a personal estimate of future trends the writer inclines to the view that the crystal-filter technique will prove least costly. In the end a reduction in bulk of equipment is usually related to reduced costs. The individual double modulation system, partly because its frequency translations on the whole take place at lower frequencies and partly because each channel is individually modulated twice, will probably be found to involve a greater bulk of equipment.

Second—If standardisation is to be carried to the limit it would be necessary to specify all components, down to individual piece parts. This is a degree of standardisation not yet attempted by the Post Office on transmission equipment, though not on that account necessarily to be regarded as impracticable.

In conclusion it is desired to thank Messrs. Standard Telephones and Cables Ltd., and Messrs. General Electric Company Ltd., for their kind co-operation in providing photographs of equipment, etc., and to colleagues in the Department for assistance in the preparation of this paper.

NOTES OF THE DISCUSSION.

COLONEL ANGWIN, in opening the discussion, pointed out that the paper fell into two main categories. The first was a general description of the 12-circuit system which he commended to the officers of the Department, and remarked that it should be of considerable value on account of the absence of official technical instructions on the matter. The absence was due to the rapidity with which the introduction of carrier telephony had occurred. The second part was one which should be of more interest to those directly concerned with the problems involved. He referred to the high frequency distribution frame which enabled the system to be inter-connected without introducing the necessity of demodulation.

He went on to point out that the difficulties in the way of complete standardisation were considerable, but that ultimately they must be faced and he hoped that the system finally standardised would contain all that was best in the existing arrangements.

It appeared that in future 12-circuit carrier working might be economical for distances of less than 80 miles, either by the application of mass production methods which might be made possible by the more extensive use of carrier working, or by the adoption of some other system.

In conclusion, he remarked that the author had not touched on the absence of echo suppressors. The speed of propagation of carrier waves is so high that any echo present on the circuit occurs so quickly after the normal received speech that it has no appreciable effect on its quality.

MR. VAN HASSELT questioned whether the introduction of the flexibility principle was justified and asked the author to explain how it was proposed to use the present system and how much spare equipment he estimated to be necessary. He thought that the author had not stressed that a carrier system fitted with feedback amplifiers was not only more economical than the old transmission arrangement but that it was also superior on account of its greater stability.

CAPT. TIMMIS referred to the application of 12-circuit carrier system to existing cables which had occurred in America and stated that the Post Office were at the moment studying the problem of utilising the system on the London-Leeds circuits. He mentioned that it was not necessary to have two cables following the same route throughout although for several reasons it was convenient if they did so. Between Leeds and Sheffield experiments had been made on 30 specially deloaded pairs of 40 lb. multiple twin cable. The attenuation of these was approximately the same as that of the special carrier cables referred to in the paper and consequently the same repeater spacing of about 20 miles would be suitable. The application of carrier working to these cables introduced two problems, firstly, that of crosstalk and, secondly, that of noise. The crosstalk could be dealt with by the application of simple networks consisting of a condenser and a resistance although in America the standard balancing network incorporated a mutual inductance. He thought that this was unnecessary and that the Post Office could secure satisfactory operation with the simple condenser and resistance combination.

In investigating the noise present on the circuits some curious effects were observed, notably the independence of the noise on the position of the frequency band. This is a characteristic of " resistance noise," but that involved could most certainly not be " resistance noise." Fortunately, the magnitude of the disturbance was not serious and it did not necessitate any measure of reduction although according to published accounts the difficulty in America had been satisfactorily overcome by the use of noise filters.

MR. WILLIS explained the manner in which the G.E.C. had come to use the double modulation system. He stated that they had utilised an existing square wave generator but had found it necessary to apply double modulation in order to obtain the frequency bands in the positions demanded by Mr. Little's performance specification. When they had done this they found that the system made possible the use of filters with much wider specification limits. He went on to stress the advantage of the double modulation system in that it demanded less stringent requirements of the filters and that this implied that the performance of the system would be less liable to changes due to variations of the filter characteristics with temperature, etc.

He expressed his doubts as to the advantages offered by the American system, which incorporated crystal filters, over the double modulation system and enquired whether Mr. Little intended, in the event of the extension of carrier working to higher frequencies, to continue his insistence on the use of the lower sideband.

MR. HALSEY suggested that the 60 db. repeater section was too short and that, by using a sending level some 10 dbs. higher than the present standard, repeater sections might be used with a length of 70 dbs. (about 27 miles) and contended that it was worth considering the incorporation of a single stage amplifier for this purpose.

He explained that there were two possible methods of equalisation and that whilst pre-equalisation was not economical with a 12-circuit system, it would probably become so if the number of channels was increased to 36. It would then be difficult to apply the flexibility principle because of the necessity for using a high frequency distribution frame.

He concluded by mentioning that the A.E.G. had developed for the German Reichpost a system employing direct modulation and conforming to the C.C.I.F. requirements as regards transmission but using only a 3 kc/s. channel separation.

MR. MONTGOMERY explained that 12-circuit carrier working was only made economical by the elimination of " frills " and he drew attention to the power equipment of repeater stations. This, he said, appeared to be too expensive and mentioned that he had recently seen in America repeater stations in which the batteries were smaller than were commonly used in this country and were located in the same room as the repeater equipment.

Regarding crystal filters, he stressed the manner in which construction and maintenance were facilitated by their use and also the way in which they enabled the size to be reduced as compared with that necessitated by the double modulation system. He stated that he was of the opinion that the application of mass production methods to crystal filter manufacture would bring about a considerable cheapening.

Dr. Rosen mentioned as a matter of interest that the C.C.I.F. would shortly be considering the standardisation of carrier working, and that they would be faced with the differences which prevented the German and Post Office systems from " marrying " up. He stressed the necessity of arriving at a unified system of carrier working because of the difficulties which would otherwise be present when operating between the various Continental countries. Whilst the problem might not be acute for the Post Office it was particularly important for those countries in which a great proportion of the traffic was incoming from other administrations.

In conclusion, he said that the application of carrier telephony to trunk working was not altogether welcome to the cable manufacturers on account of the reduction in the number of main cables.

Reply by the Author:

Mr. Little expressed his thanks to the various speakers for their complimentary remarks and said that Colonel Angwin's contribution to the discussion appeared to call for no reply on his part and that he did not feel competent to judge between the merits of the systems advocated by certain speakers.

In reply to Mr. Van Hasselt's queries regarding the flexible system, he pointed out that carrier working could only be introduced link by link and that as each link was installed it was desirable that the maximum use should be made of the apparatus already available, but that as further links were put in, it would be necessary to extend circuits to points beyond those at which they were originally terminated and that it was here that the use of the flexible system became important. He stressed the fact that traffic forecasting was still an art rather than a science, and that where adjustments had to be made the system would again show its value. He quoted Gloucester as an example of the use of the principle and explained that four cables met at this point. Concerning spare equipment he stated that the tendency would be to instal larger numbers of amplifiers at intermediate stations than were required for the projected arrangement of circuits in order that if re-routing became necessary the available terminal equipment could be used to the maximum possible extent.

He stated that he was not certain that it was possible to reduce the reserve capacity of the power plant at repeater stations in view of the basis of design adopted by the Post Office which called for a 24 hours standby capacity.

As to Dr. Rosen's misgivings concerning the capacity of cables used with carrier working, he said that he felt that, as had so often occurred in the past, an innovation which appeared at first sight to reduce the demand for an article ultimately had the effect of stimulating this demand and went on to suggest that the use of carrier working would bring about the cheapening of trunk rates and a general increase in the trunk traffic and this would in turn react in some measure of compensation because of the additional cables which it would necessitate.

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