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The Institution of Post Office Electrical Engineers.

Recent Advances in Carrier Telephony

By

R. J. HALSEY, B.Sc. (Hons.), A.C.G.I., D.I.C.

A Paper read before the London Centre of the Institution on the 14th May, 1935.

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Introduction.

It is the purpose of the present paper to describe the considerable changes which have taken place in the field of carrier telephony since 1931 and to indicate the lines on which developments are now proceeding. While the paper is primarily concerned with the work of the British Post Office, developments have been so extensive in the United States and in Germany that these are considered with a view to their probable effects on our own lines of progress.

In 1931 carrier telephony was in extensive use in the United States of America, and the position of carrier on open lines was well established. Systems of American design, notably the CS3, CN3,[1] and D1[2] systems were giving excellent service on open lines in many parts of the world, while multi-channel working on unloaded submarine cables was fairly common. In all cases the carrier frequency and one sideband were suppressed and the Carson balanced modulator or its later modification, the self-oscillating modulator, formed the standard method of frequency changing. Band-filters were used to separate the channels and, whereas grouped systems were universal for open lines, balanced (2-wire) systems were generally employed on submarine cables. Such cables were usually concentric and unloaded, with gutta dielectric, typical examples being the Key West-Havana (1931) Cable,[3] and the Catalina Island Cable.[4] In the Key West-Havana Cable, paragutta made its first appearance as a dielectric.

In Great Britain development was cramped by local conditions. Open lines were comparatively short and, since they contained many underground cable sections, the high frequency attenuation was usually relatively high. The economics of the problem, therefore, ruled out all but cheap carrier terminal equipment and this was not forthcoming except in the form of an old, and rather unsatisfactory, equipment made to a Post Office design. Experience with these old sets caused much opposition to carrier development schemes and except for a few experimental circuits using more up-to-date equipment of Post Office design (but still expensive), little progress was made on open lines.

In the field of submarine cables, the position was more encouraging since satisfactory experimental circuits had been demonstrated on various cables to Ireland and the Continent[5] and in this direction the economics of carrier working were decidedly favourable. No permanent equipment was, however, installed, partly owing to patent difficulties. Up to 1931 all schemes developed by the Post Office involved transmission of the carrier frequency, although one sideband was suppressed.

London-Rotterdam 7.

In October, 1931, Great Britain abandoned the Gold Standard and the pressure of traffic on Continental circuits increased enormously. In particular, the Dutch route was completely overloaded. The cables on this route (continuously loaded) carried phantom and super-phantom circuits to the limit, sixteen circuits on each four-quad cable and, in order to ease the situation a little, a four-wire carrier channel was set up between Aldeburgh and Domburg using temporary equipment. For the first time in this country the carrier frequency (5.8 Kc/s) was suppressed, in order to reduce the intermodulation cross-talk between voice and carrier channels. The suppression was carried out solely by means of a low-pass filter.

This carrier circuit became the submarine section of London-Rotterdam 7 and was a complete success. Judging by the traffic which it carried it was the most popular London-Rotterdam circuit on the trunk switchboards. Altogether the experimental equipment worked for 1½ years without (it is believed) a single fault, until it was replaced by permanent equipment of a similar type in 1933.

The Anglo-Dutch Carrier Scheme.

Encouraged by the success of London-Rotterdam 7, tests were made to determine the maximum number of carrier circuits which could be operated on the Dutch route. It was found that the best arrangement was to work go and return circuits within quad and in this way it was possible to work all four quads in No. 3 cable[6] and two diagonally opposite quads in No. 2 cable,[7] this having a considerably higher attenuation. The attenuation-frequency characteristics of the two cables are shown in Fig. **1** which also shows the disposition of the voice and carrier bands.

The necessary equipment was made by Messrs. Standard Telephones & Cables, Ltd., to a Post Office component specification, and the submarine carrier links were completed in May, 1933. The circuit arrangement of the carrier equipment is shown in Fig. **2**, and a photograph of the Aldeburgh carrier bays in Fig. **3**.

The operation of the modulators and demodulators has been described elsewhere[5] and for the present paper it will suffice to refer to the following main features :—

1. Each channel incorporates its own oscillator working on a frequency of 5.8 Kc/s.

[1] For References see page 34.

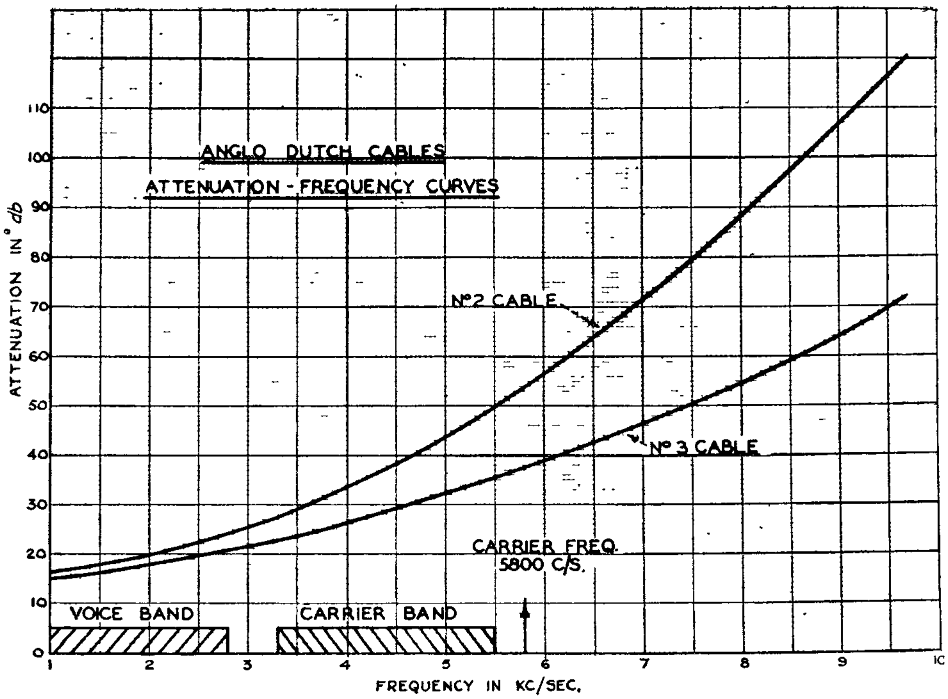


FIG. 1.

2. Anode modulation is used with balanced modulator valves. By this means the voice frequencies and their harmonics are eliminated in the bridge. The carrier is not suppressed in the modulating valves.
3. The output valves (push-pull) handle carrier and both sidebands, the carrier and upper sideband being suppressed in the filters.
4. Normal repeater equalisation is incorporated in the modulator.
5. A high-frequency equaliser is incorporated in the demodulator input circuit.
6. Full-wave demodulation is used.

As regards (2) above, the modulator was originally designed for use with transmitted carrier systems.

The overall gain-frequency characteristic of one of the carrier sections is given in Fig. 4, which also shows the approximate level diagrams for the two cables. It will be observed that the associated voice circuits are worked on a 2-wire basis.

Technically, the scheme was successful and the carrier circuits form 4-wire submarine links in the following important long distance trunks:—

London-Stockholm, London-Oslo and London-Berlin (4 circuits).

The trunk operators, both in London and on the Continent, welcomed the new circuits as enthusiastically as the original London-Rotterdam 7, and at all times they appear to be among the busiest circuits on the Dutch route.

Economically the scheme was sound for such valuable circuits on expensive cables, but the cost of the equipment was high at approximately £800 per channel end. It was still obvious that the cost of carrier equipment must be reduced if extensive developments were to take place. At the time of completion of the Dutch scheme it was clear that similar facilities could be provided at any time on a number of submarine cables including the following:

1. Anglo-French (1926).[8]
2. Anglo-Belgian (1926).[9]
3. Blackpool-Port Erin.[10]

Certain other cables such as Port Erin-Ballyhornan (Nos. 1 and 2)[10] and Port Kail-Donaghadee (Nos. 1 and 2) were suitable for multi-channel working using a similar type of equipment.

Prospects of Further Developments.

In considering the trend of further developments the following points became clear:—

1. The cost of equipment must be reduced and the Post Office contribution to this end must be a simplification of design.
2. The use of two low-impedance valves in the output stage of the modulator, without the equivalent sideband output is undesirable, particularly as these valves are short lived when 0.25 amp. filaments are used. For the working sideband output a single repeater valve handling 45 to 50 mW is adequate.
3. For extensive schemes, a common oscillator is cheaper and more desirable than separate oscillators.
4. Low frequencies must be passed more effectively by carrier circuits, and in the case of channels higher than the first, the suppression of the carrier in a bridge modulator is essential.
5. Owing to the increasing congestion in many repeater stations the size of the equipment must be substantially reduced.

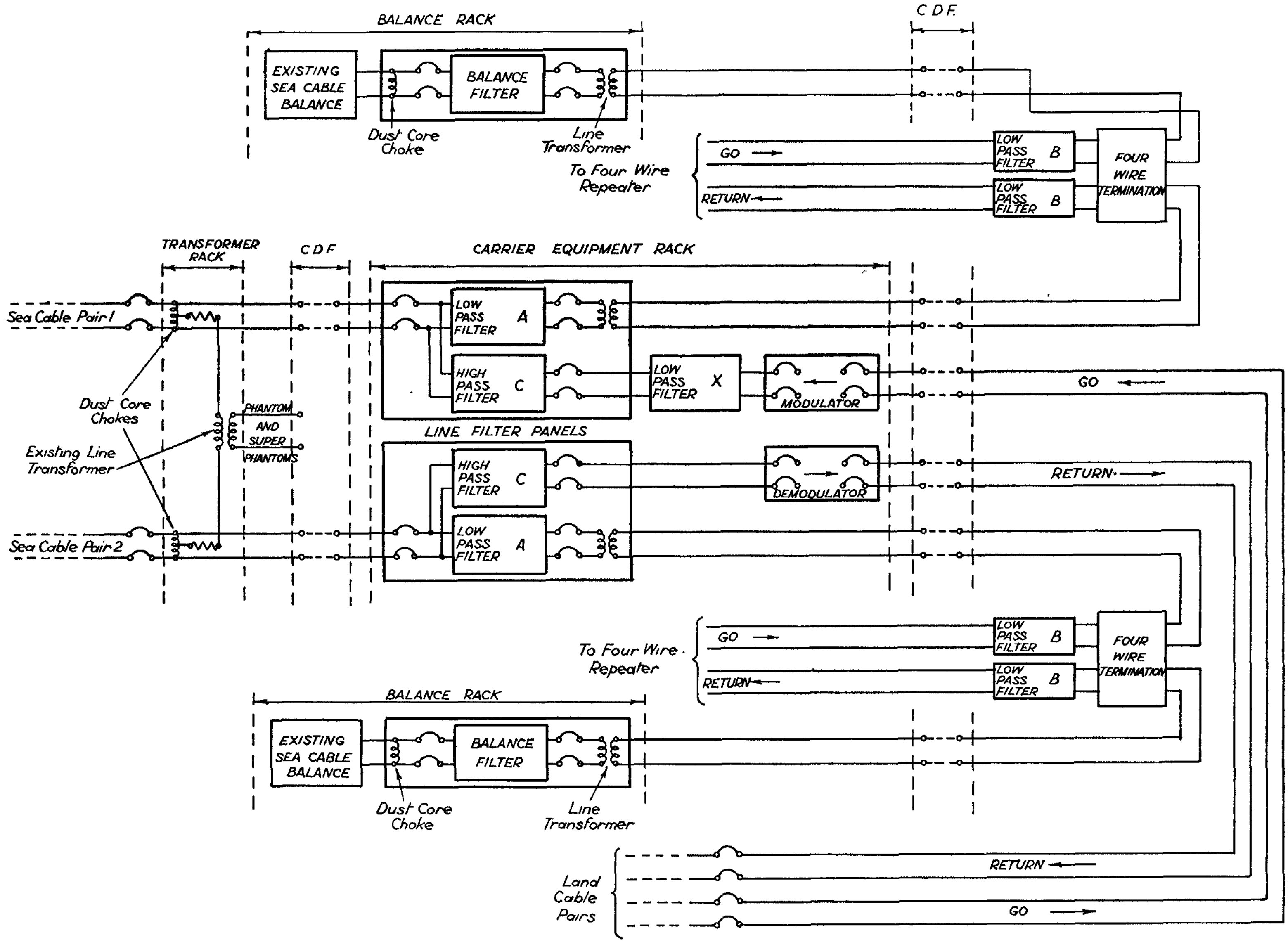


Fig. 2.—Anglo-Dutch Carrier Telephone Circuit. Block Diagram for one Quad.

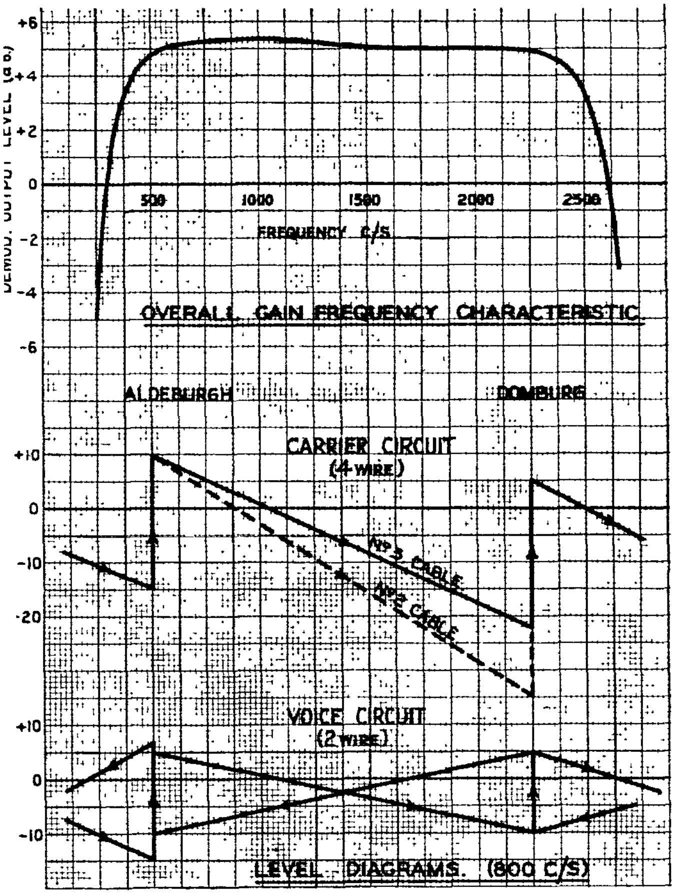


FIG. 4.—ANGLO-DUTCH CARRIER CIRCUITS. LEVEL DIAGRAMS.

Simplified Aerial Line Equipment.

Chronologically, the first step in the new scheme of carrier development was in the design of aerial line equipment. Previously, the only modern equipment available had been on the lines of the Anglo-Dutch channels, except that grouped working had been employed. This was unsatisfactory on economic grounds and a big reduction in cost was necessary to make open line carrier working a practicable proposition.

The main trunk telephone system of this country being in cables, the useful spheres of aerial line carrier circuits appeared to be :—

1. On junctions 50 to 100 or possibly 200 miles in length in the more remote parts of the country, *e.g.*, the Scottish Highlands.
2. For seasonal circuits on short junctions in all parts. These junctions, although short geographically, might be long electrically owing to cabled sections.
3. For emergency circuits.

To meet these requirements a very simple type of carrier system, primarily designed to operate from public supply mains was introduced. Carrier System No. 1, to give it its full title, or " All Mains " carrier equipment, as it is better known, contains a minimum number of valves (four) and in order to have as much gain available as possible copper oxide rectifiers were used as modulators and demodulators, the valves acting as amplifiers. Bridge networks were not introduced into this equipment as it was expected that in many places very little maintenance would be forthcoming and simplicity was the keynote of design.

This system has been fully described elsewhere,[11] but a brief description of the method of operation is given. The carrier frequency is 6.5 Kc/s and the lower sideband only is transmitted in one direction and the upper sideband only in the opposite direction.

The choice of 6.5 Kc/s as a carrier frequency was made for the following reasons :—

1. It is the highest frequency consistent with obtaining two carrier channels in the frequency band below 16 Kc/s, the frequency of the Rugby radio transmitter GBR, which is a common source of interference on the open lines in this country.
2. It is sufficiently high not to cause serious interference with B.B.C. programme circuits.
3. In cases of necessity, the band width of 0-3500 c/s on the voice circuit is not unreasonable for the actual transmission of some broadcast programmes.

As already stated, the equipment is primarily intended for mains operation, the valves being indirectly heated. Power panels, appropriate to A.C. or D.C. mains are available. The equipment is mounted on standard 19″ panels and one complete terminal occupies only 22¾″ of rack space. Such a terminal weighs rather less than one hundredweight.

Filters.

In accordance with usual Post Office practice the inductances are wound on nickel-iron dust rings. The dissipation constant is of the order of 0.006, thus ensuring low loss filters. The back of the panel accommodates the line-filter pair, separating the voice and carrier bands and the front contains the directional-filters which discriminate between the two sidebands. Every directional-filter has a loss of about 23 db. at 6.5 Kc/s and this gives a total carrier suppression of about 45 db. which is adequate for the system. Thus the filter units at the two terminals are identical.

Repeater Unit.

The repeater panels (*i.e.*, the modulator, demodulator and ringer), known as Repeater Telephone No. 32A, are also identical at the two ends except for a few differences in setting up. The connexions to the filters are, of course, reversed. The four valves are (left to right in Fig. 5), Receiving amplifier, oscillator, transmitting amplifier, ringing receiver. On the front of the panel are four test and adjustment strips as follows :—

1. (Top) Gain control. This is the receiver input potentiometer and controls in steps of 1½ db.
2. Grid bias resistances for ringer valve. These are used to adjust the anode current.

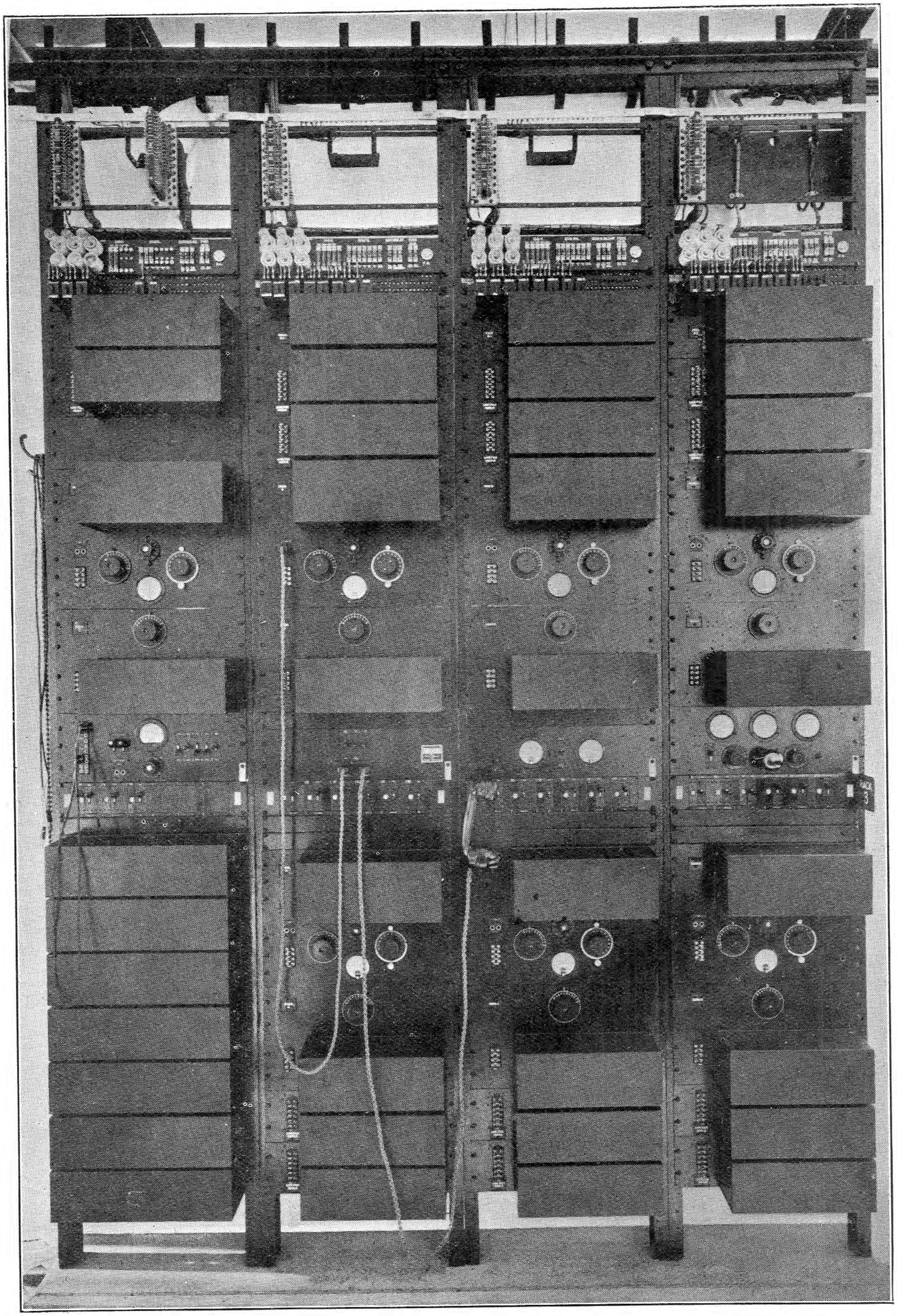


FIG. 3.—CARRIER TELEPHONE EQUIPMENT AT ALDEBURGH.

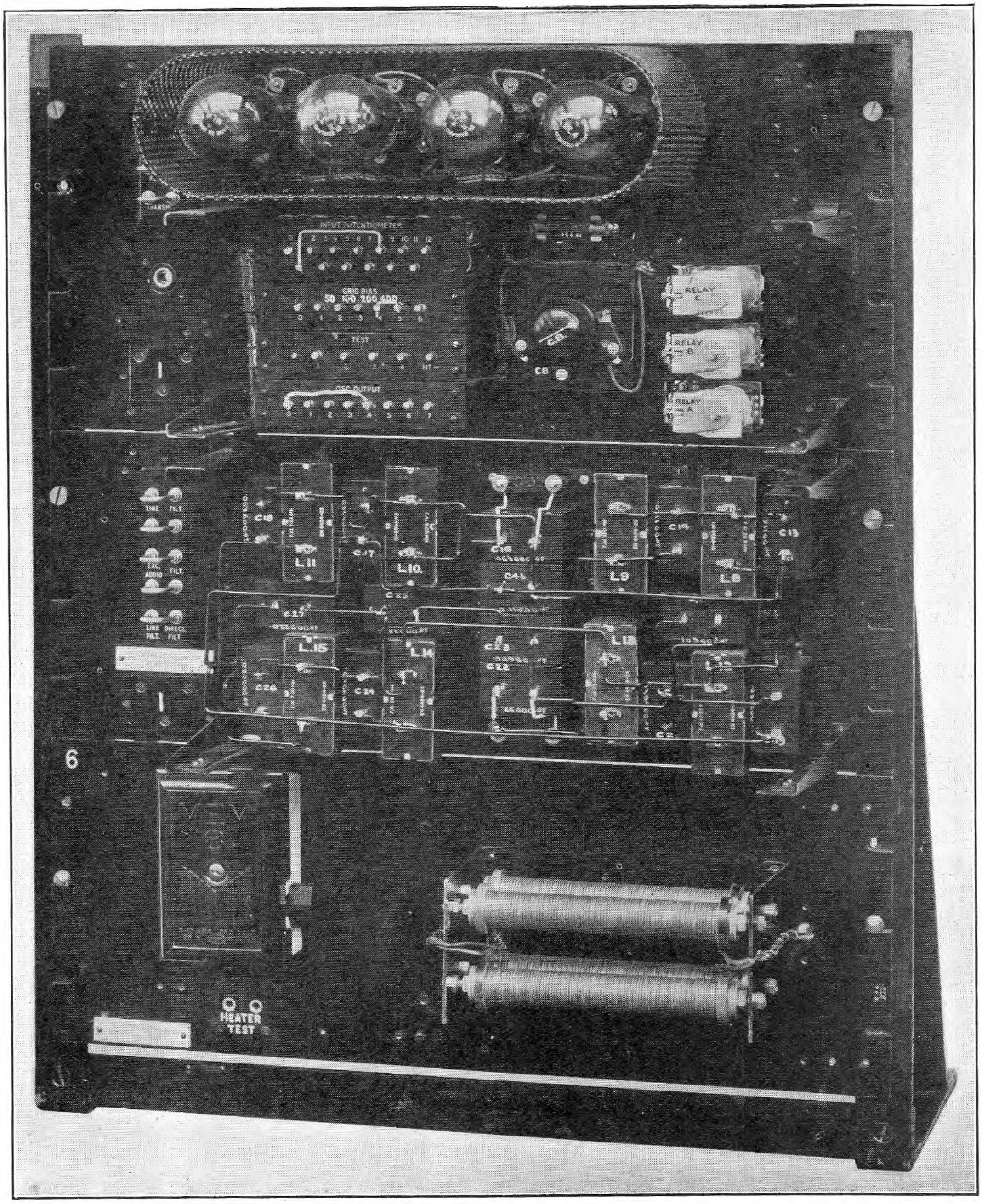


Fig. 5.—Single Channel Aerial Line Carrier Equipment.

3. Test strip for anode currents and oscillator feed.
4. Oscillator output control.

The maximum gain of the equipment is 27 db. to the upper sideband and 22 db. to the lower sideband.

Ringing over the carrier circuit necessitates generator calling and clearing, as the circuit behaves outwardly exactly as if it transmits 17 c/s ringing current. The outgoing ring from the switchboard operates a sending relay which causes the carrier to shift by 500 c/s into the appropriate transmission band of the sending filters. As a result, the steady carrier frequency, normally suppressed, is transmitted over the line and gives rise to a 500 c/s signal at the receiving terminal. This signal is made to operate a receiving relay *via* the ringer valve, which discriminates against speech signals on a form-factor basis. As an added factor of safety a delayed relay has to be operated before the local ringer is applied to the exchange line.

Power Panels.

These are suitable for all normal distribution voltages, two types being available, Panel No. 5A, for A.C. mains and No. 5B for D.C. mains.

Overall Frequency Response.

The overall response, due to the terminal equipment only, is shown in Fig. **6**. No line equalisers are fitted.

In several of the open line circuits quoted, two or more channels operate over the same pole route with satisfactory cross-talk conditions. In each case the overall transmission loss is 3 db. In the case of the Aberdeen-Wick circuit, the line is over 200 miles in length and includes two submarine cables across Beauly and Dornoch Firths. Satisfactory service is obtained and instructions are available, enabling local staffs to instal the equipment if necessary.

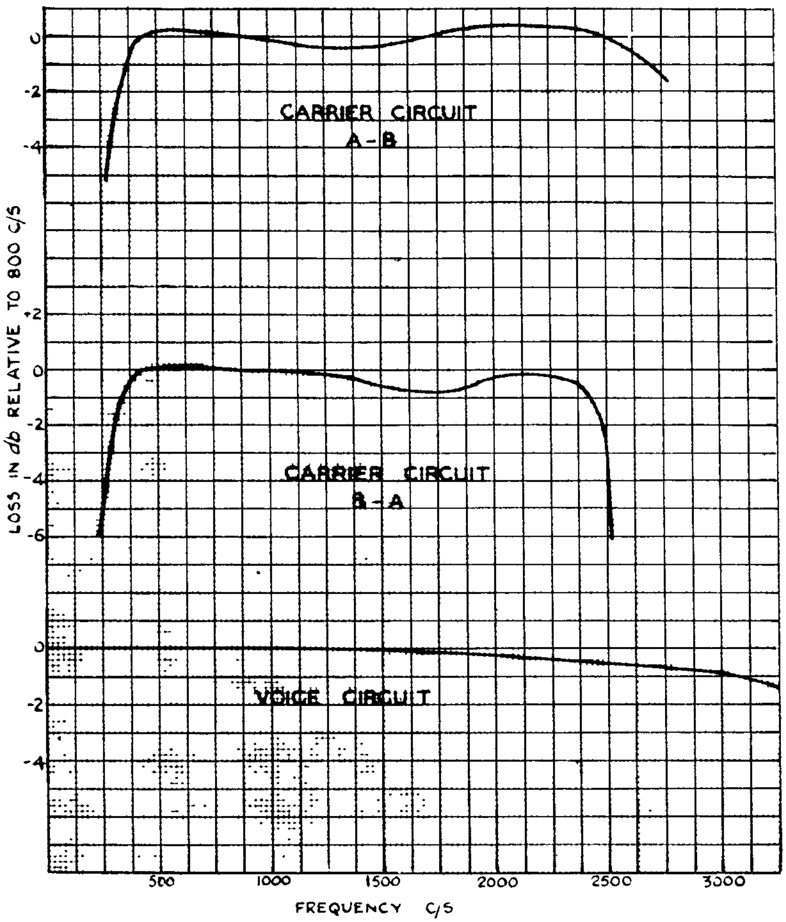


FIG. **6**.—OVERALL TRANSMISSION CHARACTERISTICS OF AERIAL LINE CARRIER EQUIPMENT.

In service the equipment has been very successful, operating for long periods without specialised maintenance. The following permanent circuits have been installed* :—

1. Glasgow-Oban.
2. Glasgow-Fortwilliam.
3. Glasgow-Campbeltown.
4. Glasgow-Lochgilphead.
5. Aberdeen-Inverness (2 circuits).
6. Aberdeen-Wick.
7. Inverness-Kyle of Lochalsh.
8. Swansea-Aberystwyth.
9. Cardiff-Llandrindod Wells.

In addition, two channels are operating as a temporary measure, on unloaded submarine cables to Ireland.

* Additional circuits have since been installed.

2nd Channel. A second channel, operating with a carrier frequency of 13 Kc/s has been designed and two circuits will shortly be installed on the West Highland* route, which already carries four carrier circuits.

Bridging Filters. It sometimes happens that no continuous physical trunk exists between the terminals of the carrier circuit. In such cases a bridging filter (Filter Frequency No. 14A) is used. A typical case of its use is on the Aberdeen-Wick carrier circuit, which is bridged from an Aberdeen-Inverness circuit to an Inverness-Wick circuit at Inverness.

* Two such circuits are now in operation, viz., Glasgow-Oban and Glasgow-Campbeltown.

Single-Channel Carrier in Land Cables.

Having thus met the requirements for carrier working on open lines it was decided to investigate the problem of carrier in land cables. In particular, single-channel four-wire carrier circuits appeared to be an attractive proposition. There are several alternative methods of operation.

1. To separate the voice and carrier bands at each repeater station and to amplify them separately. This is the arrangement on the Anglo-Dutch cables and gives perfect freedom in the choice of 2-wire or 4-wire voice circuits. If 2-wire voice circuits are used, the line-filters will need to be reproduced in the balance networks, unless stabilisers are incorporated.

   In this scheme, 2-wire carrier circuits are also possible, but these, for the present, are not considered. High singing-points are obviously necessary and in existing cables the carrier frequency cross-talk is not adequate for 2-wire working.

2. To amplify the voice carrier circuits in common repeaters at the intermediate stations and possibly at the terminal stations also. This, in the first place assumes 4-wire working on both circuits. It will be shown later, however, that modifications are possible which allow this requirement to be waived.

   If such circuits are fitted with echo suppressors, separate repeaters must be fitted at such points.

3. To employ the German Zweiband[12] scheme which eliminates the problem of interchannel cross-talk. In this scheme the voice and carrier circuits on one cable pair operate in opposite directions and form the two directions of a single (4-wire) circuit. By an ingenious device one repeater is used for the two directions of transmission.

Schemes 1 and 3 both involve filtration at each repeater station, a state of affairs which is best avoided, and Scheme 1 is too clumsy and costly. The relative merits of true 4-wire working and Zweiband are set out below.

4-WIRE CARRIER.

Advantages.	Disadvantages.
1. The carrier equipment is confined to the terminal stations. 2. The saving in the cost of filters is considerable. 3. The physical circuits can be brought into service first and carriers added later. 4. The propagation time is somewhat lower owing to absence of filters at intermediate stations. 5. Both physical and carrier circuits are suitable for VF telegraphs.	1. Intermodulation in lines and repeaters must be eliminated for system to operate satisfactorily. 2. In connection with (1) above, repeater working levels must be lower. 3. When echo suppressors are necessary these must be associated with independent repeaters at the terminals.

ZWEIBAND.

Advantages.	Disadvantages.
1. Intermodulation in lines and repeaters does not affect the system. 2. In consequence of (1) above repeater output levels can be normal.	1. Filters have to be fitted at all repeater stations. 2. VF telegraph channels cannot be operated in both directions simultaneously. 3. If it is assumed that carrier circuits are slightly inferior to physical circuits, all circuits are slightly degraded. 4. If a master oscillator is used, its failure will break down all circuits.

The disadvantages of true 4-wire working lie basically in intermodulation interference between the channels so that if this can be reduced to reasonable proportions 4-wire working is obviously the better scheme. In 1932 tests were undertaken to investigate the problem of working voice and one carrier channel through common repeaters on suitably loaded land cables.

Tests on London-Derby Loops.

The only suitably loaded pairs available for preliminary tests were music circuits between London and Derby loaded 22 mH at 1.136 miles spacing. Two loops of zero overall transmission loss were set up and repeatered thus, TSX (London)-FNR (Fenny Stratford)-LE (Leicester)-DY (Derby)-LE-FNR-TSX. All the repeaters used were 2-stage main line repeaters with equalisers and low frequency correctors, and the repeater output level was + 10 db. in each case. With the two loops, the circuit could be set up with either 7 or 14 repeaters. The carrier equipment used was the experimental set made for tests on the Anglo-Dutch cables, the levels being suitably adjusted, and the carrier circuit so obtained was also set up to zero overall transmission loss. The carrier frequency was 5.8 Kc/s, the carrier and upper-sideband being suppressed.

Cross-talk measurements were made with speech at reference volume, as determined by a Western Electric volume indicator. It is evident that, since all circuit interference depends on non-linearity of valve and iron characteristics, it is imperative that all speech volumes used must be related to reference telephonic power.

From these tests it was possible to reach the following general conclusions :—

1. All mutual interference between voice and carrier circuits is non-linear, *i.e.*, it is dependent on the transmission levels.
2. At transmission levels greater than zero the interference is much too great to be tolerated.

   Even at zero output level from the repeaters, the circuit interference, particularly from the carrier to the voice circuit, with reference volume speech, is intolerable.
3. The cross-talk is caused mainly by overloading of the output valves and can be considerably reduced by increasing the power handling capacity of these valves.

4. Cross-talk due to common repeaters is of two types (*a*) due to the non-linearity of the valve and transformer characteristics (*b*) due to grid current. With regard to (*b*) it was found that in any normal repeater, reference volume speech causes grid current in the output valve when the output level is about + 3 db. In certain cases grid current was detected at zero output level.
5. All cross-talk between physical and carrier circuits is unintelligible.
6. The syllable articulation efficiency of a carrier circuit is equal to that of a physical circuit having the same cut-off frequency.
7. The syllable articulation efficiency of one circuit is negligibly reduced by speech on the associated circuit, even if the cross-talk is intolerable.
8. The carrier circuit is suitable for the transmission of pictures provided that means can be employed to synchronise the sending and receiving picture equipment while still admitting of small frequency changes introduced by the carrier system (suppressed carrier). For the tests, the pictures were transmitted round a loop and back to the same picture equipment.
9. When pictures are transmitted over either circuit, interference from the associated circuit is just noticeable with very loud speech. The blemishes are not serious in any case.
10. It is possible to operate several VF telegraph channels on either circuit without interference from the other circuit. The question of inter-modulation between the channels of an 18-channel VF system was not investigated.

On the basis of these results it was decided to proceed with further tests and to establish experimental circuits, even if it ultimately proved necessary to use improved repeaters (*e.g.*, push-pull music repeaters).

*Terminal Equipment for Single-Channel Cable-Carrier Circuits.**

Since the common repeaters overcome the line attenuation, low-gain terminal equipment is adequate. In the simplest conception of the scheme, in which the voice and carrier circuit levels are similar and the line equalisation is perfect, the modulator and demodulator will be frequency changers only, without gain or loss. As such, the modulator will work at a level of −4 db. and the demodulator at a level of +4 db. for zero circuits.

Repeater Telephonic No. 31A is designed for these conditions, but is rather more flexible since both the transmitting and receiving sides have adjustable gains. Bridge networks including copper oxide rectifiers (Westinghouse, Type H1) are used as balanced modulators and demodulators and a minimum carrier suppression of 30 db. is obtained by this means, a limited selection of rectifiers being necessary. In each case the rectifier bridge is followed by an amplifying valve. In the case of the modulator this follows immediately, in the case of the demodulator a low-pass filter, passing speech frequencies only, precedes it.

Various arrangements of the rectifier bridge were considered and the present bridge was selected as a result of the considerations set out in the Appendix.

Schematic Arrangements of Terminal Equipment. Block schematic arrangements of the carrier terminals are shown in Figs. **7** and **8** for the following circuit conditions :—

1. (Fig. **7**). For 3 db. circuits without terminal echo-suppressors.
2. (Fig. **8**). For circuits of any overall equivalent where terminal echo-suppressors are fitted. This arrangement is also necessary at the terminals of zero circuits if echo-suppressors are not fitted.

The use of separate terminal amplifiers for arrangement 2 above is necessitated by the following considerations :—

1. A normal repeater, handling two speech channels cannot operate at a higher output level than zero on each channel even after correcting devices have been fitted.
2. Echo-suppressors require separate voice-frequency repeaters for each channel and these must operate at output levels of + 10 db. in the case of valveless suppressors. The echo-suppressors for voice and carrier circuits are conveniently situated at one terminal.

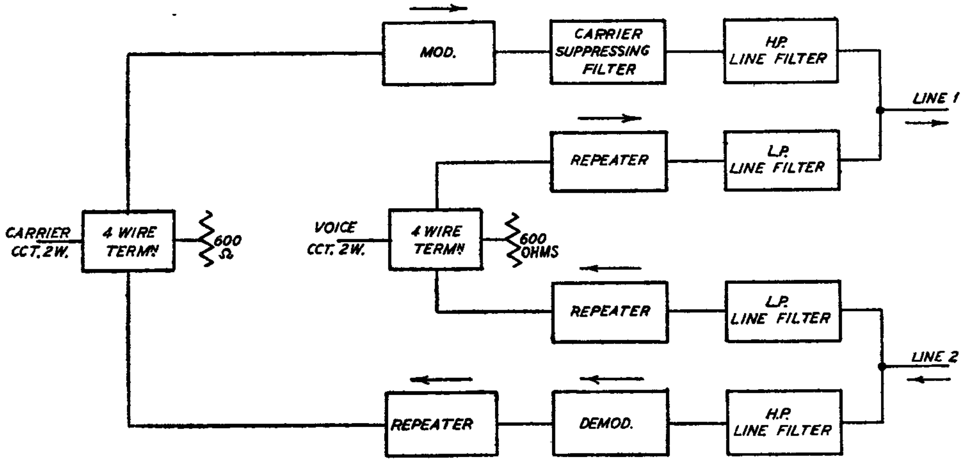
Repeater Unit.

The modulator has alternative input connexions (with and without a 12 db. pad) corresponding to the two arrangements of Figs. **7** and **8** respectively. There is a single section low-pass filter before the bridge and this serves three purposes :—

1. It limits the frequency band of the incoming signals thereby preventing the direct passage of high frequencies through the modulator and carrier line-filter.
2. Since the filter has a high attenuation at the carrier frequency, unbalances at the input terminals cannot affect the carrier leak. Without the input filter the carrier leak is susceptible to the balance at the input terminals.
3. It determines the impedance seen from the modulator rectifiers at the sideband frequencies. This is important since the rectifiers act as sideband generators which feed into two impedances in series : (*a*) the 600 ohms load impedance and (*b*) the input impedance. Thus the input impedance seen from the rectifiers determines the voltage into the 600 ohms load impedance. By suitable design of this input impedance, the gain-frequency response may be modified considerably. In the present case a sensibly flat response is required.

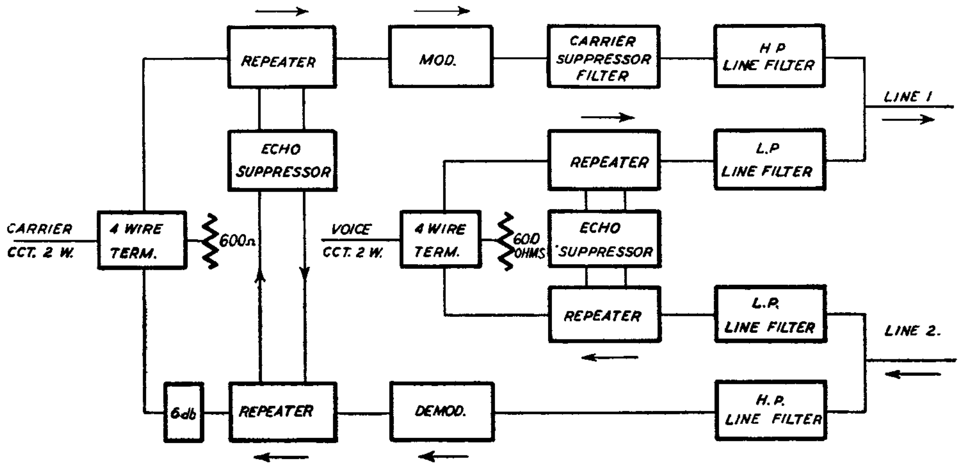
The input circuit is terminated by a nominal 600 ohms load resistance (300 ohms + 300 ohms), but it

* Now known as Carrier System No. 2.



NOTE.—If the input level to the Demod. would otherwise be lower than about −10 db. a repeater is fitted in the common receiving line.

FIG. 7.—ARRANGEMENT OF CARRIER TERMINAL USING SEPARATE REPEATERS.



NOTE.—If the input level to the Demod. would otherwise be lower than about −10 db. a repeater is fitted in the common receiving line.

FIG. 8.—ARRANGEMENT OF CARRIER TERMINAL WITH ECHO SUPPRESSORS.

will be clear that this impedance is realised only when the rectifiers are short circuited. Thus the input circuit is terminated substantially correctly during each positive half carrier wave and is substantially open-circuited during each negative half carrier wave. This is satisfactory since it is only those parts of the input signal which coincide with positive half carrier waves that are transmitted through the rectifiers and thereby enter the load impedance.

From the input filter, speech frequencies pass into the bridge modulator proper and the following frequencies are present in the load resistance :—

1. Speech frequencies (A).
2. Lower sideband frequencies (C − A).
3. Upper sideband frequencies (C + A).
4. Carrier leak (C).
5. Secondary products of modulation (2C), (2C + A), (2C − A), etc.

If a higher level of lower sideband were required it would be necessary to filter out the unwanted bands before amplification, but in the present case this is not necessary. This consideration, however, restricts the maximum output level of lower sideband, from the modulator, to zero. The theoretical loss through the bridge with ideal rectifiers is 9 db. (*i.e.*, conversion loss); the practical figure is about 11 db.

The demodulator has an input pad of 6 db. which serves the following purposes :—

1. It reduces the input signal level to −2 db. in the case of circuits terminated with a common repeater. This is a suitable level for feeding the rectifiers.
2. It ensures a flat gain-frequency response curve by fixing the back impedance seen from the rectifiers at voice frequencies.

The loading of the demodulator and its operation are similar to those of the modulator, but in this case the frequencies present in the load resistance (in addition to the carrier leak) are

1. Lower sideband frequencies (C − A).
2. Voice frequencies (A).
3. Frequencies C + (C − A) = (2C − A).

Since it is required to work the output valve at a level of +4 db. it is necessary to use an interstage filter to remove the unwanted frequencies. This is so designed that the impedance presented to the modulator is always high, relative to 600 ohms, over the sideband range. The demodulator valve may thus be worked at the required output level without distortion.

in order to allow of flexibility in their use. In particular, they are suitable for cases in which it is desirable to operate the carrier channel at a lower transmission level than the voice channel, and also for use on submarine cables. In this and other cases the voice circuits may operate on a two-wire basis, thereby giving rise to more stringent cross-talk conditions.

The carrier-suppressing filter, which is required at the sending end only, is included on the line filter panel and the line filter units are known as

Filter, Frequency No. 11A, for sending filters.
,, ,, ,, 11B, for receiving filters.

The transmission characteristics of the filters are shown in Fig. 9 for the transmitting and attenuating

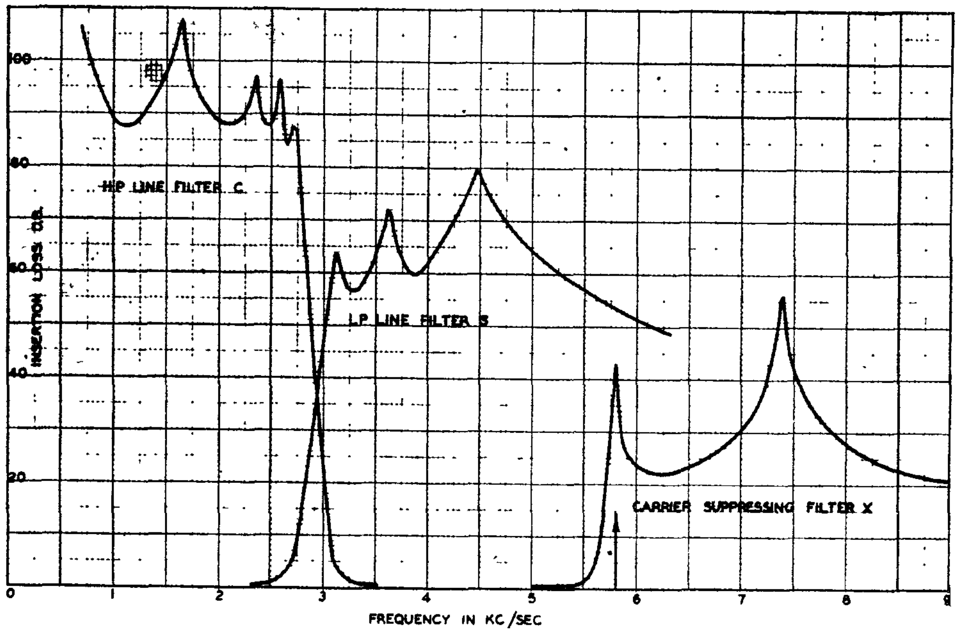


FIG. 9.—FILTERS FREQUENCY NO. 11A AND 11B. INSERTION LOSS IN ATTENUATING BANDS.

The rectifier bridges of the modulator and demodulator are arranged with opposite polarity so that the complete unit takes a symmetrical load from the carrier feed. Series resistances of 150Ω in the feed to each bridge, in conjunction with a carrier feed which has a very low impedance at all but the carrier frequency, comprise a decoupling system which reduces the cross-talk between circuits fed from a common carrier oscillator. The cross-talk attenuation between bridges is largely determined by the suppression between diagonals of the bridge. Since this suppression must be at least 30 db. the cross-talk attenuation is at least 60 db. on this score alone. In practice the cross-talk attenuation between any two units is about 100 db.

The carrier feed to Repeater No. 31A is 2 volts r.m.s. and this is reduced to about 1 volt on the bridge itself. The unit occupies one side of a standard 8¾″ panel.

Line Filters.

The design of the line filters is somewhat generous

bands. The inductances used are wound on dust rings and have dissipation constants of the order 0.006 at 3 Kc/s. The non-linear properties of the coils are limited by a maximum hysteresis factor of 18, and the inductance tolerance is ± 1% at a specified current and frequency. Condensers are clamped (mica) with tolerance of ± 1% and ± ½%. Each filter unit occupies one side of a 7″ panel.

Carrier Oscillator.

In conformity with the recommendations of the C.C.I.F., the carrier frequency is now 6 Kc/s and each terminal station derives this frequency from a single oscillator (Oscillator No. 10A). This oscillator is capable of feeding a maximum of six channels, which are mounted on a unit bay. The output transformer is tuned to the carrier frequency and, in addition to its function in the decoupling circuits, this allows the oscillator to be worked at its full output of 80 mW with a harmonic content of only 1%. Since the oscillator has to deliver its output to six repeater units, each approximately 300Ω impedance, the load impedance is 50Ω. The oscillator output may be metered and is maintained at 2 volts ± 10%. In practice adjustment is seldom necessary.

Where more than one bay is fitted, the oscillator supplies amplifiers (Units Amplifying No. 12) at the rate of one amplifier per bay of six channels. One spare oscillator and one spare amplifier are fitted at each terminal. The oscillator occupies one side of a 7″ panel and the amplifier one side of a 3½″ panel.

Performance of Carrier Terminal Equipment.

The overall gain-frequency responses of the two channels, as determined by the terminal equipment, are given in Fig. **10**. It is practically impossible to distinguish between the two circuits on cables except repeaters. A general view of the terminal bays is seen in Fig. **11**.

About fifty carrier channels of this type are now being manufactured and will be installed immediately for use between London and Edinburgh, London and Glasgow and intermediately.* Provision is also being made for similar equipment to operate on the new Liverpool-Glasgow cable which may ultimately carry 90 such circuits.

Underground Cable Transmission Characteristics.

Up to the present time, four underground cables have been coil-loaded for single-channel carrier working. In each case the cut-off frequency is between 7 and 8 Kc/s and the cables are suitable for the carrier system described.

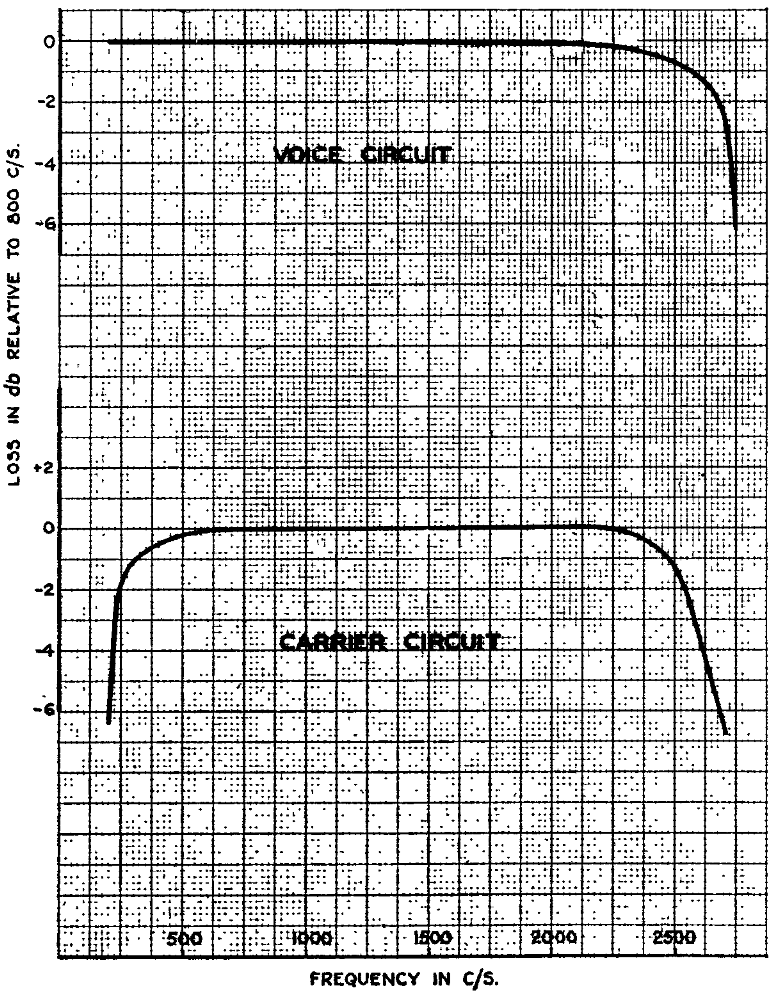


Fig. **10**.—Overall Transmission Characteristics of Underground Carrier Equipment.

that the background noise of the carrier circuit is lower and echo and transient times are rather greater.

The channel interference due to the terminal equipment is of the order of 80 db. signal to cross-talk ratio. This is, of course, reduced by the lines and

1. Certain pairs between London and Edinburgh on the main East Coast route.[13] These are loaded with 27 mH Grade I coils at 1.136 miles spacing, except for the section between

* Now working satisfactorily.

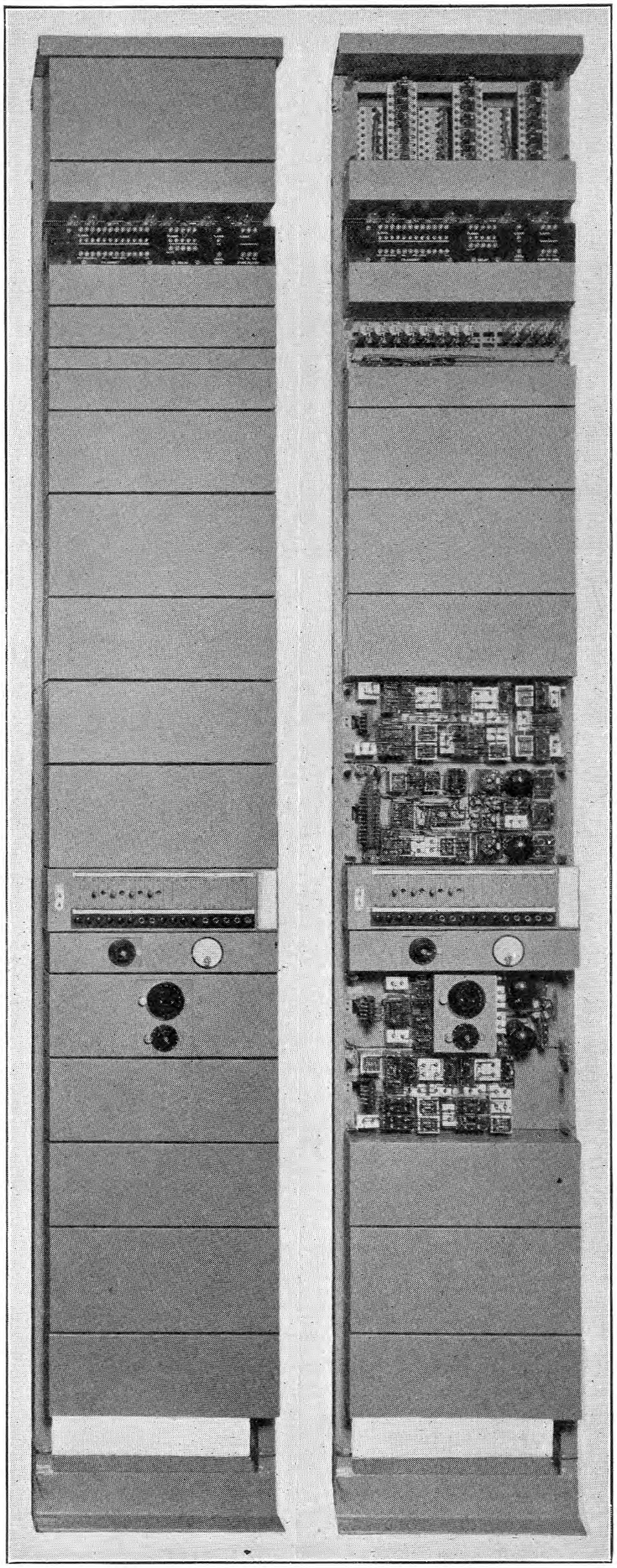


FIG. 11.—UNDERGROUND CARRIER TELEPHONE TERMINAL. BAY A.

London and Derby (BXE cable) which is loaded with 19 mH coils at 1.6 miles spacing. The conductors are 40 lbs. multiple twin.

2. The Northern Underground cable between London and Glasgow.[14] These pairs, 100 150 and 200 lbs. twin are loaded with 10 mH Grade I coils at 2.5 miles spacing.
3. The Carmarthen-Milford Haven cable (and Tenby spur).[15] These pairs are loaded with 30 mH Grade II coils at 1.136 miles spacing. The conductors are 20 lbs. star quad.
4. The Liverpool-Glasgow cable.[16] Certain groups in this cable are loaded with 22 mH Special Grade I coils at 1.136 miles spacing. The conductors, which are segregated into go and return groups, are 25 lb. star quad.

Repeater Spacing.

In cases where the go and return groups are not separated, either by screens or by other pairs, repeater spacing is settled by consideration of near-end carrier cross-talk. This gives a rough limit of 25 db. attenuation length or about 50 miles repeater spacing in the case of 40 lb. conductors.

Where groups are segregated, this does not impose the limiting condition, which is determined either by noise level or cross-talk in some other group in the cable (*e.g.*, Liverpool-Glasgow cable).

Carrier-to-Carrier Cross-talk in Cable.

In all which follows, cross-talk measurements were taken with speech using carrier terminal equipment of the type already described. The futility of single frequency tone tests is indicated in Fig. **12**, which shows how near end cross-talk varies with frequency on a long circuit (London-Edinburgh). In this case tone, of the frequency indicated, was transmitted over the carrier channel.

Fig. **13** shows a target diagram of the near end cross-talks between carrier circuits, as measured on a single repeater section (Fenny Stratford-Leicester).

The figures given are reduced to signal to cross-talk ratio at the listening point, and this also applies to all cross-talk values quoted in the present paper.

Tests on the Carmarthen-Haverfordwest cable, in which systematic jointing was employed, show carrier-to-carrier near-end cross-talks ranging from 49 to 70 db. The mean value at the two ends was slightly under 60 db. with 15% of the total worse than 55 db. This is a very good achievement for this type of cable.

The results obtained on the carrier loaded pairs between Liverpool and Glasgow are representative of latest cable practice. The figures refer to the whole circuit, including six repeaters. The go and return groups are segregated in this case.

Type of Cross-talk.	Worst Value.	Mean Value.	Worse Than 60 db.	Worse Than 70 db.
Near End at GW	70 db.	80 db.	—	—
Near End at LV	65 db.	70-75 db.	—	12%
Far End at GW	57 db.	65-70 db.	3%	53%
Far End at LV	56 db.	65-70 db.	1½%	44%

CROSS-TALK BETWEEN CARRIER CIRCUITS USING TONE. MEASURED BETWEEN EDINBURGH AND JEDBURGH.

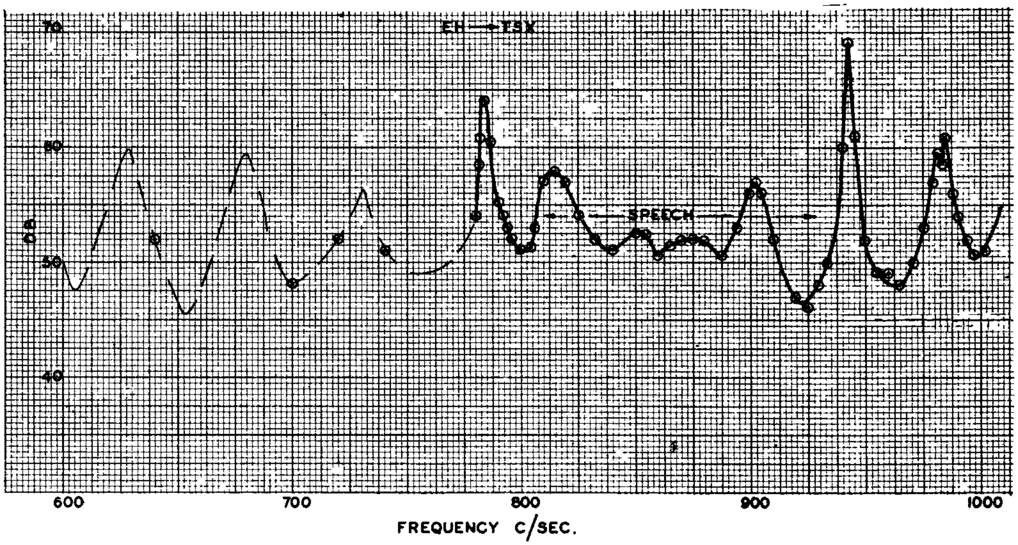


FIG. 12.—FREQUENCY/CROSS-TALK.

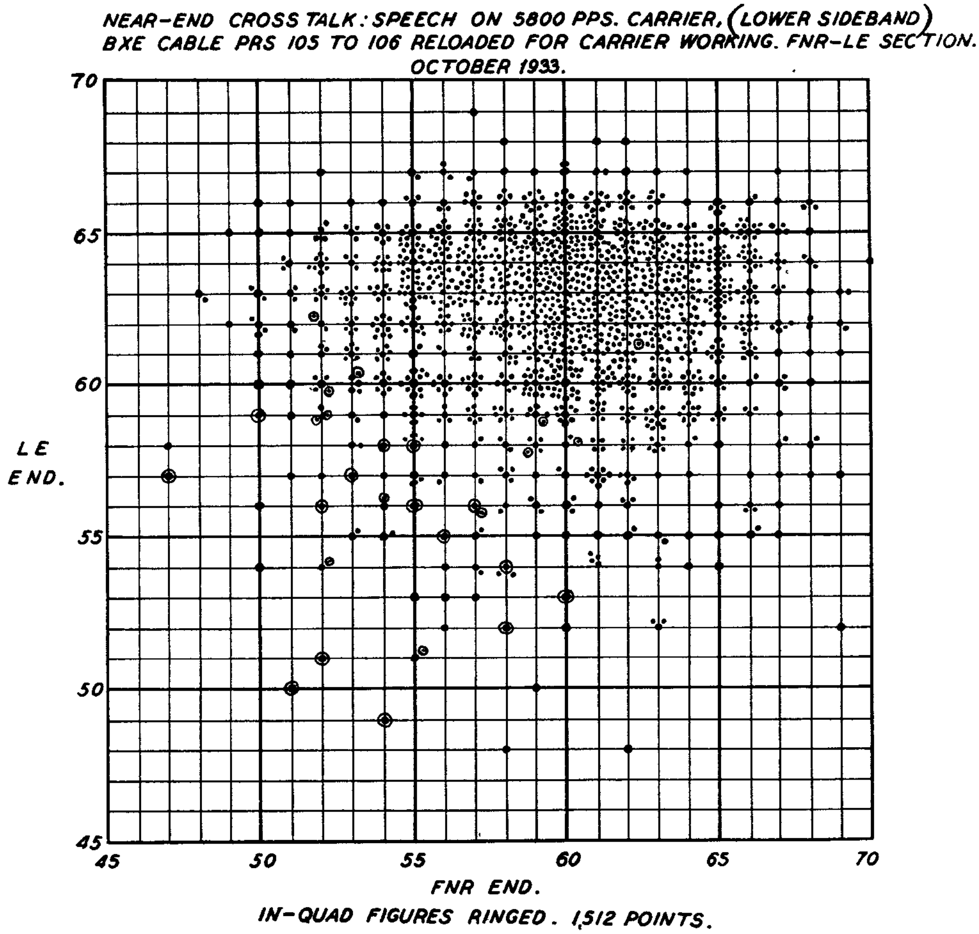


FIG. 13.—TARGET DIAGRAM CONNECTING CARRIER CROSS-TALK AT THE TWO ENDS OF SAME (LONG) CABLE LENGTH.

The technique of cable manufacture and balancing has improved considerably during the last few years.

Attenuation-Frequency Characteristics of Carrier-Loaded Cables.

Attenuation-frequency characteristics of various carrier-loaded pairs are given in Fig. 14. These are reduced to db. per mile in each case.

to equalise a long circuit (400 miles) to $\pm \frac{1}{2}$ db. from 300 to 6000 c/s. Low-frequency correctors form a very important part of the equalisers for carrier-loaded circuits.

Intermodulation.

It has been stated that the mutual interference between voice and carrier channels is negligible provided that the common conductors between the carrier

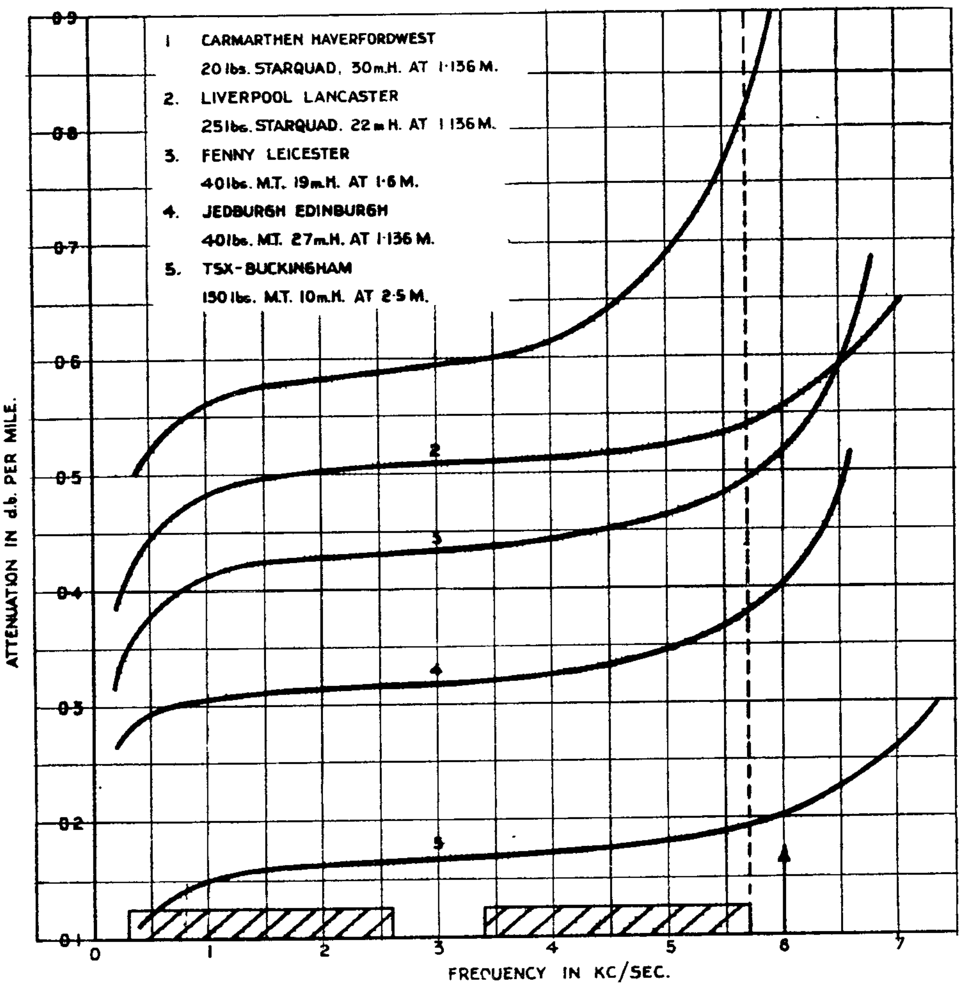


FIG. 14.—ATTENUATION OF CABLE PAIRS LOADED FOR SINGLE CHANNEL CARRIER WORKING.

Equalisation.

Equalisation of carrier-loaded pairs can be carried out effectively by means of input equalisers on the repeaters, in the normal manner. The normal inductances are not always suitable as they do not give a sufficient choice of low inductance values. Special retardation coils have been used for this purpose. In addition it has sometimes been found desirable to connect condensers across the output terminals of certain repeaters in order to reduce the slope of the gain-frequency characteristic. The tendency is to under-equalise at 3000 c/s and over-equalise at 6000 c/s. In practice it is possible

terminals are free from non-linear devices. Such devices give rise to modulation phenomena which lead to mutual interference between the channels. Intermodulation effects can usually be disregarded in problems of voice-frequency telephony, but may be very serious indeed when we consider the simultaneous transmission of two or more channels. Thus multi-channel carrier telephony or telegraphy working necessitate a thorough investigation of the effects.

In its association with a single frequency, non-linear distortion is well known to produce harmonics of various orders. Thus a three-electrode vacuum tube is known to produce even harmonics (principally 2nd) and magnetic-cored transformers or inductances without a polarising flux produce 3rd harmonics. In consideration of intermodulation problems it is necessary to consider what happens when two or more frequencies are impressed, simultaneously, on non-linear networks. If we designate two such impressed frequencies A and B respectively, then if the non-linear device is such that it produces 2nd harmonics, there will exist in the output circuit frequency terms of the order (A + B) and (A − B).[17] This is, of course, the principle of any modulator or demodulator. Similarly, if the non-linear device produces 3rd harmonics, there will exist terms of the order (2A + B) (2A − B), etc. The magnitude of such products, introduced by magnetic cores, has been the subject of a considerable amount of research, but information is still far from complete. Foremost among workers in this connexion is E. Peterson, of the Bell Laboratories.[18, 19]

It will be clear from the foregoing that modulation effects may result in the generation of frequencies lying outside the channel causing them, and this obviously involves interference between channels. The principal non-linear devices encountered in transmission systems are vacuum tubes, inductances, transformers and dryplate rectifiers. Apart from their use as modulators and demodulators, dryplate rectifiers are principally used in signalling and metering circuits and may be excluded from common transmission paths. When rectifiers are employed as group-modulators or demodulators (*i.e.,* when a number of telephone or telegraph channels are modulated together in a common modulator) special precautions must be adopted. These are referred to later.

Modes of Intermodulation Interference in Single-Channel U.G. Carrier System.

As far as the single-channel U.G. carrier system is concerned, the modes of intermodulation which may give rise to interference (cross-talk) are examined below. The effective bands are taken as 300-2600 c/s for the voice circuit and 3400-5700 c/s for the carrier circuit.

Voice to carrier interference may be caused by :—

1. 2nd harmonic (2A) of frequencies 1700 to 2600 c/s and other second order terms (A + B) of similar frequencies present at the same time.
2. 3rd harmonic (3A) of frequencies 1130 to 1900 c/s and other third order terms (2A + B) of similar frequencies present at the same time.
3. Higher harmonics (*n*A) of frequencies $\frac{3400}{n}$ to $\frac{5700}{n}$ c/s and modulation products of similar orders.

The modulation products will never be more serious than their associated harmonic products and it is convenient, in this case, to think in terms of harmonics only.

Carrier to voice interference may be caused by :—

1. 2nd order (A − B) products of any sideband frequencies 3400-5700 c/s.
2. 3rd order (2A − B) products of certain sideband frequencies.
3. Higher order products.

The energy present in a speech circuit is concentrated principally in the region 500 to 1500 c/s and it will be seen that this gives the principal causes of interference as follows, in order of importance :—

Voice to Carrier.

1. 3A products.
2. 2A products. These take precedence if grid current flows, but this condition must be rigidly excluded.

Carrier to Voice.

1. (A − B) products.
2. (2A − B) products.

The sources of the above intermodulation products must now be examined.

Modulation in Repeaters.

It has already been pointed out that when grid current flows, violent distortion is produced since the grid filament impedance is thrown across the input circuit. If the input (or interstage) transformer has a considerable step up, this grid impedance may form a severe shunt across the input circuit. In all multi-channel working it is necessary to eliminate grid current absolutely, and this may be ensured by some form of volume limiter.

In most two-stage repeaters, the design is such that the greater part of the non-linear distortion produced (principally 2nd order products) occurs in the output stage. This is for two reasons :—

1. In all properly designed repeaters the first-stage valve can never overload before the second-stage valve. In practice the output-stage overloads much more readily.
2. Owing to the fact that the first-stage valve operates as a voltage amplifier into a high plate circuit impedance, its dynamic characteristic is considerably straighter than that of the second-stage which operates at maximum power efficiency.[17]

In certain repeaters it has been found possible to make the first-stage distortion sufficient to cancel the second-stage distortion to the extent of a few decibels, but this is not of great value. In view of the type of harmonic correction now being used, every effort is now made to eliminate first-stage distortion completely. This is best done by maintaining the plate circuit impedance at a high value and in this respect resistance coupling has been found to be very satisfactory. An anode resistance about 10 to 20 times the valve impedance is found to give the best results, the gain in this case being about 1 or 2 db. below that obtained with a unity ratio inter-valve transformer.

Thus, in considering the performance of repeaters, it is not necessary to distinguish between single-stage

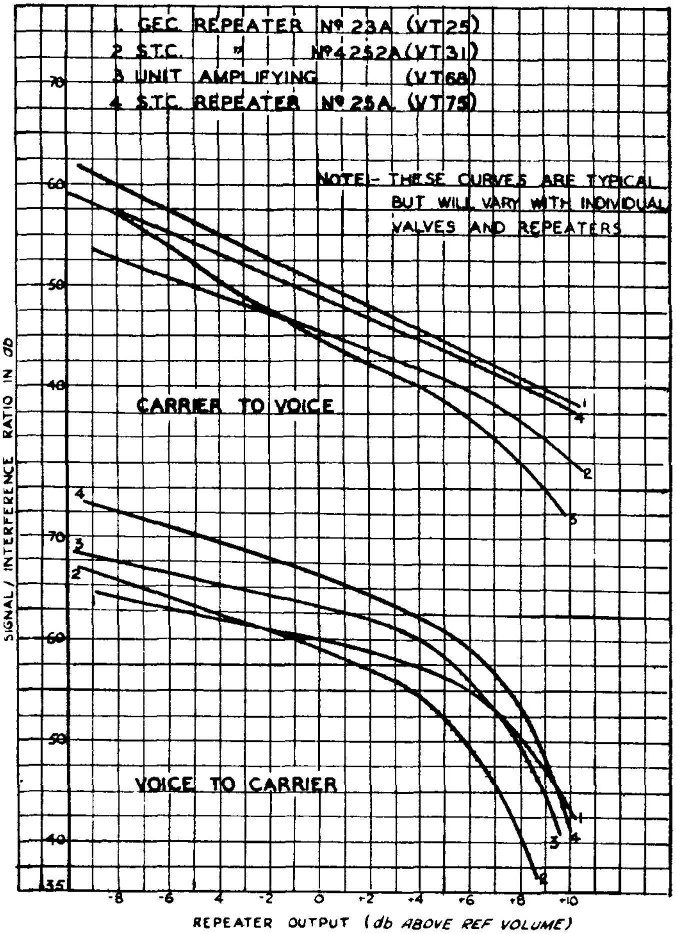


Fig. **15**.—Mutual Interference between Voice and Carrier Circuits due to a Single Repeater (without Correcting Devices).

and two-stage repeaters; the output valve is the important factor in each case. The output transformer will also contribute to the non-linear distortion, but to a much lesser extent than the valve itself.

Fig. **15** shows how voice-to-carrier and carrier-to-voice cross-talk vary with the output level from repeaters of various types when no devices are employed to reduce the interference. In each case reference volume speech, as determined by a Western Electric volume indicator was applied at a point of zero level. The cross-talk, although conveniently designated thus, is unintelligible and should perhaps be strictly classed as noise. Methods of measurement and comparison are explained later. The precise value of the cross-talk varies somewhat with the individual valves and repeaters used, but it is interesting to note that the order of merit of the normal types of repeater valve is as follows :—

1. V.T.78—G.E.C. 0.15 amp. filament.
2. V.T.75—S.T.C. 0.25 amp. filament.
3. V.T.25—G.E.C. 0.8 amp. filament.
4. V.T.31—S.T.C. 1.0 amp. filament.
5. V.T.68—G.E.C. 0.5 amp. filament.

Modulation in Loading Coils.

It is commonly known that unpolarised magnetic cores introduce third harmonics by reason of their hysteresis properties. In addition, third order products will be generated when two or more frequencies are applied simultaneously. The magnitude of these products depends, of course, on the B/H curve of the core or, in other words, on its hysteresis factor, but it also depends on the magnitude of the applied currents in a manner which permits of no simple summary.

Fig. **16** shows how a single repeater section, loaded with Grade II coils (Carmarthen-Haverfordwest), introduces interchannel interference. No common repeaters were included in this case. The hysteresis factor for these coils, as defined in an earlier paper,[20] is about 25-30 whereas that for Grade I coils is about 12. Hence an improvement of about 6 db. is to be expected from the use of Grade I coils. This is approximately realised on the East Coast route. For the Liverpool-Glasgow cable special Grade I coils, with a hysteresis factor of 7.5 were fitted, and a relative improvement in the voice-to-carrier interference appears to have been realised. In this case the cross-talk for five repeater sections (including the repeaters themselves) is about 60 db., or about 66 db. per repeater section.

Before leaving the question of modulation in magnetic cores it may be noted that the interchannel cross-talk, introduced by all types of line transformers in present use, is negligible and is of the same order of magnitude as that introduced in the terminal equipment.

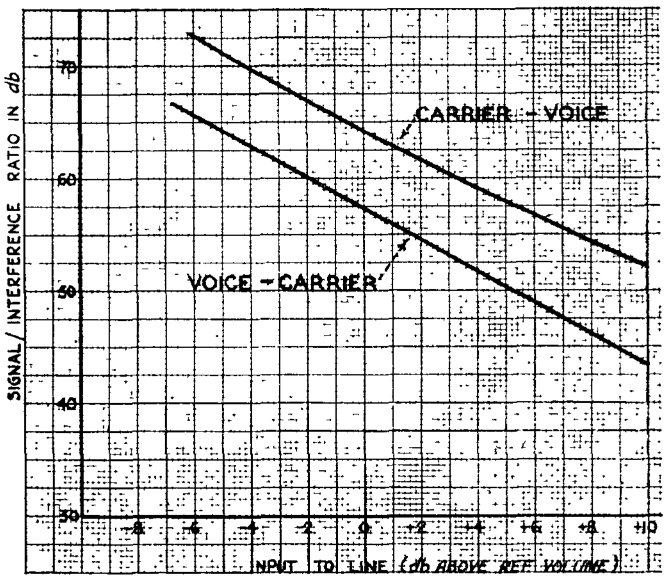


Fig. **16**.—Mutual Interference between Voice and Carrier Circuits due to Loading Coils only. (Repeater Section, Carmarthen-Haverfordwest). Grade II. Loading Coils, using Limiters.

Methods of Improvement of Repeator Distortion.

These require to be divided into two sections.

1. Devices aimed at eliminating grid current. These are volume limiters and their function is to cut off the peaks of speech.
2. Devices aimed at reducing the distortion due to curvature of the valve characteristic.

In considering methods of improving repeater distortion, increase of plate voltage and the use of valves capable of handling higher output powers will suggest themselves. The paragraphs which follow indicate methods which do not rely on such principles.

Volume Limiters.

Fig. **17** shows the results of tests made to determine the probable level of subscribers at a trunk terminal. It will be seen that levels approaching reference volume are extremely rare and it is therefore reasonable to use volume limiters provided that such devices affect only a small percentage of subscribers and, in so doing, they do not impair articulation. It has been shown that the use of limiters does not reduce the articulation from reference volume subscribers, in fact it actually improves it slightly. In considering this point it must be realised that, in telephone working, the subscriber's apparatus is far from perfect and the volume limiter merely modifies a non-linear distortion which is already obviously present.

Two forms of volume limiter appear to be practical (Fig. **18**).

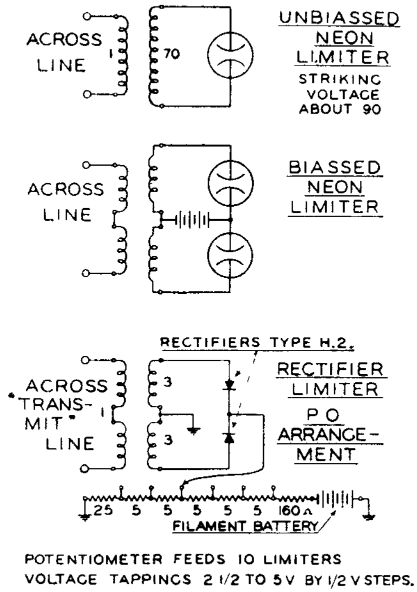


Fig. **18**.—Volume Limiters.

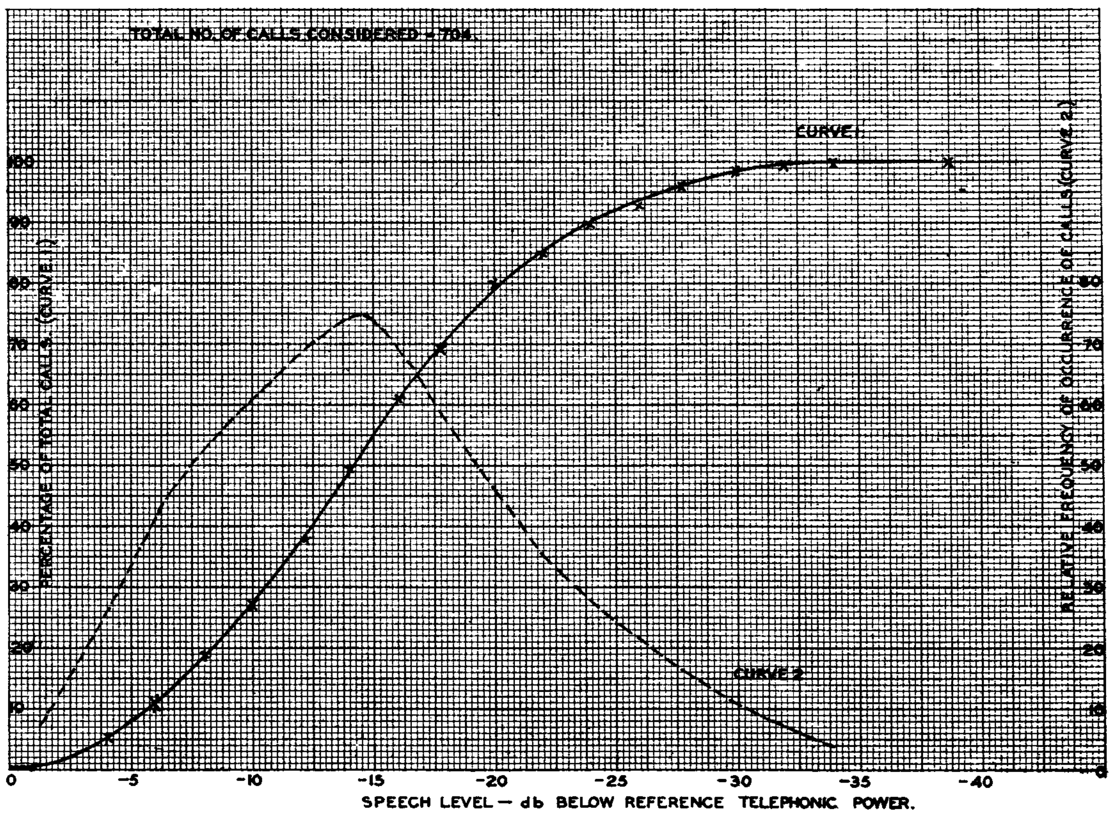


Fig. **17**.—Relationship between Percentage of Trunk Calls considered and Volume Level at the Input to the Trunk Circuit.

1. Neon tube limiters.
   (*a*) Tubes of low striking voltage (say 90 volts) connected across the line *via* a transformer of suitable raito.
   (*b*) Balanced tubes, biassed to reduce the operating voltage. This requires a much lower transformer ratio than (*a*), but requires two tubes. Also the disparity between striking and failing voltages (about 20%) is exaggerated.
2. Dryplate rectifier limiters. These must necessarily be worked in pairs with a biassing voltage.

Copper oxide rectifier limiters have been adopted by the Post Office on account of the smaller space required and lower cost.

All types of limiters have their own peculiar disadvantages, but the performance of the Post Office type is satisfactory. Ten limiters are mounted on one panel which has a common battery feed. Owing to the balanced circuit arrangement, cross-talk *via* limiters is negligible, the attenuation being greater than 90 db. Biassing voltages from 2½ to 5 volts are provided and this permits of limitation on either the 2-wire or the 4-wire go circuit; 4-wire limitation is preferred. The loss introduced by limiters at levels below the limiting voltage is about ½ db. at all speech frequencies. With reference volume speech the loss introduced is not noticeable to the ear.

It will be appreciated that limitation must always be applied before filtration; the introduction of such a device at a point where more than one channel is present would be intolerable. The effect of the limiters on interchannel cross-talk is shown in Fig. **19**.

Harmonic Compensators.

A simple method of improving the second order products from a normal repeater is due to Dr. L. E. Ryall.[21] A copper oxide rectifier is introduced into the valve circuit in such a way that it introduces harmonic equal and opposite to that generated by the valve. The rectifier may either precede or follow the valve, but the rectifier capacity introduces rather undesirable effects in the former case. In consequence, in the arrangement adopted by the Post Office, a two-element rectifier shunted by a tapped resistance (100-200Ω) is inserted in the line winding

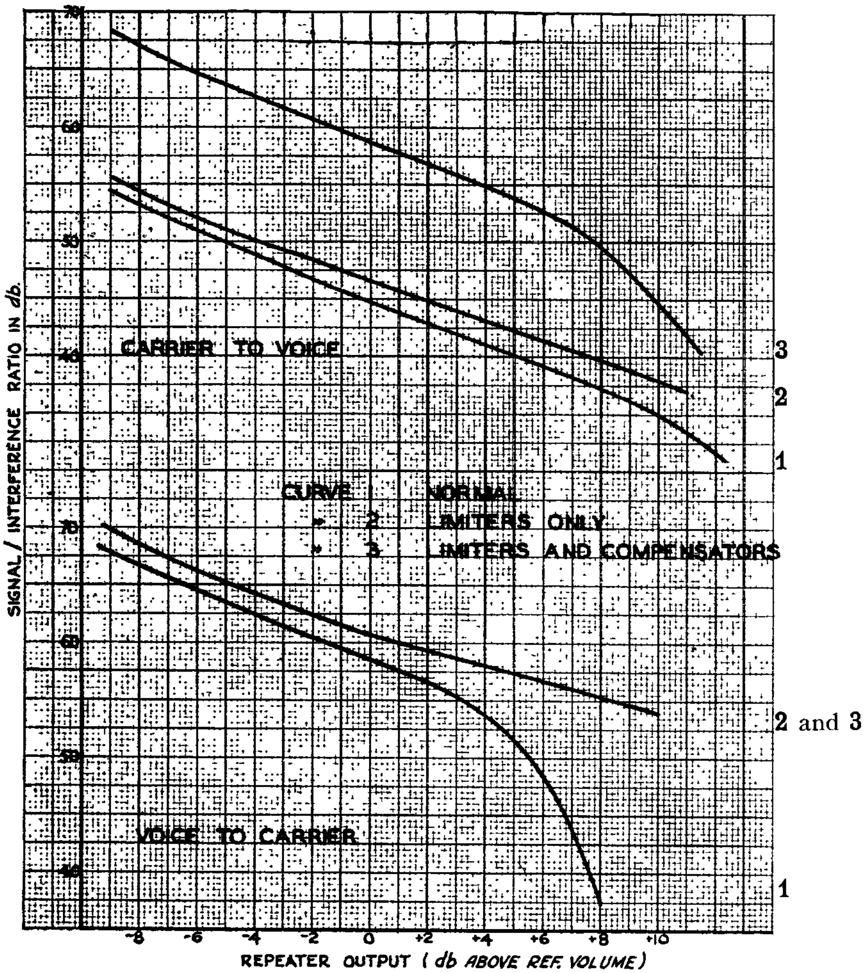


Fig. **19**.—Effect of Limiter and Harmonic Compensator on Circuit Interference in a Single Repeater (S.T.C. 4252A, VT3).

of the output transformer. By a critical adjustment of the shunt, the 2nd harmonic at a fixed level may be reduced by 20 db., but since it is obviously necessary to tolerate certain battery variations and also to handle a range of levels, an improvement greater than 8 or 10 db. cannot be relied upon. Fig. **20**

Push-pull Repeaters.

The even harmonics and even-order modulation products inherent in valve circuits can be reduced considerably by the use of a push-pull arrangement. With identical valves, equally loaded in push-pull, all even-order products vanish completely. In

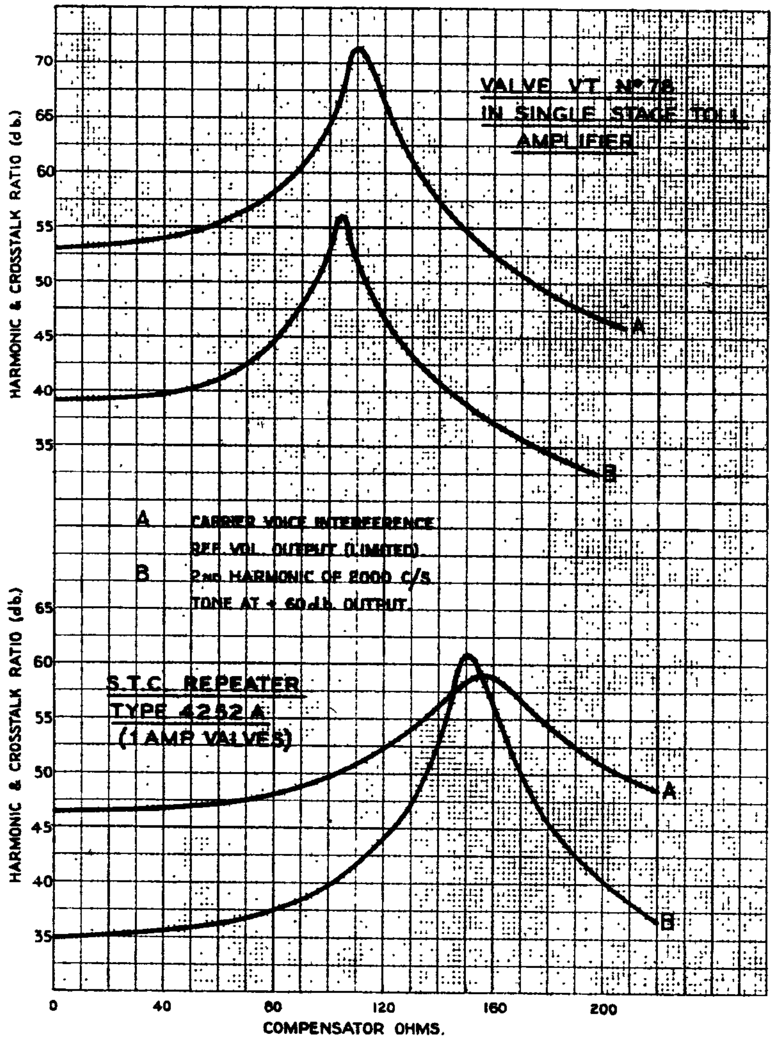


FIG. **20**.—EFFECT OF COMPENSATOR SHUNT ON HARMONIC AND CARRIER TO VOICE INTERFERENCE IN A REPEATER.

shows how the 2nd harmonic and also the carrier-to-voice cross-talk vary with the rectifier shunt. It will be seen that an adjustment which gives minimum 2nd harmonic at the maximum voltage output which the repeater is to handle (determined by the voltage limiter) is approximately correct for speech.

The improvement in the interchannel cross-talk brought about by using an harmonic compensator in conjunction with a volume limiter is shown in Fig. **19** for a typical repeater. In all cases reference volume speech is used.

In a variation of this scheme a small diode is shunted across the valve grid filament circuit (inside the valve) and this introduces the requisite amount of harmonic of reverse phase.

practice a suppression of the even-order products by about 15 db. is reasonable. The valve (2nd-order) products are then of approximately the same magnitude as the transformer (3rd-order) products. The only push-pull repeaters at present in use in this country are music repeaters; these are very suitable for combined voice and carrier working, but the cost is high.

Adjustment of Load Impedance.

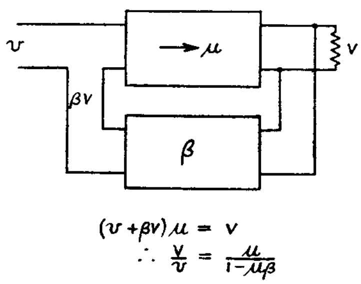
It is well known that a three-electrode valve gives its maximum output, for a given harmonic content, into a load impedance which is approximately double its internal impedance. In certain cases the sending end impedance of a circuit is of no great importance, and in these cases the second-order products may be reduced by a few decibels (say 3 db.) by a mismatch between the repeater and the line. If, however, it is necessary to maintain a correct sending-end impedance, this method is valueless.

Negative Feed-back Amplifiers.

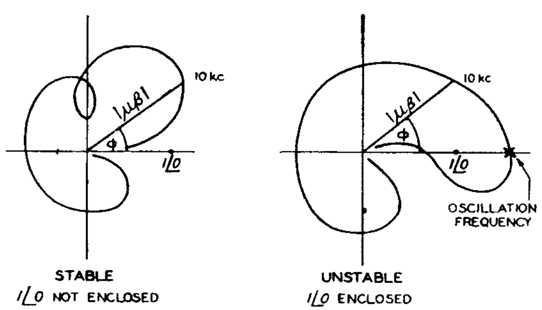
The greatest advance yet made in the elimination of repeater distortion is due to H. S. Black,[22] who has shown that if the gain of an amplifier is reduced by feeding back a fraction of the output voltage into the input circuit, its properties become more desirable in every way. Moreover, the control is positive in that any desired degree of distortion may be obtained by a suitable adjustment of the feed-back. Thus, if the feed-back is independent of frequency :

1. The gain of the amplifier becomes more nearly independent of frequency.
2. Modulation products are reduced db. for db. as the gain is reduced.
3. Noise content is reduced db. for db.
4. Gain stability with component changes is increased.
5. Gain stability with battery variations is increased.
6. Phase distortion is reduced.

Referring to Fig. **21** which utilises Black's nomenclature, let μ represent the propagation constant of



NEGATIVE FEEDBACK AMPLIFIER–EXPLANATORY



VECTOR FIELD OF $\mu\beta$.

FIG. **21**.

the amplifier proper and β that of the feed-back path. Then if an input voltage v gives rise to a (final) output voltage V.

$$(v + \beta V)\mu = V$$

$$\text{or } \frac{V}{v} = \frac{\mu}{1 - \mu\beta}$$

Thus the gain of the complete unit is $\frac{\mu}{1 - \mu\beta}$ and this expression is the key to the study of the properties of the amplifier. If the degree of feed-back is large enough, 1 becomes negligible compared with $\mu\beta$ and the gain approaches a value $-\frac{1}{\beta}$. This is seen to depend only on the feed-back circuit, in other words the gain of the unit is independent of the valve characteristics (as long as $\mu\beta$ is always large). The degree of gain stabilisation at any frequency will depend, of course, on the circuit " constants " at that frequency.

Consider an amplifier having a gain of 80 db. with a harmonic content of 30 db. below the fundamental for a given output. Now suppose $\frac{1}{100}$ part of the output voltage is fed back into the input.

$$\text{Then } \mu = 10{,}000,\ \beta = \frac{1}{100},\ \mu\beta = 100.$$

Then the amplifier gain is reduced to $\frac{10{,}000}{1 - 100}$ *i.e.*, 101 times or 40.1 db. This is almost identical with the feed-back attenuation (40 db.). In addition the harmonic level for the same output will fall to 70 db. below the fundamental, while gain variations with battery changes will be reduced to about $\frac{1}{100}$ part of their value without feed-back.

If the amplifier is required to have a gain which is not independent of frequency, this may be achieved by control of the feed-back attenuation. Thus, if it is required to equalise a given line characteristic, then the line characteristic (not the inverse) must be included in the feed-back path.

Stability of Feed-back Repeaters.

The above argument is only valid if oscillation does not occur when feed-back is applied. For a given circuit, oscillation will occur at some point as feed-back is increased. Existing theories have been found to be inadequate to deal with the stability problem and Nyquist[23] has evolved a new regeneration theory which agrees with observed results. This theory requires an investigation of the vector product $\mu\beta = |\mu\beta|\underline{/\phi}$ over the frequency range in which oscillation is possible. The upper limit of frequency will depend on the type of valve used, but for normal valves a limit of 100 Mc/s is ample. The vector field is plotted as in Fig. **21** and the criterion of stability is the position of the point $1\underline{/0}$ relative to the curve. If it is enclosed, the circuit is unstable at the frequency indicated, but if the point is not enclosed the circuit is stable.[24]

American Design.

A three-stage negative feed-back repeater of American design is shown in Fig. **22**. The feed-back is *via* input and output bridges which serve to

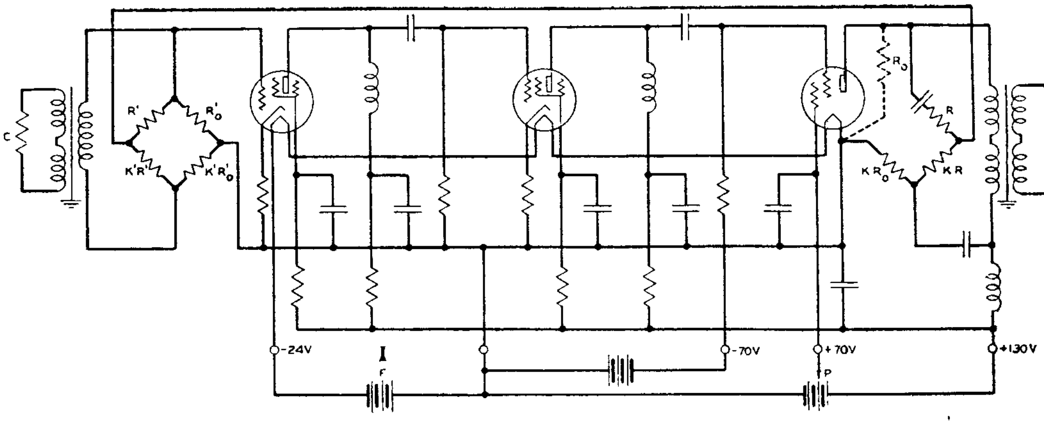


Fig. 22.—Circuit of a Negative Feed-back Amplifier.

make line and feed-back circuits independent of each other. Such an amplifier may have a gain of 100 db. without feed-back, reduced to 60 db. with feed-back and may be suitable for a frequency range of, say, 300 c/s to 50 Kc/s.*

Simplified Designs.

A much simpler type of feed-back amplifier, suitable for use with the Post Office U.G. equipment is shown in Fig. **23**.† Here, the gain of a single-stage

* These are the approximate characteristics of one type of amplifier since developed by the Post Office.

† The feed-back arrangement shown makes use of the same general principles as are employed in a feed-back amplifier used by the Dutch Administration, and whose performance had been discussed by the author's colleagues with engineers of the Dutch Administration.

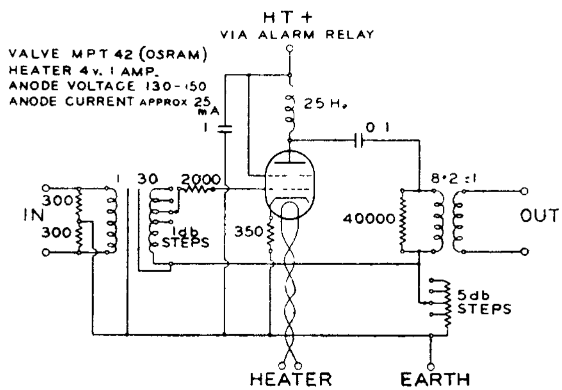


Fig. 23.—Single Stage Pentode Amplifier using Negative Feed-back. Circuit Schematic.

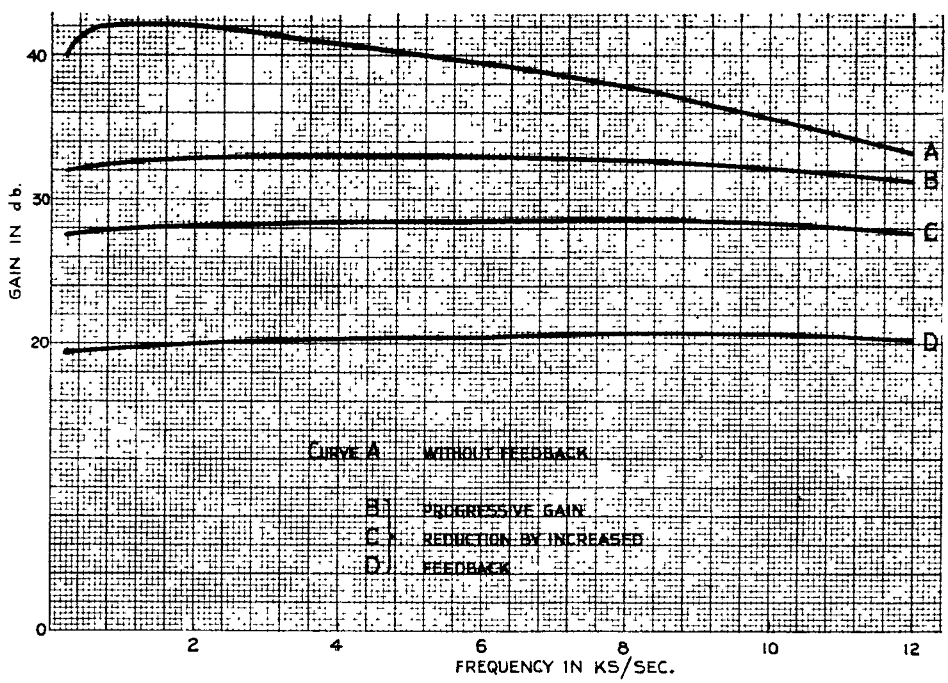


Fig. 24.—Single Stage Pentode Amplifier with Negative Feed-back. Gain-Frequency Characteristics.

pentode amplifier is reduced from about 45 db. to 30 db. by means of a simple feed-back arrangement. The frequency response, with and without feed-back, is shown in Fig. **24** and the harmonic content in Fig. **25**.

The Technique of Measuring Intermodulation Cross-talk.

It must be appreciated that, owing to the manner in which the intermodulation interference is generated, it is quite unintelligible. The problem of determining the cross-talk attenuation is therefore not a simple one. A large number of tests indicate very wide ranges in the estimates of various observers and so it appears that no individual opinion may be taken as adequate. A certain measure of success was obtained by visual balancing, using a frequency weighted noisemeter (psophometer) with an integrating device. This has, however, been abandoned in favour of a scheme which involves oral balancing of like sounds, *i.e.,* the intermodulation to be measured and a standard intermodulation of the same type. Sound film recordings have been made of a disturbing source of speech and of typical voice-to-carrier and carrier-to-voice intermodulation cross-talk. These three sound tracks are mounted on a rotating drum, each film occupying one-third of the periphery. Cams on the same spindle separate the electrical signals generated by the tracks when they intercept a beam of light focussed on a photo-electric cell and the three signals are fed to separate output terminals. The amplifier does not overload with the peaks of the signals and the relative levels of the three signals are determined in the laboratory by a number of skilled observers. The problem of testing in the field is thus reduced to the comparison of like sounds and this may be done with considerable accuracy.

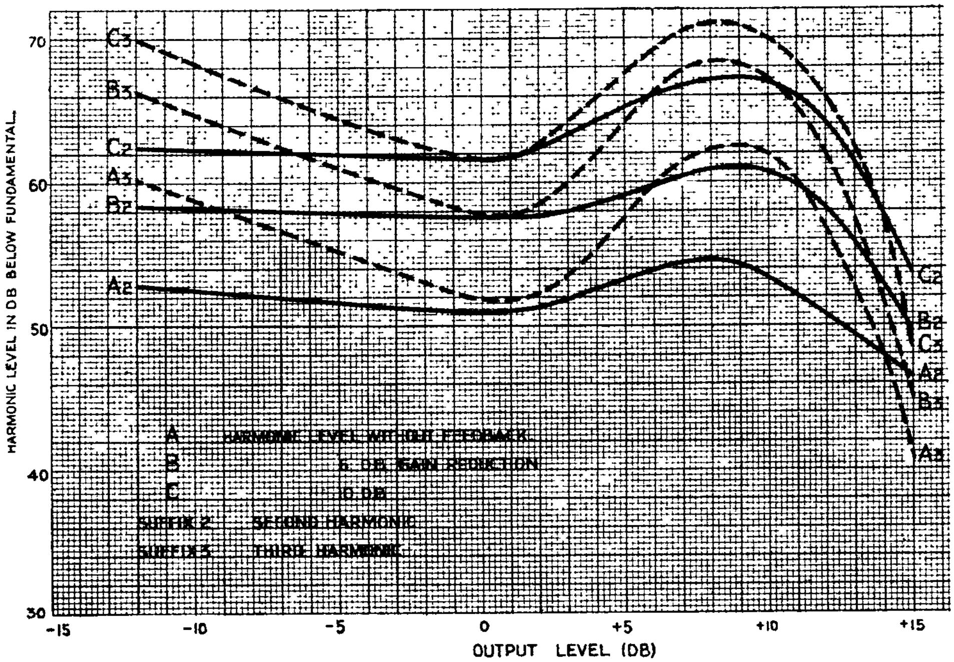


FIG. 25.—SINGLE STAGE PENTODE AMPLIFIER WITH NEGATIVE FEED-BACK. HARMONIC CONTENT AT 1000 C/S.

Addition of Interferences from Several Repeater Sections.

In the case of voice-to-voice or carrier-to-carrier cross-talk it will seldom happen that two circuits cross-talk to one another equally in a number of repeater sections. There will be an increase in " babble " as the number of sections is increased, but the cross-talk between two specified circuits will be practically that of the worst repeater section.

Where voice-to-voice or carrier-to-carrier cross-talk is concerned, this condition does not apply; the cross-talk will always get worse as the number of sections increases. The law of increase is one of the random addition of voltages, and ten repeater sections will cause interference which is 10 db. worse than that due to a single repeater section. In the case of carrier-to-voice cross-talk it will be the number of common repeaters which count. Where the number of contributing units is small, the operation of the law of random addition cannot be relied upon. If, however, the pair-to-pair cross-talk is good (as in the case of the Liverpool-Glasgow cable), practically the only contribution to the babble comes from the associated voice (or carrier) circuit. Since this interference is not intelligible, its level may rise to the maximum permissible babble level.

Overall Tests on Underground Carrier Circuits.

Test results from two different types of circuits are given. Fig. **26** shows the interchannel interference on a short cable (Carmarthen-Haverfordwest)

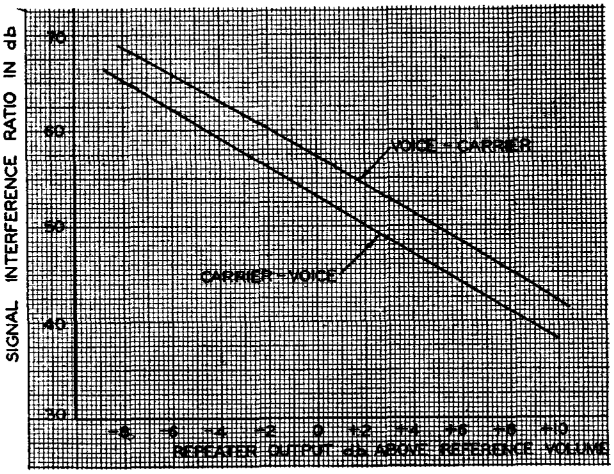


FIG. **26**.—MUTUAL INTERFERENCE BETWEEN COMPLETED VOICE AND CARRIER CIRCUITS (CARMARTHEN-HAVERFORDWEST) USING LIMITERS AND HARMONIC COMPENSATORS, 2 TOLL AMPLIFIERS, USING VALVES V.T. 68. GRADE II. LOADING COILS.

involving Units Amplifying at each terminal, with no intermediate repeaters. The cable in this case is loaded with Grade II coils.

Fig. **27** shows the results of overall tests between Liverpool and Glasgow on the new Liverpool-

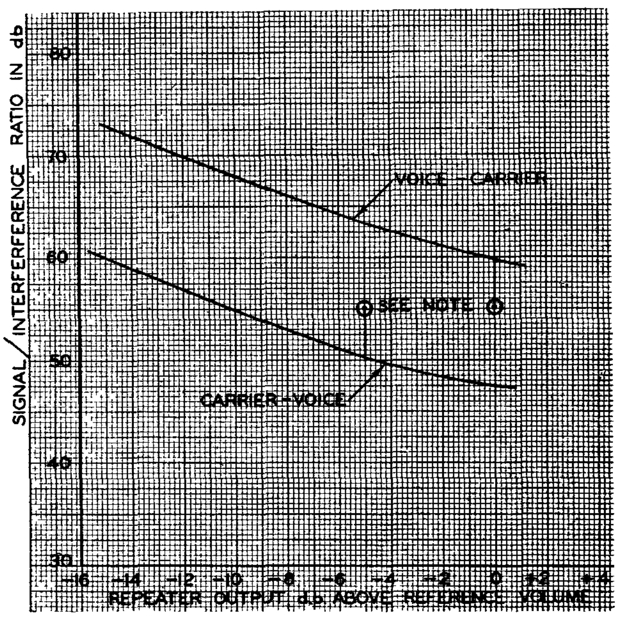


FIG. **27**.—MUTUAL INTERFERENCE BETWEEN COMPLETED VOICE AND CARRIER CIRCUITS (LIVERPOOL-GLASGOW), USING LIMITERS AND COMPENSATORS, 5 REPEATER SECTIONS (SPECIAL GRADE I. COILS), 6 MAIN LINE REPEATERS (V.T.75).

Glasgow cable. These tests involved six repeaters of which five were Type 25A and the sixth (Glasgow) was Type 4202 (1 amp. valves).

The coils in this case are Special Grade I.

In this cable, the nominal transmission levels of zero, on which basis the tests were made, are obviously not best. It is proposed to transmit the voice channel at about 5 db. higher level than the carrier channel and thereby equalise the two-channel interferences. In addition it may prove desirable to reduce the output levels from all intermediate repeaters except, perhaps, the one before the terminal receiving repeater.

The Adjustment of Harmonic Compensators.

It has been found that it is possible to adjust any repeater of the main line type, to give a carrier-to-voice interference lower than 60 db. at zero output level, but owing to battery variations and level and temperature changes it is not considered practicable to maintain a better value than 55 db. under these conditions. The adjustment of resistance to give minimum second harmonic at the maximum level passed by the limiter agrees well with the adjustment required for reference volume speech, and for a single repeater maintenance on this basis is satisfactory. Thus for a local check on a given repeater, a harmonic test is adequate.

When an attempt is made to use this method of adjustment on a circuit, it is found to be unsatisfactory since the harmonics from two or more repeaters at a single frequency, may cancel each other. In this case it becomes possible to obtain a low value of harmonic by adjustment of one compensator only. This may be overcome by using several frequencies simultaneously for the harmonic test or by testing with a modulated tone.*

In the Anglo-Dutch scheme, the voice circuits were operated on a 2-wire basis, but since the carrier signals were excluded from the voice repeaters no complications arise beyond the necessity for reproducing the line-filter in the balance network.

It happens that the light loading, close repeater spacing, and uniform cable characteristics necessary for carrier working are also particularly suited to 2-wire voice working. Fig. **28** shows how normal cable-carrier equipment may be used to operate one 4-wire carrier circuit on two 2-wire voice circuits. The filter discrimination is adequate for this purpose.

Fig. **28** also shows the arrangement of the intermediate repeater stations. It is desirable that the line balances shall be reasonably good up to 6000 c/s although a very high singing point is not, of course, necessary. A number of tests have been made with this arrangement, which presents no difficulties beyond those experienced with 4-wire working.

Fig. **29** shows a modification of this system in which two different carrier bands may be utilised to

* An overall test has since been devised and is now in use. Four frequencies are transmitted simultaneously over the carrier circuit and the modulation products are measured on the voice circuit by means of a direct reading cross-talk set.

superimpose a complete 4-wire (grouped) carrier circuit on one 2-wire voice circuit. No practical tests have yet been made with this arrangement which requires a transmission band up to 9 Kc/s and special terminal equipment. It eliminates all near-end carrier-to-carrier cable cross-talk.

The Problem of Trans-continental Trunks (World Circuits).

Experiments indicate that the maximum transmission time tolerable on any circuit is in the region of 200 mS for the single direction. When the question of world circuits is considered it becomes obvious that high velocities of propagation are essential, and these can only be obtained on unloaded or very lightly loaded circuits. This leads to the consideration of multi-channel carrier working as an economical method of utilising such pairs. There appear to be two alternatives :—

(*a*) To load to a cut-off frequency of about 20 Kc/s (6 mH at 1000 yards spacing) and work 4-channel, 4-wire carrier circuits.*

(*b*) To operate as many carrier channels as possible on unloaded conductors.

In Germany, the first alternative has been favoured while in America multi-channel transmission is more popular. In this country preliminary experiments have been made on unloaded cables with a view to multi-channel operation. In the first place, these experiments were intended to meet the requirements of the world circuits, but the results of experiments

* This scheme has since been adopted for certain circuits between Liverpool and Glasgow, forming part of the inland network.

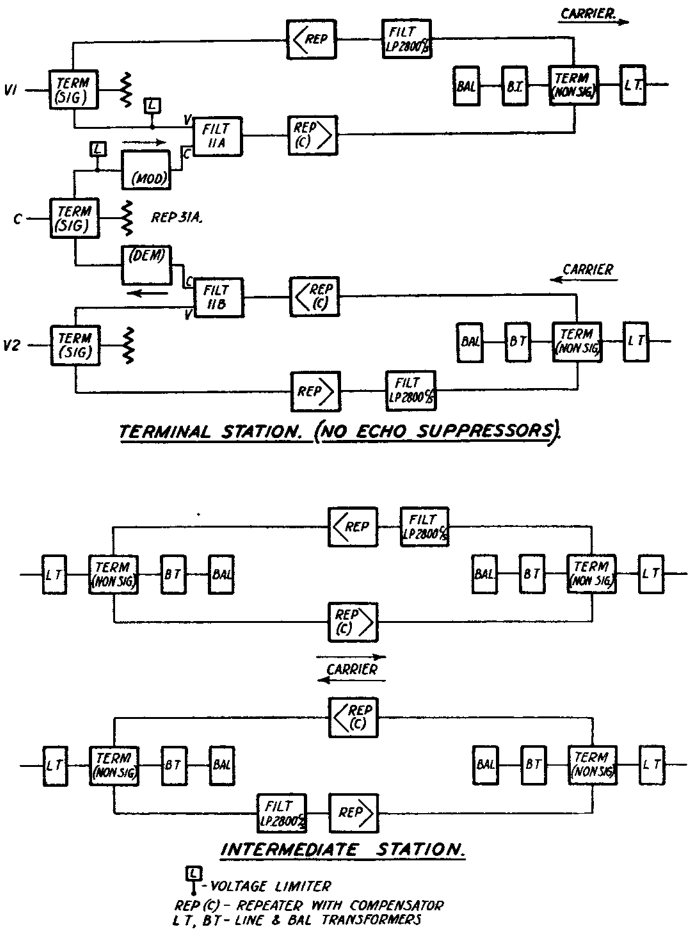
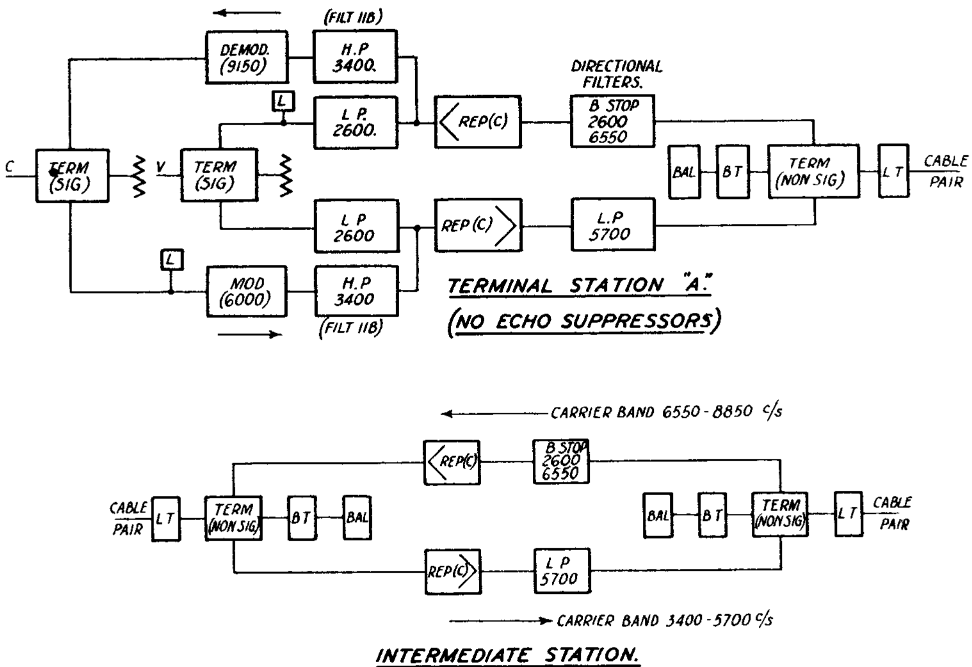


Fig. 28.—Arrangement of a 4-Wire Carrier on 2-Wire Circuit.



TERMINAL STATION " B " is as " A " above, but with Send and Receive Carrier Bands interchanged.

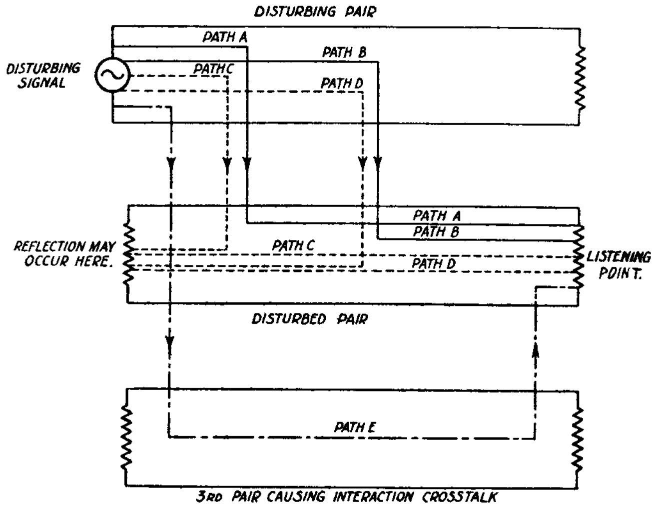
Fig. 29.—Proposed Arrangement of Grouped Carrier Circuit on one 2-Wire Voice Circuit.

carried out in America indicate that multi-channel carrier working must be seriously considered for shorter (internal) trunk circuits.

As far as our own tests are concerned, the proposal is to work multi-channel carrier circuits up to, say, 60 Kc/s on a 4-wire basis, the go and return circuits being either in separate cables or in separate screened groups. Cross-talk between two cables in the same duct is immeasurable (> 140 db.)* at 60 Kc/s, so that far-end cross-talk is the serious factor to be reckoned with. Fortunately, far-end cross-talk has the characteristic property that, with the sending-ends correctly terminated, all the characteristic components of the cross-talk are in phase. This is because far-end cross-talk always has the same effective transmission path, irrespective of the point at which it occurs (see Fig. **30**). Thus it is possible to balance out far-end cross-talk by means of networks. A combination of capacity and mutual inductance or capacity and resistance will give a considerable improvement over a wide frequency range, but the limiting factor appears to be indirect cross-talk *via* other cable pairs. This results in different networks being required to balance out cross-talk from Pair 1 to Pair 2 and from Pair 2 to Pair 1. The compromise network which is obviously necessary gives an improvement of about 20 db.

Mention has been made of correct sending-end impedance. If reflections occur at the sending-end,

* Recent tests indicate that this cross-talk is only just tolerable at 70 db. gain.



Paths A & B.—Main cross-talk paths.
Paths C & D.—Reflected cross-talk paths.
Path E.—Interaction cross-talk path.

FIG. **30**.—FAR END CROSS-TALK TRANSMISSION PATHS.

as in Paths C and D, the resultant cross-talk will be in random phase and cannot be balanced out. This is a serious point when far-end balancing is considered. Fig. **31** shows how far-end signal/cross-talk ratio varies with frequency without balancing networks. The attenuation per mile of various unloaded cable pairs is shown in Fig. **32**.

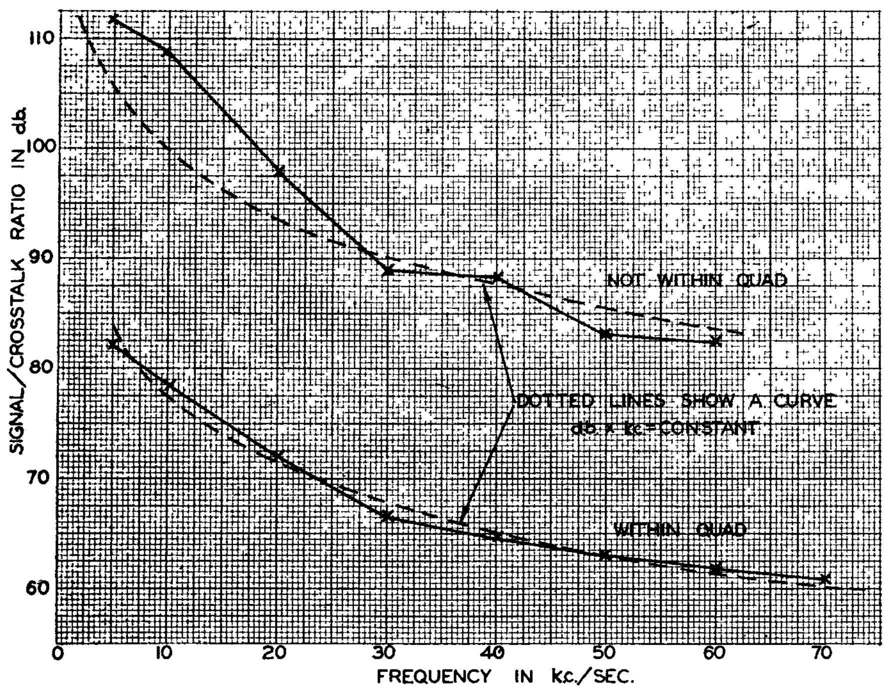


FIG. **31**.—FAR END CROSS-TALK (S/N RATIO) IN UNLOADED PAPER CORED CABLES AT CARRIER FREQUENCIES (NO NETWORKS) LEEDS-BRADFORD CABLE 40 LBS.

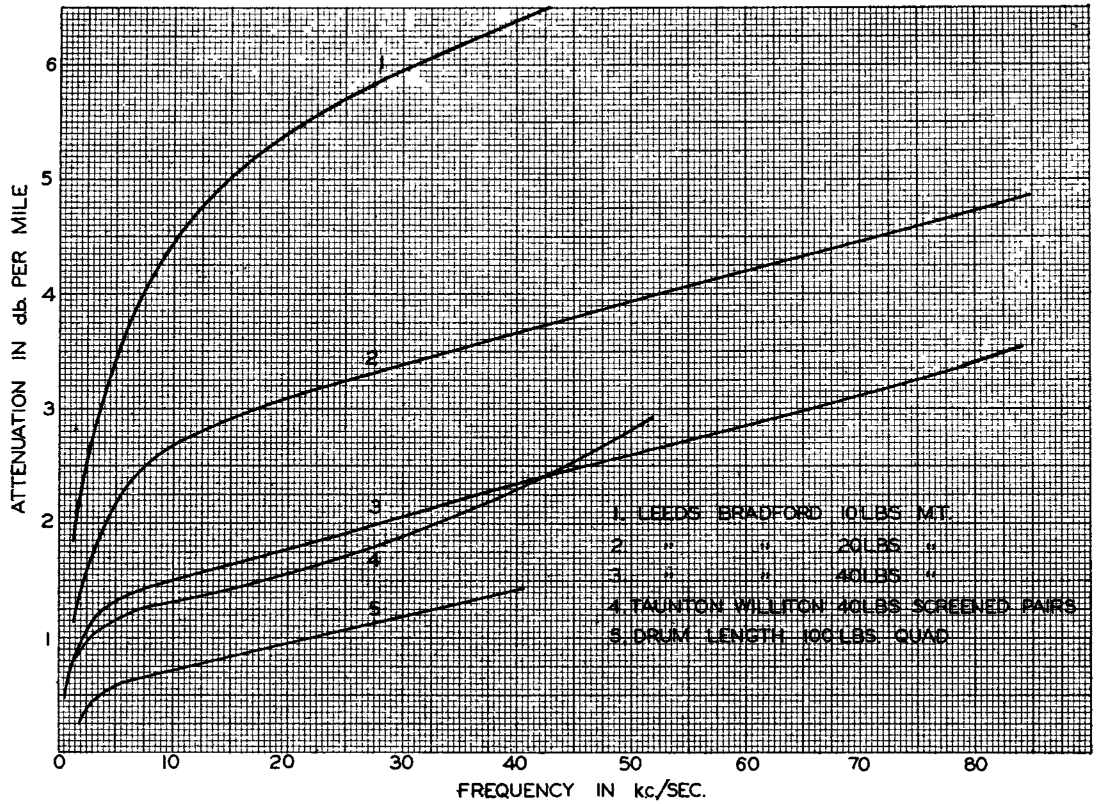


FIG. 32.—ATTENUATION OF UNLOADED PAPER CORED CABLES AT CARRIER FREQUENCIES.

Contemporary Advances in America and Germany.

The Morristown Experiments.

Just after our own preliminary tests had been started, the Bell Laboratories published the results of similar, but more advanced tests at Morristown.[25] Here a 9-channel, 4-wire carrier system was set up on the lines already described. Common repeaters were used for the nine channels and the voice circuit was not operated as its use is probably not economical. The frequency range was 4 to 40 Kc/s and the carrier frequencies used were multiples of 4 Kc/s. This allows a 4 Kc/s spacing for the channels, which gives adequate separation. The carrier frequencies were derived from a standard source of 4 Kc/s. The experiments were considered highly successful and it was stated that future toll (trunk) development would probably be on these lines. Far-end cross-talk balancing was employed, networks being midway between repeaters and Black amplifiers were used.

The Phoenixville Experiments.

The success of the Black amplifier and the Morristown experiments led to an even more ambitious attack on the problem. Patents[26] published in 1931 disclosed some extremely satisfactory properties of coaxial (concentric) transmission lines with low loss dielectrics. In particular it is pointed out that these conductors become self screening at high frequencies and thus cross-talk between metallic circuits improves with increase of frequency. Thus a cross-talk attenuation of 40 db. at 1 Kc/s becomes 140 db. at 15 Kc/s. Also, the velocity of propagation approaches that of light.

In 1933, a transmission line of coaxial conductors[27] was set up at Phoenixville and tests were carried out to prove that multi-channel carrier operation up to at least 1 Mc/s is practicable.[28] In this way 200 carrier channels may be multiplexed and worked through common repeaters. Here, of course, negative feed-back amplifiers are indispensable, and at the highest frequencies, a gain of about 90 db. is reduced to about 60 db. by feed-back. Equalisation was carried out in the feed-back circuit, and the sending and receiving levels were +10 and −50 db. respectively at the highest frequency.

In these tests, the properties of piezo electric crystals as filter elements were utilised and excellent filtration and band characteristics were obtained by this means. The equivalent circuit of a piezo electric crystal is a series resonant circuit, shunted by a capacity, and such a crystal may replace condenser and inductance elements of the same formation.[29] There are certain severe limitations brought about by the relationship between the crystal constants, and the design of suitable filters (usually of multiple bridge type) calls for considerable ingenuity. The results are, however, very satisfactory, as the crystals have dissipation losses comparable with best quality condensers.

Another feature of the Phoenixville experiments was the employment of group modulators. The speech bands were first modulated with carriers at 4 Kc/s intervals, into twelve primary positions between 60 and 108 Kc/s. One such group of twelve bands was fed to line directly. In order to fill the next group of 108-156 Kc/s, a primary group was modulated en bloc with a carrier frequency of 112 Kc/s, the upper (group) sideband being employed. This group modulation was repeated for higher frequencies. Copper oxide modulators were used as primary modulators and valve (Carson) modulators as group modulators. It will be noted that the group 60-108 Kc/s may be group modulated because it consists of a frequency band less than 1 : 2; thus all intermodulation products lie outside the band and are filtered out.

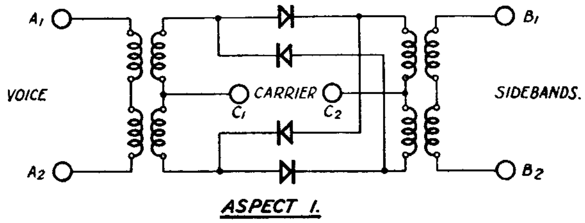
The Phoenixville experiments open up an enormous scope for wideband transmission. It is considered practicable to extend the frequency range to 5 Mc/s and tests have been made up to this frequency. It is proposed to operate unattended repeaters at 10 miles spacing, the power feed being taken over the concentric conductor at the usual power frequency. Questions of equalisation and temperature compensation problems have been investigated.

All authorities in America are not convinced of the desirability of coaxial cables, which are not so sound mechanically as pair cables, and in a recent article,[30] it is pointed out that much may be accomplished with pair cables.

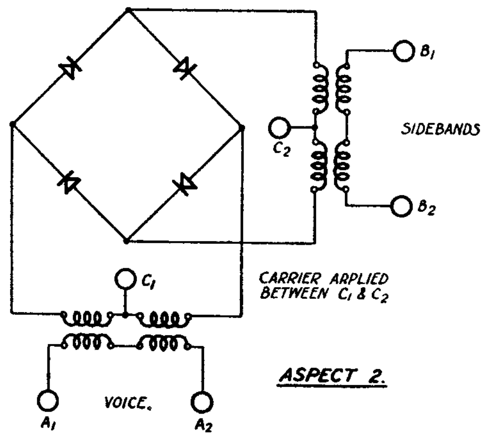
Contemporary Developments in Germany.

Developments in Germany have been principally in the nature of one and three-channel cable systems. As in America, a 4 Kc/s spacing has been adopted for multi-channel working, but for the single-channel system a frequency of 6 Kc/s is used.[31] A particularly interesting contribution from Germany takes the form of a copper oxide rectifier bridge which goes a stage further than our own, for both the input signals, speech (or sideband) and carrier are balanced out. Fig. **33** shows the bridge in two aspects, the first showing more clearly how the carrier is balanced out by being applied along an axis of symmetry, the second showing how the input signal is suppressed in the diagonal of a balanced Wheatstone bridge. The whole unit is known as a "frequency transformer." The same effect may be produced by the use of two bridges of the Post Office type.

In the direction of wideband cable working, workers in Germany appear to favour a screened pair construction, partly on account of noise level.



This shows the bridge as a balanced network with the carrier introduced on the line of symmetry. Thus the carrier is suppressed in the output as in the P.O. bridge.



This shows the bridge as a balanced Wheatstone network, the input to one pair of diagonals being suppressed in the opposite diagonals.

FIG. **33**.—GERMAN FREQUENCY TRANSFORMER. (FREQUENZWANDLER).

Multi-Channel Carrier Working on Cables in Great Britain.

In this country there are two fields for the application of multi-channel cable working.

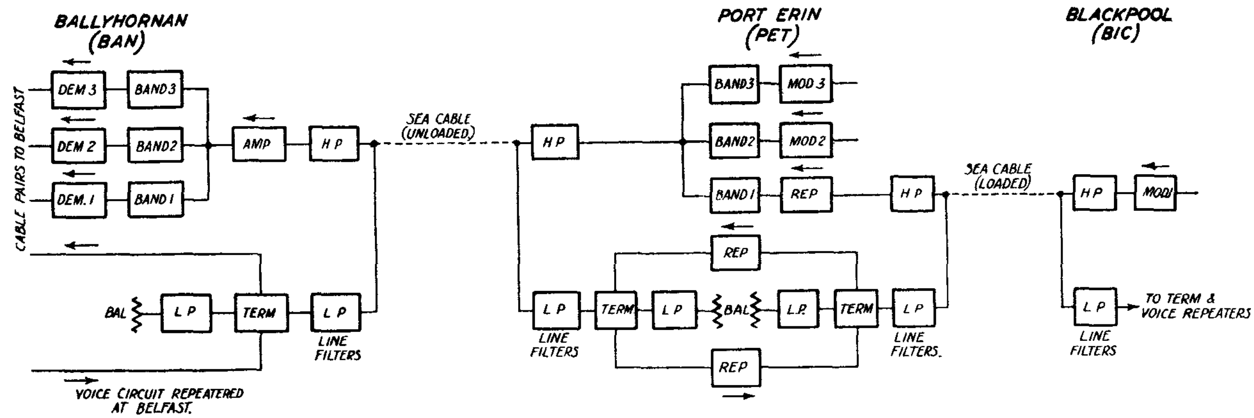
1. An urgent need for use on unloaded sea cables.
   (*a*) Port Erin-Ballyhornan No. 1 and No. 2 cables.
   (*b*) Port Kail-Donaghadee No. 1 and No. 2 cables, with suitably loaded land lines to Stranraer and Belfast.
2. A general need for land cable development.

To meet these requirements the first three channels of a multi-channel system have been designed and tested out. Each modulator and demodulator has two valves, one a low frequency amplifier and the other a sideband amplifier, and in each case the overall gain (including frequency change) is 40 db. The modulators have voice frequency equalisers as single stage repeaters and operate at an output level of +10 or rather higher. The demodulators have a flat gain, with no equalisation and operate at an output level of +10 db. The rectifier bridges are identical with those on Repeater 31A and are fed by similar oscillators.

The band-filters are designed so that further channels can be added as required. At the receiving terminal a multi-channel amplifier, operating at a low level, and a constant impedance equaliser specially designed for the cable are fitted between the line-filter and the band-filters. The coils of the high-pass line filter have a lower hysteresis factor (8) to reduce intermodulation interference between the bands.

An idea of the flexibility of the system may be obtained from Fig. **34**, which shows the arrangement which will be fitted on the Anglo-Irish cables. The continuously loaded 4-quad cable between Blackpool and Port Erin will carry four single-channel carriers, while each of the two unloaded balata cables between Port Erin and Ballyhornan will carry one three-channel system, with facilities for extension as required. Two of the low frequency channels are to be repeatered at Port Erin.

between Blackpool and Ballyhornan, with a carrier repeater at Port Erin. These two circuits went into service as Traffic Nos. 1 and 2, the voice circuit being No. 1. Within a few weeks their order was reversed and the carrier circuit was made Traffic No. 1. For this circuit the temporary equipment used for Rotterdam 7 was employed. Late in 1934, after the reduced night rate was introduced, it become necessary to increase the number of Belfast trunks. To



Channel 1 (4W). Bic-Ban, repeatered at Pet.
Channels 2 and 3 (4W). Pet-Ban.
Voice Circuits 2W. or 4W. as required.
Carrier Circuit Equalisers—Constant Impedance Type following Receiving H.P. Line Filter.

FIG. **34**.—ANGLO-IRISH CARRIER SCHEME. PROPOSED ARRANGEMENT OF CIRCUITS.

The choice of carrier frequencies for multi-channel working is rather difficult. For high frequency channels the 4 Kc/s spacing standardised in America and Germany is undoubtedly very satisfactory and will probably be adopted in this country. The band spacing of 4 Kc/s is adequate for transmission of a speech band of about 2,800 c/s and the harmonic relationship between the carrier frequencies simplifies the maintenance of constant frequencies and of synchronisation of carriers if required. This is further facilitated by the provision of a standard frequency service or crystal clock.[32, 33]

In this country it is desirable that the first channel of a multi-channel system shall coincide with the single-channel system (see the Anglo-Irish scheme). To this end, the following frequencies have been standardised, 6.0, 9.15, 12.5, 16.0* Kc/s. These are designed to give similar band widths for all channels (channel 1 is already fixed by the C.C.I.F.). Thereafter, the 4 Kc/s spacing may be adopted and it is proposed to operate higher bands on this basis.

Temporary Carrier Schemes now working on Irish Routes.

In 1933, two London-Belfast circuits, previously 2-wire in the sea cables, were upgraded to " zero " 4-wire circuits by means of a single channel carrier

* C.C.I.F. has since recommended the use of multiples of 4 Kc/s for multi-channel systems.

help in this respect the following circuits were fitted as a temporary measure :—

1. A 4-wire carrier superimposed as a 2nd channel on the TSX-BE carrier (Carrier frequency 9.4 Kc/s) between Port Erin and Ballyhornan. This was extended as a 2-wire circuit to Blackpool and thence to Liverpool as a LV-BE trunk (3 db.).
2. A grouped carrier using Carrier System No. 1, between Port Erin and Ballyhornan. This was also extended 2-wire to Blackpool and thence to London as a TSX-BE trunk (3 db.).
3. A similar circuit between Stranraer and Belfast using the special carrier loaded pairs in the land cables. This was a very difficult circuit and even with the filters at the cable huts it was only possible to maintain an overall of 5 db. This circuit was extended 4-wire to Glasgow as a GW-BE trunk (5 db.).

All the above circuits are giving good service despite their temporary nature, but they will be replaced with more suitable equipment as soon as possible.

Schemes for the Anglo-Belgium (1932)[34] *and Anglo French* (1933)[35] *Cables.*

The loss-frequency characteristics of these cables are given in Fig. **35**. Both cables are suitable for single-channel carrier working and special flat gain repeaters (50 db. max.) have been installed at St.

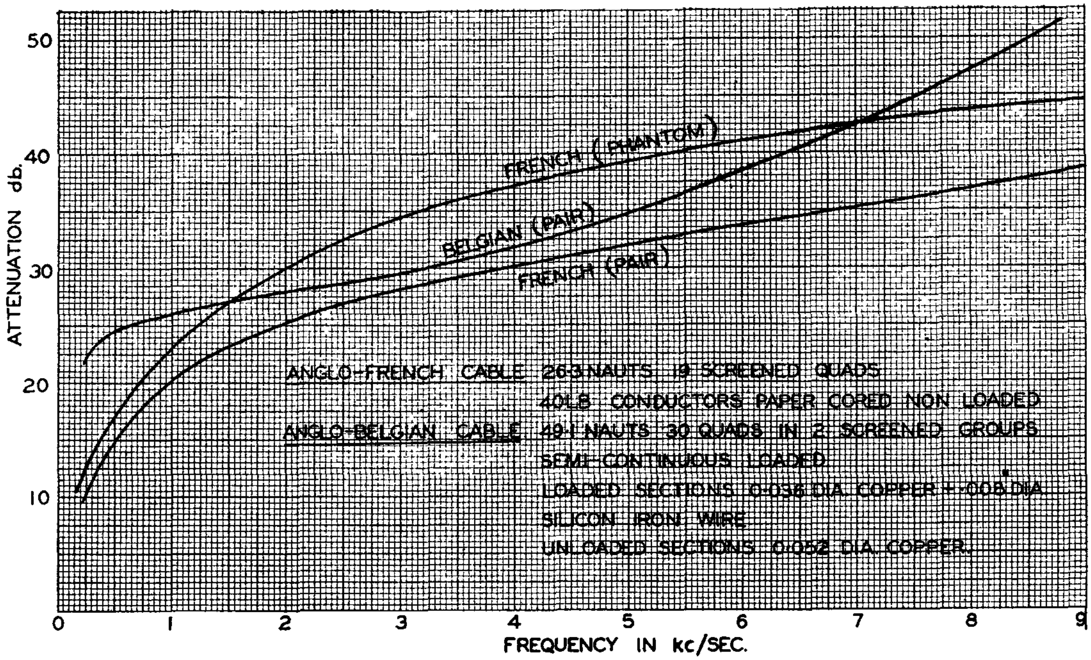


FIG. 35.—ATTENUATION FREQUENCY CURVES FOR ANGLO-FRENCH (1933) CABLE AND ANGLO-BELGIAN (1932) CABLE.

Margaret's Bay to permit of operation up to 6 Kc/s. Both bands will pass through these repeaters, for which constant impedance equalisers will be fitted. With only two repeaters in each circuit and very light loading (none on Anglo-French cable), the inter-channel cross-talk should be negligible, with transmission levels suitably adjusted.

In the Anglo-French cable, most of the quads are sufficiently good to permit of working the two side circuits and the phantom on the above basis. All three circuits would, of course, transmit in the same direction.

Voice Frequency Telegraphs on Carrier Circuits.

The band width and frequency response of cable carrier circuits (with particular reference to the single channel U.G. scheme), are such that it is practicable to transmit standard 18 channel VF signals over the circuits. There are, however, two difficulties :—

1. Maintenance of frequency stability of carrier oscillators to ± 1 cycle per second which is the maximum drift which can be permitted. This has been overcome by means of a small temperature controlled oven which encloses the oscillatory circuits. The requisite stability with battery variations can be obtained.
2. Intermodulation between the various VF channels in the carrier modulator, which now becomes a group modulator. The simple precaution of avoiding a two to one ratio between the end frequencies of the signal band, cannot be adopted and it is not yet certain that 18 channels can be operated satisfactorily. Tests with 6 channels have, however, been made with complete success. The modulating level must obviously be kept low.*

Provided that these difficulties can be successfully overcome there is no reason why satisfactory operation of VF telegraphs should not be achieved. In this case it becomes possible to use the upper part of the frequency band associated with 44 mH loading, to advantage. The available (spare) band width may be taken as 3,400 to 4,500 c/s and this can be made available for carrier telegraph working. By using normal VF equipment 6 Kc/s carrier equipment, the eight highest VF channels may be operated. This scheme has not yet been subjected to trial.

The Trend of Future Developments.

To state that carrier working must play an increasingly important part in telephone communication would belittle recent developments. In America, revolutionary changes are pending and if the preliminary results on wideband transmission are ultimately justified, it may well happen that voice-frequency telephone circuits may disappear completely from the main cable system. To infer that such will also happen in this country is to assume that our problems and American problems are similar, which, in fact, they are not. Nevertheless, such radical changes cannot fail to be reflected in our own policy, and whereas in the past a balance has had to be found between copper, loading and repeater costs, a fourth factor, terminal multiplexing equipment, must now be added. The proportions which will ultimately prove to be economical are, as

* Further tests have since been carried out and the operation of the 18-channel system appears to be satisfactory.

yet, by no means evident. For the moment, high grade pair cables, loaded for two-channel (voice and carrier) working are in favour and as the technique improves, the number of channels will be increased to the economical maximum. To attempt to set a limit to the highest frequency which can be operated on a suitably designed cable would be premature at this stage. It would appear to be limited, however, by the following factors :—

1. The highest frequency at which carrier signals can be generated and amplified. In this respect oscillators[36] are at present well in advance of amplifiers which have not yet been successfully operated above 400 Mc/s.
2. The precision with which transmission bands can be located at high frequencies.
3. Inherent noise in valve and metallic circuits.[37] This limits the gain at which amplifiers may operate, and thus limits the repeater section attenuation.

It may be noted that in a recent patent, the metallic conductor is dispensed with completely and is replaced by a bar of insulating material of high permittivity. This serves to direct the signals which are of very high frequency. Such a scheme as this would appear to be impracticable at the present time, but it indicates the extremes which may have to be considered.

Articles, etc., referred to in the Paper.

1. "Carrier Systems on Long Distance Telephone Lines." H. A. Affel, C. S. Damarest and C. W. Green. Bell System Technical Journal, July, 1928.
2. "A Carrier Telephone System for Short Toll Circuits." H. S. Black, M. L. Almquist and L. M. Ilginfritz. A.I.E.E. Trans., 1929.
3. "A new Key West-Havana Carrier Telephone Cable." H. A. Affel, W. S. Gorton and R. W. Chesnut. B.S.T.J., April, 1932.
4. "Carrier Current Communication on Submarine Cables." H. W. Hitchcock. B.S.T.J., Nov., 1926.
5. "Carrier Current Telephony." A. C. Timmis. I.P.O.E.E. Paper, No. 131. Feb., 1930.
6. "Anglo-Dutch No. 3 Continuously Loaded Submarine Cable." A. B. Morice. J.P.O. E.E., 1926.
7. "The Anglo-Dutch Telephone Cable." E. F. Petritsch. J.P.O.E.E., 1923.
8. "The Anglo-French (1926) Cable." J.P.O. E.E., 1927.
9. "Anglo-Belgian (1926) Continuously Loaded Telephone Cable." W. T. Palmer. J.P.O.E.E., 1926.
10. "The Anglo-Irish and Manx (1929) Submarine Telephone Cables." W. T. Palmer. J.P.O.E.E., 1929.
11. "A Simplified Carrier Telephone System for Use on Open Lines." R. J. Halsey. J.P.O.E.E., June, 1933.
12. Hopfner, Europäischer Fernsprechdienst. Oct., 1929.
13. "Reconditioning Telegraph Circuits for Audio and Carrier Working." E. J. Woods. J.P.O.E.E., 1933.
14. "Carrier Telephony in Underground Cables." J.P.O.E.E., 1934. (Brief note).
15. "The Snow Storm of February, 1933." J. G. Hines. J.P.O.E.E., 1933.
16. "The New Liverpool-Glasgow Cable." A. O. Gibbon. J.P.O.E.E., Jan., 1935.
17. "Modulation in Vacuum Tubes used as Amplifiers." E. Peterson and H. P. Evans. B.S.T.J., 1927.
18. "Impedance of a Non-Linear Circuit Element." E. Peterson. A.I.E.E. Trans., 1927.
19. "Harmonic Production in Ferromagnetic Materials." B.S.T.J., Oct., 1928.
20. "The Design and Construction of Electric Wave Filters." R. J. Halsey. I.P.O.E.E. Paper No. 155, May, 1934.
21. "A Few Developments in Telephone Transmission Apparatus." L. E. Ryall. I.P.O. E.E. Paper No. 155, May, 1934.
22. "Stabilized Feed-back Amplifiers." H. S. Black. B.S.T.J., Jan., 1934.
23. "Regeneration Theory." H. Nyquist. B.S.T.J., Jan., 1932.
24. "Regeneration Theory and Experiment." E. Peterson, J. G. Kreer and L. A. Ware. B.S.T.J., Oct., 1934.
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26. British Patents Nos. 352011 and 353020.
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28. "Systems for Wide-band Transmission over Coaxial Lines." L. Espenschied and M. E. Strieby. B.S.T.J., Oct., 1934.
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31. "Carrier Frequency System for Trunk Cable Circuits." R. Dolman and H. F. Mayer. Europäischer Fernsprechdienst, Jan., 1934.
32. "The Crystal Clock." W. A. Marrison. Bell Monograph B.505. July, 1930.
33. "Modern Developments in Precision Clocks." A.I.E.E. Trans., June, 1932. W. A. Marrison and A. L. Loomis.
34. "Electrical Tests on the Anglo-Belgian (1932) Submarine Telephone Cable." E. M. Richards. J.P.O.E.E., Oct., 1933.
35. "The Anglo-French (1933) Submarine Telephone Cable." E. M. Richards. J.P.O. E.E., Jan., 1934.
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APPENDIX.

Rectifier Bridge Structures.

The choice of a suitable bridge structure for modulators and demodulators was determined after a survey of the following factors :—

1. The maximum back voltage which it is permissible to apply to each rectifier element is about 5 volts.
2. There is a condition for maximum efficiency of the bridge.
3. Both the backward and forward impedances vary with temperature, the back resistance being non cyclic. It is theoretically possible to make the two temperature coefficients neutralise each other in their effect on the bridge transmission loss.
4. The input impedance of the bridge, in the case of Repeater Telephonic No. 31A, must not be sensibly dependent upon temperature.
5. It is desirable to feed a bay of six channels from a single repeater valve.
6. Volume distortion must be small. This will automatically ensure low levels of intermodulation products when the bridge is used as a group modulator (*e.g.*, for multi-channel VF telegraphs).

Apart from the bridge shown in Fig. **33**, which was not known at the time, choice appeared to rest between the three arrangements shown in Fig. **36**.

Of these three types No. 3 was investigated first as it possessed certain advantages.

(*a*) The input impedance is substantially constant through a carrier cycle.

(*b*) The modulation is very pure as the network is effectively a fixed resistance with the output taken from a sliding potentiometer point, *i.e.*, the carrier voltage merely varies the ohmic distribution on the two sides of the slider.

The temperature coefficient of the rectifiers, however, provided a difficulty which led to abandonment of the network. The input impedance depends primarily on the back impedance of the rectifiers and this varies so considerably with temperature that the gain of the modulator is seriously effected.

Network No. 2 has the advantage over No. 1 that the current density in the rectifiers may be greater, but for the loadings required by the present equipment this was found to be of little value. The arrangement of No. 1 gives a slightly increased power handling capacity for a given harmonic distortion.

Since the design of the present bridge, rectifier bridges have been devised in great variety and it is not suggested that finality of design has yet been reached. It will be clear, however, that other factors, in addition to efficiency of modulation, must be carefully considered.

The bridge of Fig. **33**, while ideal in many respects, has a very small power handling capacity compared with that of the two-rectifier bridges tested. This is due to the low carrier voltage impressed on the rectifiers over the " negative "

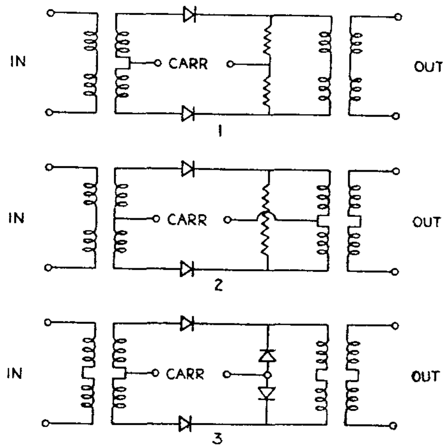

FIG. **36**.

half cycle. While in all rectifier bridges the modulation is effected on a current basis, the instantaneous voltage on the rectifier determines its switching action. In the two-rectifier bridges the carrier voltage rises over the non-conducting part of the carrier cycle, whereas in the four-rectifier bridge this voltage does not rise.

SUMMARY OF DISCUSSION.

The discussion was mainly confined to the broader aspect of carrier working. One speaker gave details of the new Bristol-Plymouth cables which are being laid with a view to multi-channel carrier working. Two cables, each 19 pairs, 40 lbs. unloaded conductors, are drawn into the same duct and all " Go " circuits will be worked on one cable and " Return " circuits in the other. Repeaters, using negative feed-back, are spaced at about 20 miles and with this arrangement it is expected that 12 circuits will be workable on each group of four wires. Some preliminary details of the new coaxial cable between London and Birmingham were also given.

Another speaker visualised land and sea cables of the future with no loading or very light loading. In the latter case the coils would need to have very low hysteresis losses. Land cables would all be designed for carrier working and would probably fall into two classes; firstly, somewhat similar to the present type of trunk cables with fewer and heavier conductors which might be operated up to about 100 Kc/s and, secondly, coaxial cables operating up to about 5 Mc/s. The use of unattended and even buried repeater stations would have to be considered.

Figures were given to substantiate the economics of carrier working and these indicated that multi-channel working shows a saving of about 75% on circuits 400 miles in length and about 40% on circuits 100 miles in length.

Deploring the low anode voltage which has been standardised in this country (130 volts), a speaker gave details of a system of anode voltage control which has been installed experimentally. Some such system may be necessary as the number of repeaters increases.

Reference was made to the short life of the valves used in the Anglo-Dutch carrier equipment, but with this exception the equipment was completely satisfactory.

Another speaker referred to the use of far-end cross-talk balancing networks and expressed the opinion that the initial cross-talk must be kept low rather than rely on large improvements from the networks. Doubts were also expressed as to the accuracy of the law of random addition of cross-talk voltages, when the repeater sections are short.

Several speakers referred to the use of harmonic compensators on the repeaters and expressed the hope that adjustment in service would not be necessary. The provision of testing equipment to localise intermodulation cross-talk would be necessary.

The wisdom of expending money on labour in terminal equipment, instead of on material in cables, was questioned. Material is recoverable, labour is not, and this must be allowed for in computing the economics of carrier working, together with the lack of flexibility of carrier systems on the line side.

In a written contribution, Mr. A. W. Montgomery referred to a carrier broadcast channel which has been developed by Messrs. Standard Telephones & Cables, Ltd. This operates over the frequency range 34-42.5 Kc/s and is used on open wire lines with considerable success. He also referred to experience with multi-channel VF telegraph circuits on carrier channels. A 12-channel telegraph is operating on a carrier circuit over a distance of about 1000 miles in South Africa and is entirely satisfactory. The circuit carrying capacity of the new Australia-Tasmania cable was given. On this single core cable will operate one physical telephone channel, five carrier telephone channels and one broadcast channel. Over one telephone channel will operate seven telegraph channels. The frequency response curve of the feed-back amplifiers is flat from 200 c/s to 50 Kc/s and the performance is consistent with Mr. H. S. Black's theory.

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