TECHNICAL INSTRUCTIONS

LINES

VOLUME 1

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Page reissued February 1966

TECHNICAL INSTRUCTION

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BBC Multi-channel Telephone Carrier Communication System

Second Edition

First edition September 1951
Second edition May 1965

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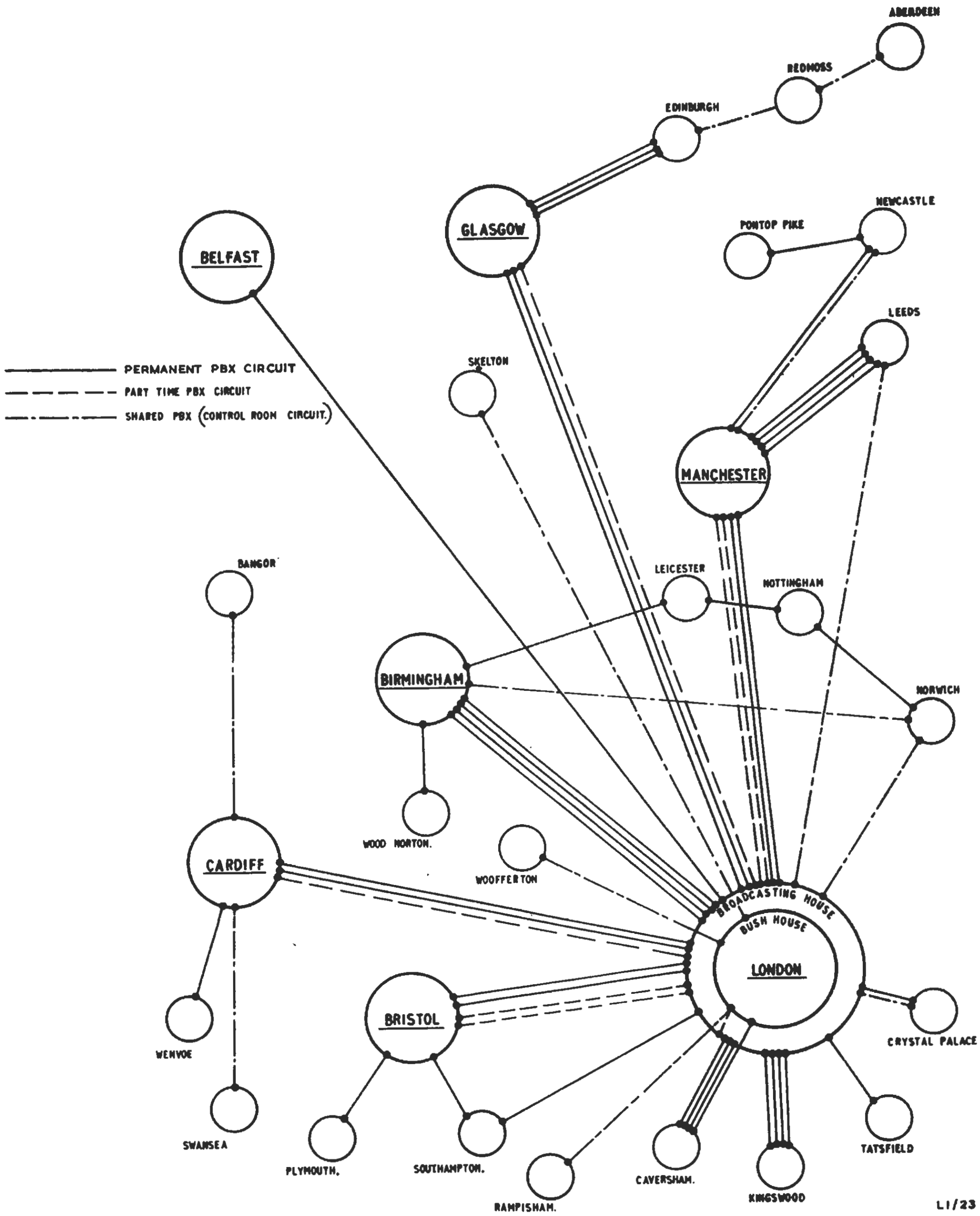


Fig. 1.1. BBC Communication System

BBC MULTI-CHANNEL TELEPHONE CARRIER COMMUNICATION SYSTEM

SECTION 1

INTRODUCTION

As a result of a comprehensive survey of BBC inter-office telephone and teleprinter traffic requirements made by Lines Department in 1945, a carrier system was set up, principally between London and the main Regional studio centres, to handle this traffic. Each carrier circuit in each direction occupied one programme or 'music' circuit, with a nominal upper transmission limit of 8 kc/s. Initially, this provided three telephone channels with the possibility of deriving a teleprinter or other telegraph channel on each telephone channel if desired, so that six communication channels could be obtained on one 4-wire network. Later, a fourth telephone channel was added in some instances, after experience had shown that many of the programme circuits (which consist normally of the phantom circuits in Post Office multi-channel carrier cables) were capable of transmitting a frequency range of up to 11·5 kc/s. A fourth telegraph channel has also sometimes been derived.

Fig. 1.1 shows the extent of the BBC communication system (excluding engineering control lines) in January 1965.

Two compelling reasons at the time for choosing the carrier method of providing communication channels were (a) the possibility of exploiting during office hours many programme circuits which in any event would have to be rented either for evening use on the Third programme or as reserve, and (b) the fact that the terminal apparatus would be situated on BBC premises, which would avoid all the local-end losses inevitable if Post Office private wires were rented, since the Post Office do not usually install their terminal equipment on subscribers' premises.

Other important advantages to be expected from this method of circuit provision were (c) the greater reliability of the network, both on account of the greater amount of control the BBC could exercise over the apparatus and also because the Post Office maintain programme circuits to a higher standard than speech private wires, and (d) greater flexibility in the use of the channels, which could be readily switched in the evenings to be either cue, control or PBX circuits, or could be arranged to form a complete network of control circuits to the transmitting stations to cover unstaffed periods in the early morning.

Although the carrier communication system has now been in use for a number of years and is working satisfactorily, the reasons given above for its introduction are today no longer all entirely applicable, and carrier working would at present (1965) probably not be considered economically justifiable, if the system were not already installed.

SECTION 2

GENERAL PRINCIPLES OF CARRIER COMMUNICATION

2.1 Definitions

2.1.1 Carrier Communication

For the purposes of this Instruction, *carrier communication* means the transmission and reception of telephone and telegraph messages by means of amplitude-modulated carrier currents, transmitted over either physical circuits or other carrier channels.

2.1.2 Multi-channel Telephone Carrier Communication System

A multi-channel telephone carrier communication system implies a number of telephone or telegraph channels, or a combination of both, derived from a 4-wire network of lines by dividing the available frequency range into a number of bands of restricted width and using each band for a separate communication channel.

The BBC network is built up from a number of so-called 1 + 2 systems, in which one telephone channel operates at voice-frequency and two others are translated to different parts of the frequency range. The system is so designed that a telegraph channel may be derived from each telephone channel if required. In many instances a fourth telephone channel has been added to make a 1 + 3 system, and here too a telegraph channel can be derived, provided the band-width available on the music circuits approaches 11·5 kc/s.

2.2 Frequency Bands

In good commercial telephone practice it is generally accepted that an audio-frequency band of about 300–3,400 c/s is adequate for high-quality transmission of speech, but if the overall loss on a telephone circuit can be kept down to a maximum of 15 dB, it is possible to reduce the upper frequency limit to 2,300 c/s without imparing the efficiency of the channel. This of course assumes that there is no noticeable impairment due to noise or crosstalk, a condition usually not difficult to meet in carrier systems operated in the way described here. (These matters are discussed in Lines Report No. 50.1, 'Technical Basis for the Design of Proposed BBC Communication Network,' and in Chapter 9 of the BBC Engineering Training Manual, 'Studio Engineering for Sound Broadcasting'.) Because the overwhelming majority of local-end connections on a trunk call on the BBC carrier system are short and therefore have small losses, it is readily possible to keep the overall loss down to 15 dB, so that with a bandwidth of 300–2,300 c/s at least 90 per cent of all calls between main centres on the network obtain immediate appreciation of 90 per cent of the intelligence transmitted, which is a reasonable basis for design.

A modern Post Office music circuit has a usable frequency range of at least 50–8,000 c/s and it is therefore always possible to derive three bandwidths of the order indicated above from such a line, while still leaving adequate space for three telegraph channels where required, if, as is the practice in the BBC, these are used for teleprinter purposes. A 50-band teleprinter channel (see Instruction L.6, Section 2.3) requires a bandwidth of the order of 100 c/s, and the practice is to derive three telephone channels of about 2,300 c/s bandwidth (300–2,600 c/s) from the 50–8,000-c/s line and to derive such teleprinter channels as may be required from the individual telephone channels. In this way those telephone channels with superposed teleprinter channels still have the required bandwidth of 2,000 c/s and if there are no teleprinter channels they retain the advantage of additional bandwidth up to 2,300 c/s.

2.3 Modulation and Demodulation

The object of the modulation process is to shift the frequency band to be transmitted so that it occupies some desired position in the frequency spectrum available on the line; having been transmitted, it is then demodulated at the receiving end and restored to its original position in the audio range so that it can be understood by the recipient.

Fig. 2.1 shows the basic circuit of the telephone channel modulator, the demodulator being similar. This arrangement is the so-called *ring modulator*, which acts as though it were a reversing switch; to explain its operation the transmission of one frequency will be considered. Imagine first that an 8-kc/s signal is applied to the centre-taps of the two transformers at P and Q, at such a level as to drive the rectifiers hard. During the positive half-cycles, i.e., when P is positive with respect to Q, rectifiers A and B are conducting and rectifiers C and D are kept at high impedance by the reverse voltage across them. There is thus a conducting path between points W and X, and between points Y and Z. During the negative half-cycles, rectifiers C and D conduct and the paths through rectifiers A and B are closed; there is therefore now a conducting path between points W and Z, and between points Y and X. This arrangement of rectifiers, in

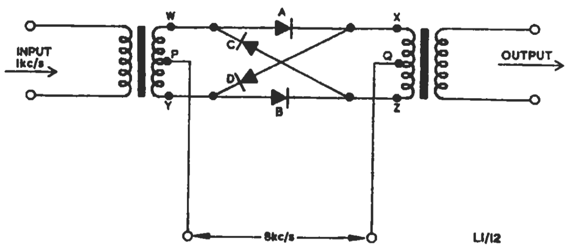


Fig. 2.1. Principle of Ring Modulator

conjunction with the 8-kc/s driving signal, thus acts as a reversing switch which changes the polarity of the connection between the two transformers 16,000 times per second. Since the 8-kc/s signal is applied to the centre-taps of the two transformers, it divides equally in the two halves of each winding; the resultant induced voltage in the outer windings is thus zero, and no 8-kc/s current appears either in the input or in the output.

Now suppose a 1-kc/s signal at low level, say −10 dB, is fed into the left-hand transformer. From what has been said above it is clear that the waveform at the output from the modulator will be as shown in Fig. 2.2, because of the reversing action of the 8-kc/s signal. It can be shown that the output contains sum and difference first-order side frequencies of (8 + 1) and (8 − 1) kc/s, i.e., 9 and 7 kc/s. Many other frequencies also appear, but these are higher order side frequencies which are not useful for the transmission of the intelligence and are in any event filtered out before transmission. It is in fact necessary to transmit only one of the first-order side frequencies; in this example suppose the lower one, 7 kc/s, to be the one transmitted. At the receiving end a similar arrangement of rectifiers is used with a carrier supply of 8 kc/s, and in this case the two main side frequencies produced are (8 + 7) kc/s and (8 − 7) kc/s, i.e., 15 kc/s and 1 kc/s. The former is of no interest and is removed by a filter; thus 1 kc/s, the frequency required to be transmitted, is left at the output.

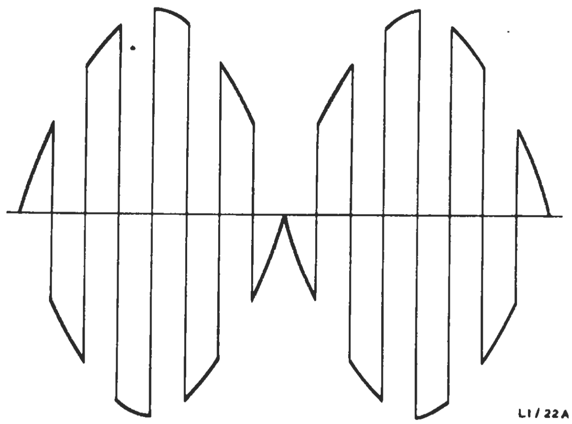


Fig. 2.2. Ring Modulator: 8-kc/s Carrier Modulated by 1-kc/s Signal

If, instead of the 1-kc/s input signal imagined, a signal containing speech frequencies in the range 50–2,300 c/s is applied to the modulator, the side frequencies are replaced by complete sidebands containing all the speech frequencies applied. Filters are used to select one of the first-order sidebands, which is then transmitted. At the receiving end, the demodulating process is similar in principle to that already described.

2.4 2-wire and 4-wire Working

At its point of connection to a telephone or a PBX switchboard, every circuit consists of two wires upon which transmission takes place in both directions simultaneously, and is therefore known as a *2-wire circuit*. Modern long-distance circuits, however, almost invariably use one channel for transmission in each direction; such a channel may consist of a pair of wires or it may even be a radio channel, in which event no wires at all are involved, but the complete two-way path is always known as a *4-wire circuit*, because the principle is the same as if two pairs of wires were being used, one in each direction.

The two channels must obviously be combined at their ends to enable two-way conversation to take place between telephones or switchboards, and this is done by a bridge network, usually called a *4-wire terminating set*. The latter is realised in practice either by a three-winding transformer called a *hybrid coil*, or by two transformers interconnected in a special way as in Fig. 2.

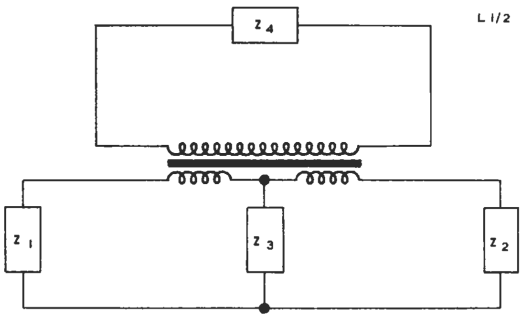


Fig. 2.3. Principle of the Hybrid Coil

The theory of the hybrid coil is given in Appendix A. The application of the coil to convert from 2-wire to 4-wire working is illustrated in principle in Fig. 2.3. Assume that one pair of the 4-wire circuit, say the incoming channel, is represented by the impedance Z_1 and the other, the outgoing channel, by Z_2. Z_4 is the 2-wire extension to the local switchboard, and Z_3 is a balancing impedance which is made as nearly as possible equal to the impedance Z_4 viewed through one half of the split winding. Z_1, Z_2 and Z_4 would ordinarily have the standard value of 600 ohms. It is explained in Appendix A that if the above impedance conditions are fulfilled there is no power transfer between Z_1 and Z_2, nor between Z_3 and Z_4.

Fig. 2.4 indicates the application of the hybrid coil to a practical 4-wire circuit. This diagram shows that the possibility exists of an oscillatory condition being set up. There is a closed loop containing amplifiers, and if the gain round that loop fails to meet certain criteria, oscillation will occur. Starting from amplifier C, the closed loop comprises amplifiers C and D, that part of the output of amplifier D that is transferred via the 4-wire terminating set T to the input of amplifier A, amplifiers A and B and that part of the output of amplifier B that is transferred via the 4-wire terminating set T′ to the input of amplifier C. The transfer of power from the output of amplifier D to the input of amplifier A depends upon the degree of balance between Z_3 and Z_4; the degree of balance between Z_3' and Z_4' affects the amount of power transferred from the output of amplifier B to the input of amplifier C.

Consider now a signal supplied from the two-wire side from the source impedance Z_4. If Z_1 equals Z_2, there is no transfer of power to Z_3, and so it divides equally between Z_1 and Z_2. The power dissipated in Z_2 is the only useful power, which means that half the power from the 2-wire source is wasted. There is, therefore, a loss of at least 3 dB in passing from the 2-wire side to the 4-wire side and, taking into account transformer losses, a more practical figure is 4 dB. At the other termination there is again a division of power in the impedances Z_3' and Z_4', so that there is another 4 dB loss in

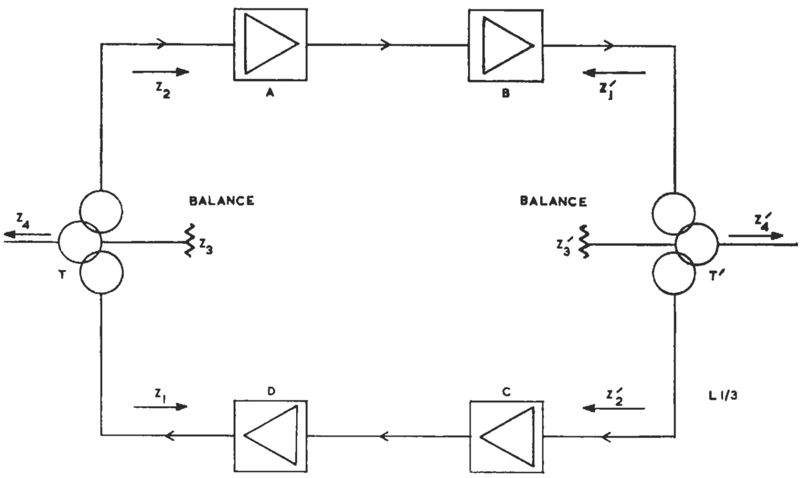


Fig. 2.4. Principle of 4-wire Telephone Circuit

transferring from the 4-wire side to the 2-wire side.

Though the balance between Z_3 and Z_4 and between Z_3' and Z_4' is never perfect, it is always good enough to give a stable 4-wire circuit which has only 3 dB loss between the 2-wire ends. A more detailed discussion is given in Appendix A.

2.5 Telegraph Channels

The telegraph channels in the BBC carrier systems are used for the transmission of teleprinter signals consisting of reversals of d.c. voltage. These reversals are converted into pulses of a carrier frequency, and the principle of the process is discussed in Instruction L.6. It will be sufficient to observe here that when the teleprinter is not actually transmitting signals, a steady tone at the telegraph carrier frequency, 2,600 c/s, is sent on the channel from the telegraph terminal equipment.

SECTION 3

GENERAL DESCRIPTION OF THE BBC MULTI-CHANNEL TELEPHONE CARRIER COMMUNICATION SYSTEM

3.1 Introduction

The practical design of the BBC Multi-channel Telephone Carrier Communication System was first outlined in Lines Department Report No. 51.5 issued in 1946. A summary of the final design appeared in Designs Department Description No. 24 issued in 1950. This Section is based on the information supplied in those reports, supplemented and modified where necessary to bring it up to date.

The terminals of each 1 + 2 or 1 + 3 system are installed at BBC studio centres (mainly the Regional Headquarters), and the systems work on programme circuits having a useful bandwidth of about 50–8,000 c/s or 50–11,500 c/s. If the upper frequency of 11,500 c/s is not quite attained, it may not be possible to operate a fourth teleprinter channel.

Telephone channels of 2,000 c/s bandwidth, using frequencies from 300 c/s to 2,300 c/s, are satisfactory for commercial quality telephone channels provided the overall loss on any one channel does not greatly exceed 15 dB. The BBC Carrier System has been designed on this basis and consists basically of a 1 + 2 system (one channel operated at voice frequency and two carrier channels), to which a further bay of equipment can later be added to give a fourth channel. Each telephone channel on such a system would have a bandwidth of 2,300 c/s with an overall loss of 3 dB between the 2-wire terminals, if no telegraph channels were derived in the system. One telegraph channel, however, can be derived from each telephone channel, and this reduces the bandwidth of the telephone channel to 2,000 c/s. The telegraph channels each have a bandwidth of 120 c/s, which is wider than the minimum band necessary for teleprinter working, but provides a good margin of safety when a number of channels in different systems are connected in tandem, and allows for the possibility of working at a higher speed than the standard 66 words per minute of the teleprinter. The overall loss on the voice-frequency path of the telegraph channels is 0 dB.

3.2 Layout of Equipment

The terminal equipment is mounted on a number of apparatus bays, though the bays may not always be fully equipped. For convenience, the equipment on the Telegraph Bay CTB/1 is included here, since it is nearly always, although it need not necessarily be, associated with the carrier system. The equipment on this bay is discussed in Instruction L.6.

3.2.1 Carrier Bay CCB/1

Front of bay

- 2 Channel Sets CHS/2, each comprising:
  - 1 Filter F/27
  - 1 Amplifier GPA/3
  - 1 Ring Modulator MR/2
  - 1 Ring Modulator MR/3
  - 1 Trap-valve Amplifier TV/23
- 1 Channel Set CHS/1, comprising:
  - 3 Amplifiers GPA/3
  - 1 Trap-valve Amplifier TV/23
- 1 Attenuator Panel AT/24
- 1 Key Panel KP/1
- 2 Splitting Filter Panels FSP/1
- A Mains Unit MU/51A
- 2 U-link strips D66290 on 4½-in. panel to drawing LA 560
- 1 Jackfield JF/101

Rear of Bay

- 3 Splitting Filter Panels FSP/2
- 2 Mains Distribution Panels MDP/1
- 3 Connection Strips No. 23A
- 1 Jack Mounting JM/11

3.2.2 Telegraph Bay CTB/1

Front of Bay

- 3 Telegraph Converters TGC/5
- 1 D.C. Jackfield containing miscellaneous jacks and equipment
- 1 A.C. Jackfield containing seven JF/1As
- 2 Telegraph Converters TGC/5
- 2 Mains Units MU/51A

Rear of Bay
- 3 Telegraph Converters TGC/5
- 1 Mains Distribution Panel MDP/2 (No. 2)
- 2 Telegraph Converters TGC/5
- 1 Mains Distribution Panel MDP/2 (No. 1)
- 3 Connection Strips, 1 No. 41A and 2 No. 23A

3.2.3 Miscellaneous Bay CMB/1

Front of Bay
- 1 Carrier Oscillator Unit COU/1C
- 1 Carrier Oscillator Unit COU/1B
- 1 Carrier Oscillator Unit COU/1A
- 1 Voice-frequency Oscillator OS2/1
- 1 Key Panel KP/8
- 3 Jackfields JF/1A
- 1 Mains Unit MU/29
- 1 Mains Unit MU/51A

Rear of Bay
- 2 Telephone Units TLU/1
- 2 Mains Distribution Panels MDP/1A
- 3 Connection Strips No. 23A

3.2.4 Fourth Channel Bay CFCB/1

Front of Bay
- 1 Carrier Oscillator Unit COU/1D
- 4 Channel Sets CHS/2, each comprising:
  - 1 Filter F/27
  - 1 Amplifier GPA/3
  - 1 Ring Modulator MR/2
  - 1 Ring Modulator MR/3
  - 1 Trap-valve Amplifier TV/23
- 1 Attenuator Panel AT/23
- 4 U-link Panels D66290 (Mark 1) mounted on two Fish Plates (DC 2007 detail 1)
- 1 Jackfield JF/101
- 1 Splitting Filter Panel FSP/4
- 2 Mains Units MU/16H

Rear of Bay
- 3 Splitting Filter Panels FSP/4
- 1 Jack Mounting JM/11
- 2 Mains Distribution Panels MDP/3
- 3 Connection Strips No. 23A

3.3 Frequency Allocation

3.3.1 Telephone Channels

The frequency allocation for the three telephone channels is approximately as follows:

Telephone Channel	*Method of Transmission*	*Band Occupied c/s*	*Carrier Frequency c/s*
1	audio	50 to 2,730	—
2	carrier	2,900 to 5,300	5,600
3	carrier	5,700 to 8,000	5,400

The table shows that the second channel uses the lower sideband of the higher carrier frequency, 5,600 c/s, and the third channel uses the upper sideband of the lower carrier frequency, 5,400 c/s. This arrangement was adopted to economise in the frequency space taken up by the individual channels and hence by the system; it means that neither of the carrier channels transmits frequencies below about 250 c/s, but fortunately these do not contribute to speech intelligibility.

For a fourth channel, the frequency band extends from about 8,300 c/s up to about 11,500 c/s, or lower, where the frequency characteristic of the line sets an upper limit. The carrier frequency is 8,000 c/s and the upper sideband is transmitted.

Specimen loss frequency characteristics of the channels are shown in Figs. 3.1 and 3.2, the overall loss of each channel being 3 dB.

3.3.2 Telegraph Channels

A telegraph channel may be derived from any one of the telephone channels and the method of doing so is the same for all channels; teleprinter signals are converted into bursts of 2,600-c/s tone by a so-called *static relay* in the way described in Instruction L.6 and passed over a 120-c/s channel derived from the 2,300-c/s bandwidth telephone channel.

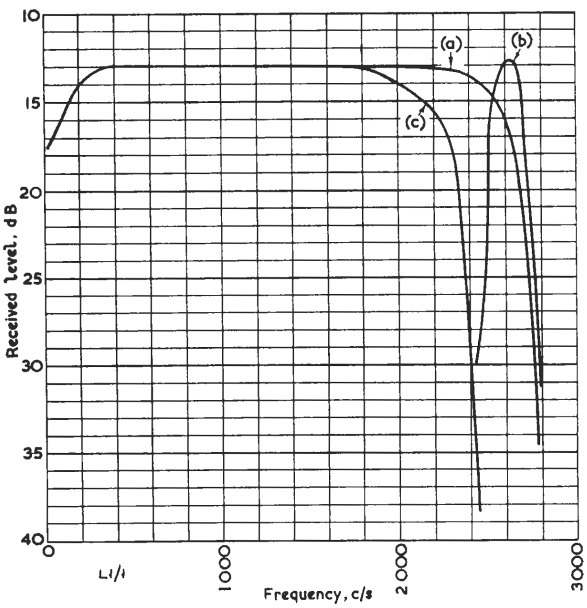


Fig. 3.1. Frequency Characteristic of Channel 1 (Audio Channel)

(a) Telephone Channel, (b) Telegraph Channel, and (c) Telephone Channel when Telegraph Channel is Derived

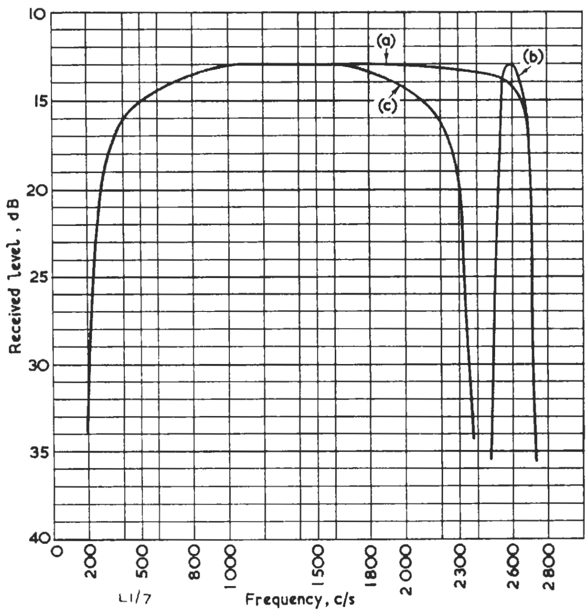


Fig. 3.2. Frequency Characteristic of a Carrier Channel

(a) Telephone Channel, (b) Telegraph Channel, and (c) Telephone Channel when Telegraph Channel is Derived

On the line, the telegraph frequencies of the various teleprinter channels are as follows:

Teleprinter Channel	*Telegraph Frequency*
1	2,600 c/s
2	3,000 c/s
3	8,000 c/s
4	10,600 c/s

When no teleprinter signals are being sent, the tongue of the teleprinter transmitter contact set rests on *mark* and in this condition a steady tone is sent to line, the *space* condition being characterised by no tone on the line or channel. This method is adopted to allow automatic gain control to be used and so that when no signals are passing the presence of tone may enable a continuous watch to be kept on the channel; its continued absence gives warning of an abnormal condition.

3.4 Description of Operation (Fig. 1)

Fig. 1 shows, in block form, the interconnections between apparatus at one terminal of the BBC Carrier System. The normal operating levels of tone for the telegraph channels and the levels of test tone for the speech channels are also shown. The level of test tone at the sending point has been chosen to be −10 dB to avoid any limiting effect by the limiters in the 4-wire terminating sets.

3.4.1 Telephone Channel 1

From left to right the circuit starts at the *2-W. App.* U-link of channel 1, where test tone would normally be sent at a level of −10 dB. The test tone passes through the hybrid coil in the 4-wire terminating set FWTR/2A to the *Go* circuit, on which it starts at a level of —14 dB. If a telegraph channel is fitted it passes on to the low-pass filter LP3 of the telegraph splitting filter panel FSP/2 via a 5-dB attenuator. LP3 limits the speech band to an upper frequency of 2,300 c/s and the tone then passes on at a level of —19·5 dB to the splitting filter panel FSP/1A. If a telegraph circuit is not derived, the filter panel FSP/2 is not fitted, but a 5·5-dB attenuator is connected instead to preserve the correct level. The filter LP1 then sets an upper limit to the outgoing speech band. A 19·5-dB (nominal) attenuator reduces the level of the hypothetical test tone to —39·5 dB at the output from the filter LP1.

If no fourth channel is fitted the test tone then passes through the *Send* amplifier to line at a level of —12 dB, but if a fourth channel is fitted the test tone passes through the make contacts A1 and A2 of relay A to the splitting panel filter FSP/4, and from thence through the *Send* amplifier to line at the standard —12 dB level. Contacts A1 and A2 serve to switch the line equipment either to programme sending apparatus or to the output of filter panel FSP/1A. In either condition channel 4 is preserved as a PBX or engineering-control circuit.

The operation of the *Return* path may be understood by reference to the lower part of Fig. 1. Test tone arrives from line at a level of —12 dB and passes via a repeating-coil (since all the filters are unbalanced with respect to earth) to the splitting filter panel FSP/4 if fitted. The only possible path for the frequencies present in channel 1 speech is through LP5 and make contacts A3 and A4 (relay A being operated) to the receiving side of the splitting filter panel FSP/1B. From LP1 the test tone goes on through a fixed 7·5-dB (nominal) attenuator within the filter panel and an external 5-dB (nominal) attenuator to the input to the channel amplifier, the gain of which is set at 30 dB. Next in the chain comes the telegraph splitting filter, if there is a telegraph channel, and then the test tone enters the *Return* side of the 4-wire terminating set at a level of —9 dB. Owing to the losses in the terminating set this level is further reduced to —13 dB at the 2-wire side, and since the test level at the sending end was —10 dB, the overall loss is therefore 3 dB. As at the sending end of the channel, if no telegraph channel is derived, the splitting filter panel FSP/2 will not be fitted, and a 5·5-dB (nominal) attenuator will be fitted instead.

3.4.2 Telephone Channel 2

This channel is a carrier channel operating on a carrier frequency of 5,600 c/s, speech being transmitted on the lower sideband only. The speech path is similar to that of the first channel up to the output of the telegraph splitting filter panel FSP/2, but then the hypothetical test tone passes via a 5-dB attenuator into the modulator MR/2, which is driven by a carrier frequency of 5,600 c/s fed from the output of an amplifier TV/23. The resultant sidebands pass through a 9-dB attenuator in the splitting filter panel FSP/1A, first to the low-pass filter LP2 and then to the high-pass filter HP1, which between them allow only the lower sideband to pass. The rest of the path to line is the same as for channel 1.

At the receiving end, channel 2 test tone takes the same path as channel 1 as far as the junction of filters LP1 and HP1 in the splitting filter panel FSP/1B. The tone can only pass through HP1 and LP2 and thence via a 2-dB (nominal) attenuator and an external 5-dB (nominal) attenuator to the demodulator MR/3; this, like the modulator at the sending end, is driven by a carrier frequency of 5,600 c/s. Two sidebands are of course produced, the upper of which is removed by the low-pass filter LP4, and the original test tone is then passed to the input of the 30-dB channel amplifier. From the output of this amplifier, the path of the channel-2 test tone, and the levels at the different points in the circuit, are similar.

3.4.3 Telephone Channel 3

This circuit is a carrier channel operating on a carrier frequency of 5,400 c/s, speech being transmitted on the upper sideband only. The speech path at the sending end is similar to that of the second channel up to the input to the splitting filter panel FSP/1A, where it enters filter HP2 instead of LP2. Filter HP2 removes the lower sideband, and at the output of HP2 the upper sideband joins channel 2; at the output of filter HP1 channels 2 and 3 join channel 1 and follow the same path as channel 1 to line.

At the receiving end, the upper sideband is accepted by filter LP5 (if the fourth channel is fitted) and by filter HP2; the sideband is thus guided into the terminal equipment peculiar to channel 3 which, after HP2, is precisely similar to that in channel 2.

3.4.4 Telephone Channel 4

Frequency space on the line is set apart for channel 4 by the addition of a supplementary splitting filter panel FSP/4, the circuit position of which lies between the common line equipment (send amplifier, receiving repeating-coil and variable attenuator) and the basic 3-channel carrier system. Filters HP4 and LP5, which are contained within the splitting filter panel FSP/4, divide the available frequency range on the line into a broad band carrying either the three lower channels or a programme channel, and a narrower band carrying the fourth channel. Low-pass filter LP6 limits the upper end of the desired upper sideband so as to minimise the risk of sending out frequencies which might disturb Post Office circuits.

Normally the need for a fourth telegraph channel does not arise, and the *Go* side of the 4-wire terminating set of the fourth channel therefore leads direct to the modulator MR/2, which is driven by a carrier of 8,000 c/s. The upper sideband is accepted by filters LP6 and HP4 and passes to the send amplifier together with the frequency bands from the other three channels. At the receiving end filters HP4 and LP6 in the splitting filter panel FSP/4 accept the incoming upper sideband and pass it on at the correct level to the demodulator MR/3, after which the path is precisely similar to that of channels 2 and 3 without telegraph splitting filters.

3.4.5 Telegraph Channels

Fig. 1 shows telegraph channels derived from telephone channels 1, 2 and 3. Each telegraph channel is derived in exactly the same way. A 2,600-c/s audio-frequency tone from an oscillator COU/1A is fed to a static relay operating in the way described in Instruction L.6. When the teleprinter is sending a *mark* signal (—80 volts applied to line), the static relay passes 2,600 c/s out through the high-pass filter HP3, the cut-off frequency of which is 2,500 c/s; when the teleprinter is sending a *space* signal (+80 volts applied to line), the static relay suppresses the 2,600-c/s tone. The two filters LP3 and HP3 serve to combine the telephone and telegraph channels and, at the receiving end, to separate them out again. The nature of the teleprinter signals transmitted on these channels is discussed in Instruction L.6.

SECTION 4

4-WIRE TERMINATING AND RINGING SETS

4.1 4-wire Terminating and Ringing Set FWTR/2A (Fig. 2)

It was explained in Section 2.4 that the transition from 2-wire to 4-wire working at the end of a 4-wire circuit was effected by a hybrid coil or 4-wire terminating set, and Fig. 2 shows the circuit of the FWTR/2A 4-wire Terminating and Ringing Set currently used with the BBC carrier systems.

The design of this set includes certain calling and supervisory facilities which, however, have not yet been brought into operation pending the settlement by Designs Department of certain outstanding circuit problems. These facilities would be provided by the relay L shown in the circuit diagram, but as they are not in operation the relay is immobilised and the *Go* side of the 4-wire circuit is connected to terminals 7 and 8 of the set.

The transformer used as a hybrid coil is the P.O. No. 149H coil, which in fact consists of two transformer assemblies mounted on a common plate and connected to give the facilities of a hybrid coil. This results in all four circuits connected to the set being balanced and of the same impedance, i.e., 600 ohms. All windings of each coil are equal and in series aiding connection from the odd-numbered to the even-numbered tag.

Consider a voice-frequency current arriving from the 4-wire circuit at terminals 11 and 12. Let this current be assumed to pass through the windings of the lower transformer in the sense 1—2, 3—4. Electromotive forces will be induced in the other windings in the sense 12—11, 10—9, 8—7, 6—5, and currents will flow in the PBX circuit via terminals 1 and 2 and in the 600-ohm balancing network R5. These two currents, however, flow in the opposite senses through the windings of the upper transformer, the one in the sense 12—11, 10—9, i.e., from even to odd, and the other in the sense 5—6, 7—8, i.e., from odd to even. When these two currents are equal (i.e., when the impedance presented by PBX is equal to the balancing network R5), no e.m.f. is induced in the windings of the upper transformer, and consequently no current appears in the 4-wire *Go* side of the coil.

A similar argument to a voice-frequency current arriving from the PBX circuit. Such a current passes through the upper coil windings in, say, the sense 5—6, 7—8, and induces an e.m.f. in the windings 4—3, 2—1, which is the desired transmission path. The PBX current, however, also passes through windings 8—7, 6—5, of the lower coil and it further induces an e.m.f. in windings 12—11, 10—9, of the upper coil. This e.m.f. drives a current through windings 12—11, 10—9, of the lower coil and the balancing network R5, and the effect of this current is added to the effect of the current flowing in the windings 8—7, 6—5, of the lower coil to induce an electromotive force in the windings 1—2, 3—4, of the lower coil. Energy is thus transferred to the 4-wire return side, where it is of course ineffective and is lost. This loss of energy accounts for a 3-dB drop in level in passing from the 2-wire side of the hybrid coil to the 4-wire *Go* circuit; the addition of copper and iron losses in the coils makes the actual drop in level about 4 dB. The current flowing in windings 8—7, 6—5, of the lower coil induces an electromotive force in windings 9—10,11—12, of the same coil, which in turn drives a current through windings 9—10, 11—12, of the upper coil and the balancing network R5.

When the impedance of the *Go* circuit is equal to the impedance of the *Return* circuit (as seen by the 4-wire terminating set) the two currents fed to the balancing network R5 are equal and in opposite senses. The two currents therefore cancel one another and no signal reaches the balancing network R5 from PBX.

Capacitor C1 blocks the passage of direct current from the PBX cord circuit, and C2 balances C1 on the network side of the 4-wire terminating set; the balancing network, in fact, consists of C2 and R5.

To avoid overloading and crosstalk in the transmission path, it is desirable that the output to the 4-wire circuit should be limited, and this is done by two silicon junction diodes MR1 and MR2 bridged in opposite senses across the 4-wire *Go* side of the 4-wire terminating set. The limiting effect of these diodes is negligible at a level of −10 dB on the 2-wire side of the 4-wire terminating set, but is very pronounced at levels of zero and higher. It is for this reason that test tone should be sent at −10 dB on the 2-wire side.

4.2 4-wire Terminating and Ringing Set FWTR/2 (Fig. 3)

In some of the first carrier systems to be installed, an earlier form of 4-wire Terminating and Ringing Set, the FWTR/2, was used. Like the FWTR/2A, this set was also designed to give certain calling and supervisory facilities which are not yet in use. The circuit of the unit, which is entirely similar in principle to that of the FWTR/2A, is shown in Fig. 3.

In this version of the 4-wire terminating set the hybrid coil is the BBC Type LL/126RA, which is a single coil; consequently, R5, the balancing network resistance, is 300 ohms instead of 600 ohms. Limiting is effected on the 2-wire side by a Thyrite element driven through a step-up transformer TR1, bridged across the 2-wire terminals 1 and 2 of the hybrid coil.

SECTION 5

FILTERS

5.1 Splitting Filter Panels FSP/1A and FSP/1B (Fig. 4)

Splitting filter panel FSP/1A is used on the *Go* side and panel FSP/1B on the *Return* side of the system. Each panel contains four filters comprising two pairs made up of one low-pass and one high-pass filter. The first filter pair, LP1 and HP1, forms the boundary in the frequency range between channel 1 and all channels above, while the second pair, LP2 and HP2, forms the boundary between channel 2 and channel 3 (together with channel 4 if fitted). The frequency characteristics of these filters, in terms of insertion-loss between 600-ohm terminating resistors, are tabulated below. Fig. 4 shows the circuit and gives the design data.

The tabulated figures represent the average of a number of tests and include the insertion-loss of the repeating-coils shown in Fig. 4.

5.2 Splitting Filter Panel FSP/2 (Fig. 5)

Splitting filter panel FSP/2 contains four filters, two on the *Go* side and two on the *Return* side, arranged in pairs of low- and high-pass filters designated LP3 and HP3 respectively. These filters split any desired channel, on the voice-frequency side, into telephone and telegraph channels. The insertion-loss/frequency characteristics of the filters are tabulated on page 5.2. Fig. 5 shows the circuit of the panel and gives the design data.

FILTERS FOR PANEL FSP/1A OR FSP/1B: FREQUENCY CHARACTERISTICS

LP1		*LP2*		*HP1*		*HP2*	
Freq. c/s	*Loss dB*	*Freq. c/s*	*Loss dB*	*Freq. c/s*	*Loss dB*	*Freq. c/s*	*Loss dB*
50	1·0	50	1·2	50	66·5	500	68
1,000	0·8	1,000	1·7	1,000	57	1,000	67·5
2,730	10·0	2,200	0·8	1,500	57	3,000	80
3,000	66	4,500	0·8	2,000	75	4,500	70
4,000	75	5,400	14·2	2,860	8	5,100	72
8,000	72	5,600	54·5	3,600	0·8	5,400	58
10,000	72	6,000	67	5,000	0·7	5,600	11·5
		8,000	77·5	7,000	0·5	6,500	0·6
		10,000	62	10,000	0·5	8,000	0·5
						10,000	0·5

FILTERS FOR PANEL FSP/2: FREQUENCY CHARACTERISTICS

LP3		*HP3 (with LP section)*		*HP3 (without LP section)*	
Freq. c/s	*Loss dB*	*Freq. c/s*	*Loss dB*	*Freq. c/s*	*Loss dB*
50	1·2	500	77	500	66
1,000	0·5	1,200	58	1,200	50
2,370	13	1,500	57	1,400	47
2,600	70	2,000	56·5	2,000	48
3,000	58·5	2,300	46	2,300	42
4,000	39	2,500	7	2,500	9·5
8,000	45	2,600	2·5	2,600	1·3
10,000	47	3,000	3·3	3,000	0·7
		4,000	7·5	4,000	0·5
		6,000	18·5	6,000	0·5
		7,000	23	7,000	0·5

The tabulated figures represent the average of a number of tests and include the insertion-loss of the repeating-coils shown in Fig. 5.

A prototype low-pass section with a cut-off frequency of 3,000 c/s is included in one of the HP3 filters on each FSP/2 panel. This filter is on the sending side in the telegraph channel, and the purpose of the low-pass section is to set an upper limit to the telegraph frequency band, so as to suppress harmonics of 2,600 c/s which would otherwise go out to line on the top channel of the system. (On lower channels, other filters would suppress these harmonics, but it has been found convenient to make all FSP/2 panels identical.)

5.3 Splitting Filter Panel FSP/4 (Fig. 6)

The FSP/4 contains six filters, three on the *Go* side and three on the *Return*. HP4 and LP6 together form a band-pass filter accepting the fourth channel and eliminating all frequencies on either side of it; LP5, with HP4, forms the boundary in the frequency spectrum between channel 4 and all lower channels. The insertion-loss/frequency characteristics of these filters are tabulated on page 5.3. Fig. 6 shows the panel circuit and gives the design data.

FILTERS FOR PANEL FSP/4:
FREQUENCY CHARACTERISTICS

LP5		*HP4 + LP6*	
Freq. c/s	*Loss dB*	*Freq. c/s*	*Loss dB*
50	<2·5	1,000	>80
1,000	<1·9	8,000	>60
6,000	<2·0	8,200	>35
7,000	<3·0	8,300	10·5 ± 2
7,800	<4·0	8,400	< 5·7
8,000	<5·5	9,000	< 2·7
8,100	<11·0	10,500	< 2·3
8,130	>10·0	11,000	5·3 ± 1
8,200	>27·5	12,000	>20
8,250	>40·0		

These figures represent the worst performance expected from the filters and include the insertion-loss of the repeating-coils shown in Fig. 6.

5.4 Demodulator Filter LP4 (Fig. 5.1)
This filter, the cut-off frequency of which is 3,000 c/s, follows the demodulators MR/3 (Fig. 5.1); its function is to eliminate the upper sideband and any other unwanted high-frequency terms appearing at the output of the demodulator. The insertion-loss/frequency characteristic of the filter, representing the average of a number of tests, is given in the table in the opposite column.

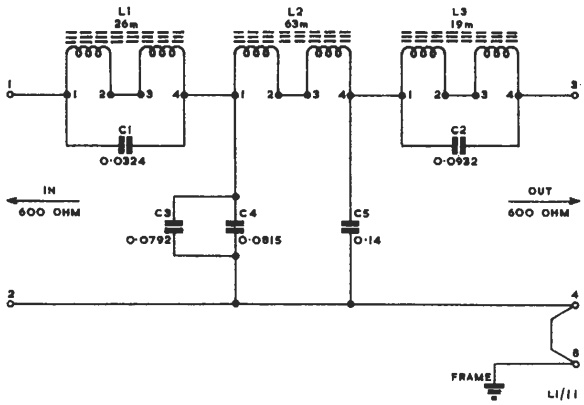


Fig. 5.1. Demodulator Filter LP4: Circuit

FILTER LP4: FREQUENCY CHARACTERISTIC

Frequency c/s	*Insertion Loss dB*
50	0·3
1,000	0·2
2,000	0·5
3,000	4·5
3,800	50
5,400	51
6,000	51
8,000	43
10,000	44

SECTION 6

MODULATORS MR/2 AND MR/3

6.1 Introduction

The function of the modulators in the carrier system has been explained in Section 2.3, and they appear in practical form in the units MR/2 and MR/3. The former serves as modulator and the latter as demodulator; the difference between them is that the modulator MR/2 has a 600-ohm 5-dB pad at the input, to ensure the correct level into the unit, and a variable potential divider for minimising the carrier leak.

The components of each unit are mounted on a small sub-chassis which in turn is mounted on a 9-inch panel designated Channel Set CHS/2, which also carries the low-pass filter LP4 described in Section 5.4.

The circuit of the MR/3 is similar except for the two features described above.

Tone at carrier frequency obtained from a Carrier Oscillator Unit COU/1 is fed through a Trap Valve Amplifier TV/23 to the MR/2 and MR/3 in parallel, and applied to the switching rectifiers via the centre-points of the two transformers T1 and T2. The carrier supply must be of sufficient amplitude to cause the appropriate pair of rectifiers to conduct readily during each half-cycle. A 5-ohm resistor is connected in series between the carrier supply and the mid-point of a transformer; the voltage level across this resistor may be measured by an amplifier-detector and when it is $-10{\cdot}5 \pm 1$ dB the carrier current will be satisfactory. The carrier currents in the MR/2 and MR/3 are equalised by connecting a resistor between terminal 5 of the appropriate unit and terminal 5 on the CHS/2 panel block.

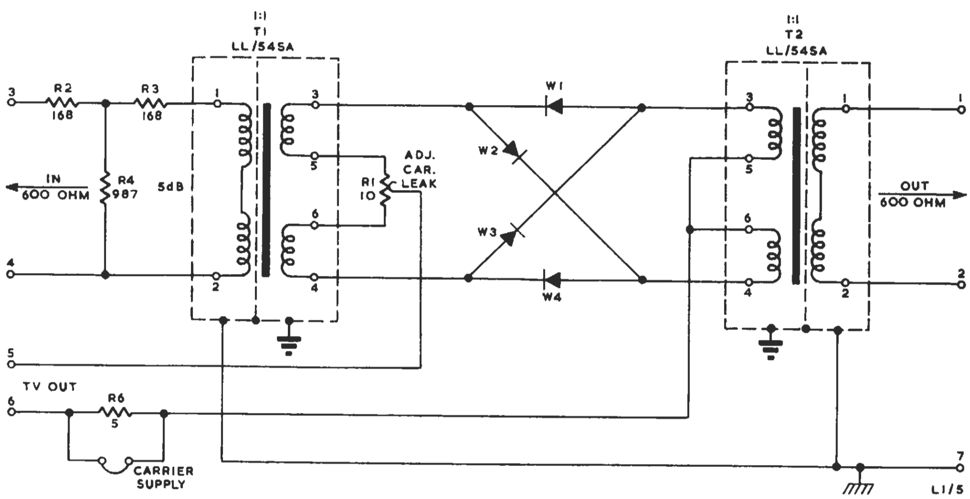


Fig. 6.1. Modulator MR/2: Circuit

6.2 Circuit Description (Figs. 6.1 and 6.2)

Fig. 6.1 shows the circuit of the modulator MR/2 and Fig. 6.2 that of the demodulator MR/3. In Fig. 6.1, the rectifiers are connected between transformers T1 and T2, both of which have a turns ratio of 1 : 1. T1 has a potential divider R1 connected between the two halves of the secondary winding and the carrier current is fed into the transformer through the movable contact, which is adjusted to give minimum carrier leak back into the circuit towards the talking subscriber; any of the carrier frequencies used would of course be easily audible.

With the MR/2, two sidebands and a partially suppressed carrier are found at the output; with the MR/3 there are also two sidebands and a

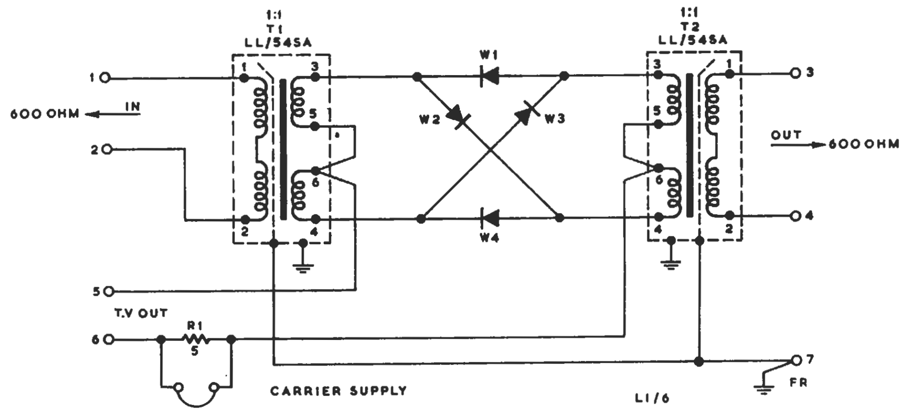


Fig. 6.2. Demodulator MR/3: Circuit

partially suppressed carrier, but the filter LP4 removes all but the lower sideband, which is the desired speech band.

6.3 Layout of Components

The components of each unit are mounted on a sub-chassis measuring $1\frac{3}{4}$ by $7\frac{7}{16}$ inches. The rectifiers are carried on a small detachable plastic holder, which is plugged into a 5-pin valve-holder on the sub-chassis.

6.4 Selection of Rectifiers

It is essential that the rectifiers should be carefully selected in pairs so as to achieve as good a balance as possible and thus reduce the carrier leak to a minimum. Selection of rectifiers is made by measuring the d.c. potential drop across each rectifier for two different values of direct current, 0·5 mA and 10 mA; the p.d. across each rectifier in a set of four must match to within say 2 per cent at both values of current.

6.5 Input and Output Impedance

Input and output impedance depends on the state of the switching action due to the carrier at any particular instant. This means that, as the two units are nearly always preceded and followed by filters the performance of which depends on their being correctly terminated, it is essential to buffer the filters from the modulators or demodulators by 600-ohm loss-pads of at least 5 dB attenuation where the specified filter performance is required. The positions of these loss-pads are shown in Fig. 1.

SECTION 7

AMPLIFIERS

7.1 Introduction

The amplifiers TV/23 and GPA/3, described in this Section, are both single-stage units, each using an EF50 valve. Each amplifier is mounted on a sub-chassis measuring $7\frac{7}{16}$ by $3\frac{17}{32}$ inches, designed for fixing to a General Purpose Mounting GPM/1. To simplify manufacture, the same component values are used on both amplifiers where possible.

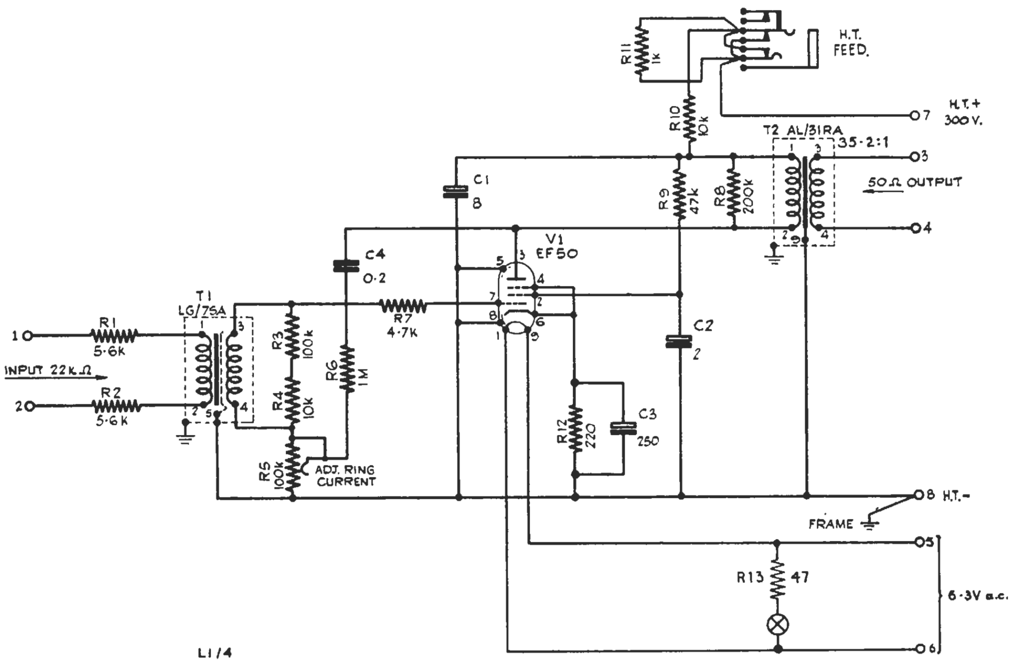


Fig. 7.1. Trap Valve Amplifier TV/23: Circuit

means of the resistors R1 and R2 in series with the primary winding of the input transformer T1. (Fig. 7.1.) R3 and R4 give the correct loading on the secondary winding. R7 is the usual anti-squegger resistor in the grid-circuit; C1, C2, C3, R9 and R10 are the decoupling components, the cathode resistor R12 giving the correct value of control-grid bias voltage. A negative feedback path is provided by C4, R6 and the variable resistor R5; the feed-back fraction, and hence the gain, can be adjusted by R5. This control, labelled *Adj. Ring Current*, enables the carrier level to the modulator and demodulator of the channel to be set to the correct value. (See 6.4.) R8 provides an additional resistive load for the valve to protect it in the event of accidental disconnection of the modulator and demodulator. R11, which is normally short-circuited by the contacts of the *H. T. Feed* jack, enables a measurement of anode current to be made with a milliammeter plugged into the jack.

7.2 Trap Valve Amplifier TV/23 (Fig. 7.1)

7.2.1 Description of Operation

This amplifier is used on channels 2, 3 and 4 of the carrier system and acts as a buffer stage between the carrier oscillator unit COU/1 and the channel modulators and demodulators MR/2 and MR/3, as shown in Fig. 1.

The input impedance is 22 kilohms and the output impedance 50 ohms, the output circuit being designed to deliver a current of 45 mA into a 50-ohm load.

The 22-kilohm input impedance is obtained by

7.2.2 Summary of Operating Conditions

(*a*) *General*

Anode current, 6·5 mA.
Filament voltage, 6·3 volts.
H.T. supply, 300 volts.

(*b*) *Impedances*

Input impedance, 22 kilohms at 1 kc/s.
Output impedance, 50 ohms at 1 kc/s.

(*c*) *1-kc/s Gain*

With the input shunted by 600 ohms, the output terminated in 50 ohms, the input level at −15 dB and the *Adj. Ring Current* control at maximum, the gain should be 15 dB.

(*d*) *Frequency Response*

With the *Adj. Ring Current* control at maximum, the frequency response should be flat within ±1·5 dB between 250 c/s and 10 kc/s.

(*e*) *Harmonic Content*

Less than 3 per cent at 1 kc/s with maximum gain and −15 dB input level.

(*f*) *Noise Level*

The signal-to-noise ratio should be greater than 55 dB for zero-level output.

7.3 Amplifier GPA/3 (Fig. 7.2)

7.3.1 Description of Operation

This single-stage amplifier is used in the carrier communication system at two positions; these are (1) at the sending end of the system between the common point of FSP/1A (or FSP/4 in a 4-channel system) and the outgoing line, and (2) at the receiving end in the return path of each channel. In the former position it is designated *Send Amplifier* and in the latter *Channel Amplifier*. The positions of these amplifiers can be seen in Fig. 1. For both purposes the working gain is fixed at 30 dB.

The circuit of the GPA/3 is shown in Fig. 6.2. In this R6 acts as a gain trimmer with limits of ±2 dB, and if a gain lower than 30 dB is required, a 600-ohm attenuator R1, R2, R3, R4, of the appropriate value can be fitted between the input terminals 1, 2 and the input transformer T1.

Cathode injection feedback is provided by returning the cathode circuit to earth via a feedback winding 5—7 on the output transformer T2. The secondary of this transformer is built out to 600 ohms output impedance by the series resistors R14 and R15.

C1, C2, C3, R9 and R10 are normal decoupling components, and the total h.t. feed can be read directly on a milliammeter plugged into the *H.T. Feed* jack, the feed resistor R11 being shorted out

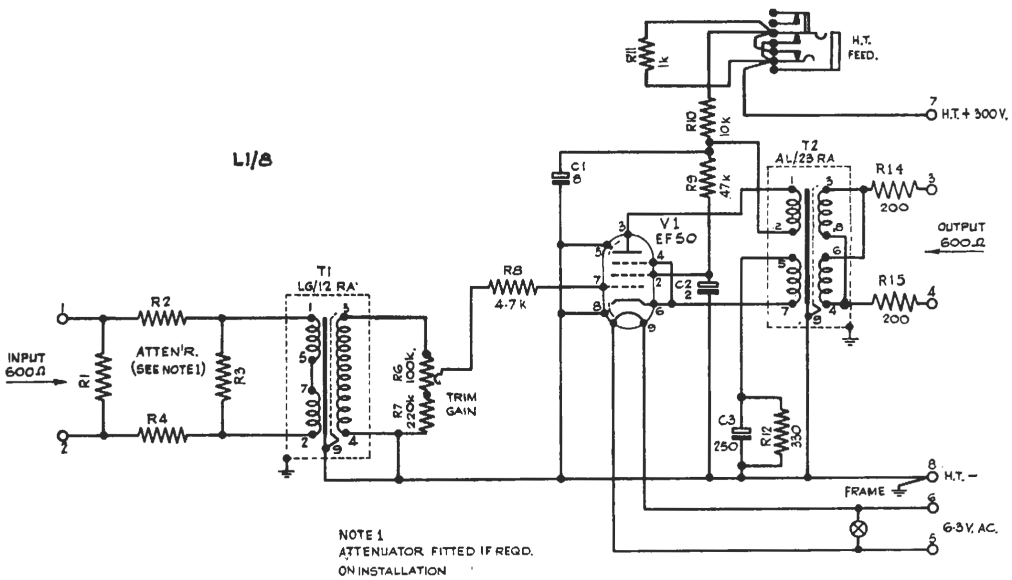


Fig. 7.2. General Purpose Amplifier GPA/3: Circuit

by the jack contacts when there is no plug in the jack.

7.3.2 Summary of Operating Conditions

(*a*) *General*

Anode current, 5·5 mA.
Screen current, 1·5 mA.
Filament voltage, 6·3 volts.
H.T. supply, 300 volts.
Input and Output Impedances, both 600 ohms.

(*b*) *1-kc/s Gain*

With the *Trim Gain* control set at maximum, the gain measured between 600-ohm terminating resistances should be 30 ±1 dB.

(*c*) *Frequency Response*

Flat to within ±1 dB from 50 c/s to 10 kc/s.

(*d*) *Harmonic Content at 1 kc/s*

At +10 dB output level, less than 0·5 per cent.
At +20 dB output level, less than 3 per cent.

SECTION 8

ATTENUATOR PANEL AT/23

This variable-attenuator panel consists of four separate but similar attenuators (Fig. 8.1). Each of the attenuators can be varied in steps of 0·5 dB from zero to 15·5 dB by the manipulation of U-links.

The other three attenuators, designated Channel Attenuators, precede the receiving channel equipment peculiar to each channel and are used to adjust the overall loss of the channel.

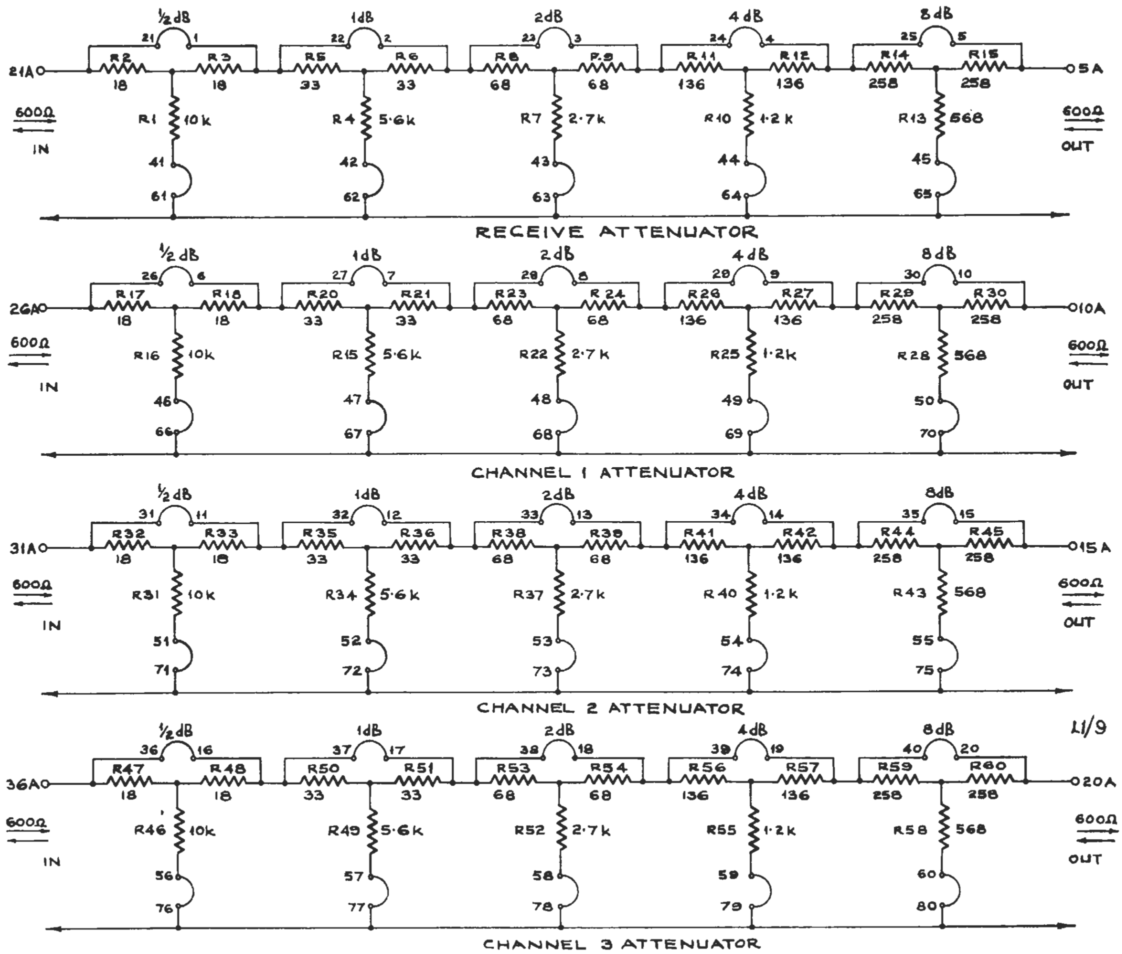


Fig. 8.1. Attenuator AT/23: Circuit

The attenuators are symmetrical and unbalanced with an impedance of 600 ohms. The component resistors are mounted on the back of a 4½-inch U-link panel provided with a dust cover.

One attenuator, designated the Receive Attenuator, follows the receive-line amplifier and is used for compensating small changes in the gain or loss of the line and line-terminating equipment.

The panel contains four rows of U-link sockets. To select the required value of attenuation, the U-links are placed in the lower two rows; when all the U-links are in the upper two rows the attenuation is zero. The attenuators in channels 2 and 3 act as buffers between the filters and demodulators (see Fig. 1), and the loss should therefore not be reduced below 5 dB, which in fact is the normal setting for all the attenuators.

SECTION 9

CARRIER OSCILLATORS: COU/1 SERIES

9.1 Introduction

The various Carrier Oscillator Units in the COU/1 series are used to drive the modulators and demodulators in the carrier telephone channels and to supply voice-frequency telegraph current for the telegraph channels. All the oscillator units have the same basic design but employ different operating frequencies to suit their application and are coded as follows:

Code	*Frequency c/s*	*Application*
COU/1A	2,600	telegraph channel
COU/1B	5,400	telephone channel 3
COU/1C	5,600	telephone channel 2
COU/1D	8,000	telephone channel 4

Each unit comprises two similar oscillators, a normal and a spare; if the normal oscillator fails, the spare is switched into circuit immediately and automatically. Both oscillators are mounted on a standard 22⅛-inch by 6¾-inch panel; the A, B and C units are installed on the Miscellaneous Bay CMB/1, and the D unit, which of course is required only when there is a fourth channel, is mounted on the Fourth-channel Bay (see Section 3).

9.2 Circuit Description (Fig. 9.1)

Fig. 9.1 shows the circuit of one of the oscillators of the unit; the circuits of both are identical except that the change-over contacts of the relay in the spare oscillator are not wired, since they are not needed. The oscillator is a Wien-bridge-controlled type, the theory of which will be found in Instruction S.4 Appendix 9.1. Briefly, the oscillator consists of a two-stage amplifier V1, V2, over both stages of which positive feedback is applied through the Wien bridge R1, C1, R2, C2, C13, C14, R6,

L1/10

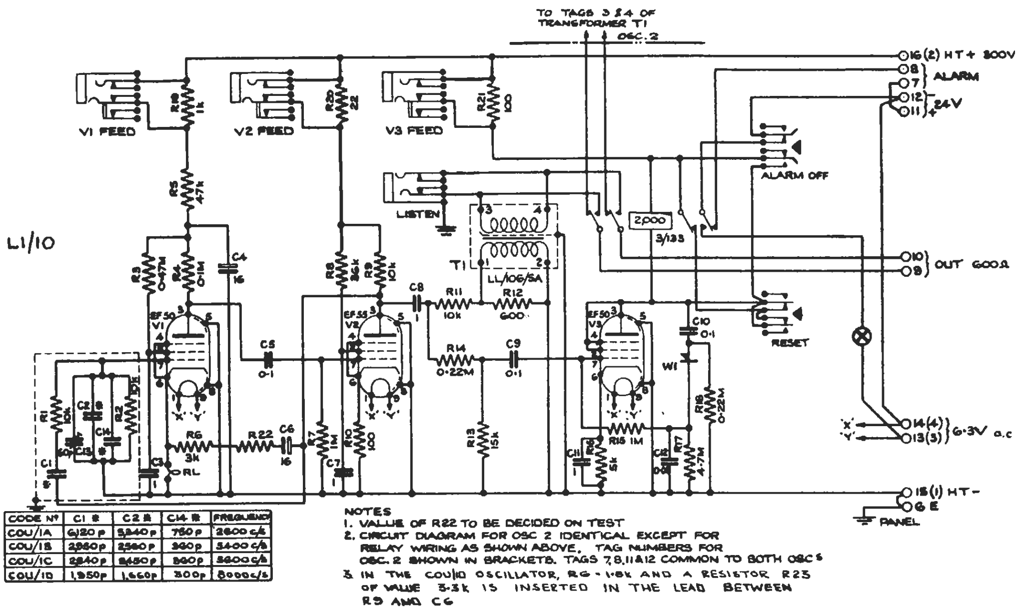


Fig. 9.1. Carrier Oscillator COU/1: Circuit

R22, C6 and the varistor lamp RL. The phase-shift and loss introduced by this network vary as the frequency varies; oscillation occurs at the frequency at which the phase-shift is zero, provided the amplifier gain at this frequency is at least equal to the loss in the network.

The network is in the form of a detachable assembly, the components being selected to give the required frequency; fine adjustments are made by the variable capacitor C13. Compensation for frequency-drift with varying temperature is provided by the shunt capacitors, which contain a proportion of capacitance with negative temperature coefficient.

The output level is stabilised by using a varistor lamp RL in one arm of the bridge, in the position shown. The resistance of this lamp increases with the current passing through it, and is arranged to have a value, under operating conditions, rather less than that required to balance the bridge. If the output level rises, the resistance of the lamp RL will also rise and will therefore bring the bridge more nearly into balance, with the result that there will be less voltage applied to the grid of the valve V1. The value of resistor R22 is adjusted on test to suit the lamp; if the lamp is changed, the value of R22 may have to also be changed.

The output is taken from a potential divider R11, R12, through the 1 : 1 transformer T1 to the output terminals via relay contacts; a listen jack is connected across the secondary of the transformer T1.

The valve V3 controls the relay which switches the spare oscillator into circuit should the normal one fail. The valve is used as a triode and operates as an anode-bend detector, biased nearly to cut-off; the grid is fed from the anode of V2 and the output from V3 is rectified and applied to its own grid as a positive d.c. signal, thus opposing the standing negative bias on the valve. When the oscillator is functioning normally, therefore, the anode current of V3 is high enough to energise the relay, the make contacts of which complete the oscillator output circuit.

If the output from V2 falls, the positive bias on the grid of V3 also falls, and with it the anode current of V3, so that the relay is de-energised. The release of the relay in the normal oscillator causes

1. the output terminals of the unit to be switched from the faulty oscillator to the reserve;
2. the pilot lamp on the faulty oscillator to go out;
3. an alarm buzzer to sound.

An *Alarm Off* key is provided to prevent the buzzer from sounding continuously after the alarm has been given, and when the faulty oscillator again functions normally, it may be put back into service by depressing the *Re-set* button and thus removing a short-circuit across the relay winding. The *Alarm Off* key should be released before the *Re-set* button is operated.

If the reserve oscillator should fail, its relay will become de-energised causing the alarm buzzer to sound; the pilot lamp goes out but the output circuit is not transferred to the normal oscillator until the *Re-set* button of the latter has been operated.

9.3 General Data

Output impedance, 600 ohms ±10 per cent.
Output level, zero ±1 dB into 600-ohm load.
Frequency stability, within 1·5 c/s of nominal value.
Harmonic content, 1 per cent.

Valve	*Type*	*Total Feed mA*	*Condition*
V1	EF50	0·8—1·5	—
V2	EF55	22—30	—
V3	EF50	1·0—2·0 8·0—12·0	not operated operated

L.T. supply, 6·3 volts, 3·2 amps.
H.T. supply, 300 volts.

The values of the capacitors in the Wien bridge are as follows:

(a) Frequency 2,600 c/s: 6,120 pF
(b) Frequency 5,400 c/s: 2,950 pF
(c) Frequency 5,600 c/s: 2,840 pF
(d) Frequency 8,000 c/s: 1,950 pF

These values are the same for both series and shunt *RC* arms of the network; the series arm is a single-unit capacitor but the shunt arm is made up of a number of capacitors to give a proper proportion of positive and negative temperature coefficient components and to facilitate adjustment. If for any reason it becomes necessary to change the value of the capacitance, proper attention must be paid to temperature compensation, and Communications Department will give guidance if re-adjustments should be necessary.

9.4 Adjustment of Level and Waveform

R6 should first be adjusted if necessary so that the alternating current flowing in it is 6 ±0·5 mA. The waveform should then be examined for purity and the total harmonic content should not exceed −40 dB, although it should not be less than −50 dB because oscillation might then be unstable. If the waveform is found unsatisfactory during these tests a new varistor lamp should be inserted and the rest of the circuit checked. The lamp used for setting up the oscillator in this manner should be left associated with that particular oscillator. The output level should now be checked; it should be zero ±1 dB into a 600-ohm load.

9.5 Adjustment of Frequency

The frequency of the oscillator must be adjusted to within 1 c/s of the nominal frequency. This is achieved by the small adjustable capacitor C13 in the Wien bridge circuit. After the unit has been switched on for five hours the frequency should again be checked; a small re-adjustment will probably be found to be necessary.

9.6 Frequency Stability

Frequency stability is checked by observing the change of frequency which occurs when the temperature of the unit rises by about 10 degrees C (50 degrees F). The change due to such a temperature variation must not exceed a total of ±1·5 c/s. In practice this test may be made simply by comparing the frequency at the time of switching on from cold with that five hours later when the unit has thoroughly warmed up. Thorough warming up may be helped by covering the dust covers to provide thermal lagging.

A change of ±10 per cent in supply voltage from the nominal value must not change the frequency by more than $\pm\frac{1}{2}$ c/s.

J.H.H. 1/65

APPENDIX A

THEORY OF HYBRID COIL

Return Loss

A simplified circuit incorporating a hybrid coil is shown in Fig. A.1. It will first be assumed that the following equalities hold: $ab=bc$; $Z_1=Z_2$; $Z_3=\frac{1}{2}Z_1$.

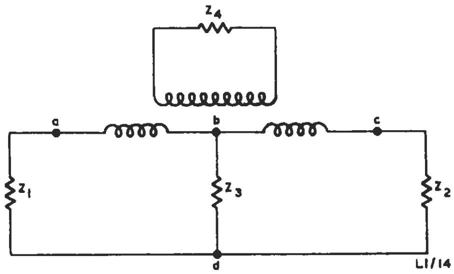


Fig. A.1.

Let the turns ratio be such that the impedance Z_4, viewed through either *ab* or *bc* is $Z_3=\frac{1}{2}Z_1$.

Under these conditions, no transfer of power can take place between Z_1 and Z_2 nor between Z_3 and Z_4.

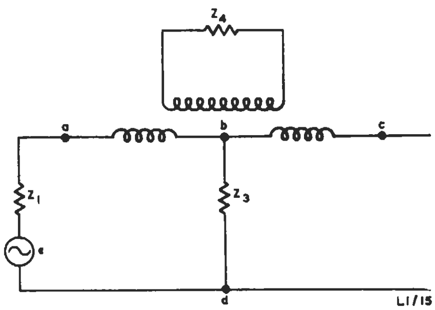


Fig. A.2.

Imagine an alternating e.m.f. to be in series with Z_1, and Z_2 to be disconnected (Fig. A.2). Then all the current due to this e.m.f. flows through Z_3, and, since $Z_{ab}=Z_3$, the voltage-drop across the points *ab* is equal to and in the same sense as that across the points *bd*, i.e.

$$V_{ab} = V_{bd} \qquad (1)$$

From transformer theory, the current through *ab* induces an e.m.f. in the winding *bc*, and, since $bc=ab$, the voltage across *bc* is equal both in magnitude and sense to that across *ab*. Thus

$$V_{cd} = V_{bd} - V_{bc} = 0 \qquad (2)$$

Since the points *c* and *d* are at equal potential, no current can flow between them, whatever impedance may be connected across them. Thus, while there is a transfer of energy from Z_1 to Z_3 and Z_4, there is none from Z_1 to Z_2 and, because of the symmetry of the circuit, none can be transferred from Z_2 to Z_1.

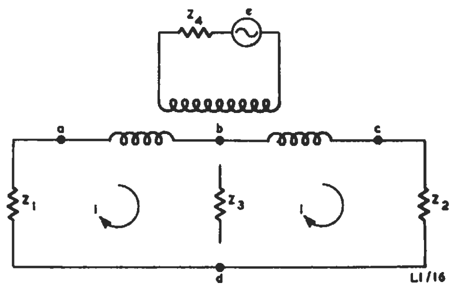


Fig. A.3.

Consider now an e.m.f. in series with Z_4 and let Z_3 be disconnected (Fig. A.3). A current *i* will flow through the equal impedances Z_1 and Z_2. The electrical mid-point of the generator of this current is *b*, while that of the load is *d*. There is thus no p.d. between points *b* and *d*, whether Z_3 is connected or not, and no power can be transferred from Z_4 to Z_3.

Conversely, an e.m.f. in series with Z_3 produces no e.m.f. in the third winding (Z_4). This is because the two halves of the winding *abc* are equal and wound in series aiding. The currents in the two half windings will thus be equal and opposite and no flux is induced in the core.

Let it now be supposed that Z_4 comprises the output circuit of an amplifier A1 (Fig. A.4). Z_1 and Z_2 represent a line L and a network N simulating its impedance, respectively; Z_3 represents the input impedance of a second amplifier A2.

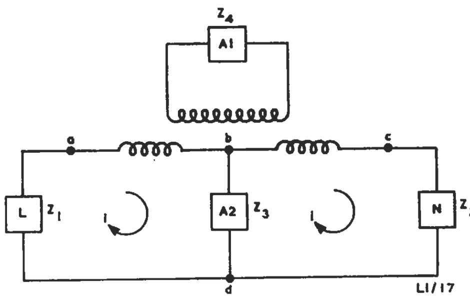


Fig. A.4.

Assuming $Z_1 = Z_2$, the currents i in Z_1 and Z_2 will be equal, and there is no p.d. across Z_3. Under such conditions, power supplied from the amplifier A1 will be divided equally between the line L and simulating network N. The amplifier A2 will have no potential across its input terminals and will therefore give no output.

It must now be shown what proportion of power will be transferred to A2 when line and network have *unequal* impedances (Fig. A.5).

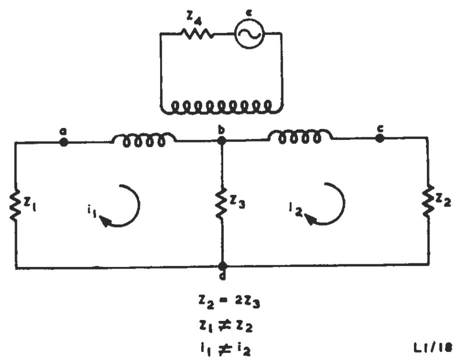


Fig. A.5.

Let it be assumed that Z_1 differs from Z_2 by an amount Z' where $Z' = Z_1 - Z_2$ (Fig. A.6). Let the currents in the two halves of the circuit be i_1, i_2. Then the current in Z_3 will equal $i_1 - i_2$. If the impedance Z' were reduced to zero, the currents i_1, i_2 would be equal, as in Fig. A.4.

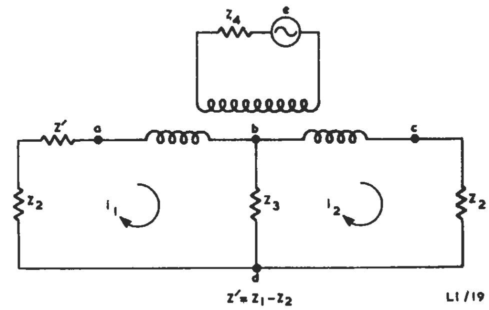


Fig. A.6.

By the Compensation Theorem, i_1 and i_2 could also be made equal by introducing a compensating e.m.f. e' in series with Z' (Fig. A.7). The magnitude and phase of e' must be such that it will produce a current equal in value but opposite in phase to the change in current produced by Z', i.e.

$$e' = -iZ' \qquad (3)$$

Given this condition, both i_1 and i_2 will be restored to their former value i.

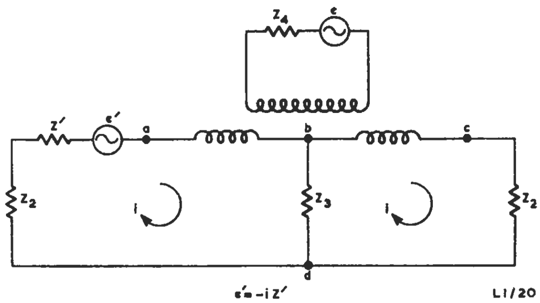


Fig. A.7.

If the e.m.f. in series with Z_4 now be suppressed (Fig. A.8), the magnitude of the current change introduced by Z' can be ascertained by considering the current i_3 which remains, due to the retention in the circuit of e'.

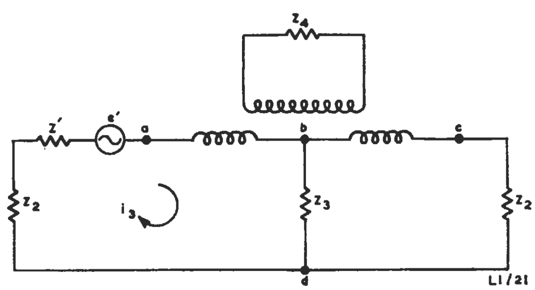


Fig. A.8.

As previously shown in (2), there will be no current in Z_2 because the points c and d are now at equal potential. This indicates that the impedance change, Z', produces no change in the current through Z_2.

The current i_3, due to e', flows in the left-hand branch of the circuit only and must therefore be equal in magnitude and opposite in phase to the current produced in Z_3 by the impedance change represented by Z'. Its value may be given as

$$i_3 = \frac{e'}{Z_2+Z'+Z_{ab}+Z_3} \qquad (4)$$

Since $Z_{ab}=Z_3=Z_2/2$ and $e' = -iZ'$, the unbalance current i' due to $Z' = -i_3$. Thus

$$i' = -i_3 = \frac{iZ'}{Z_2+Z'+Z_2/2+Z_2/2} \qquad (5)$$

But $Z' = Z_1 - Z_2$

$$\therefore\ i' = i\frac{Z_1-Z_2}{Z_2+(Z_1-Z_2)+2Z_2/2} \qquad (6)$$

$$= i\ \frac{Z_1 - Z_2}{Z_1 + Z_2} \qquad (7)$$

$$\text{and } \frac{i'}{i} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \qquad (8)$$

The current i' in the above equations may be regarded as the current returned from the line because the line impedance has deviated from its 'correct' value Z_2; thus in considering the transmission loss between the output of amplifier A1 (Fig. A.4) and the input of amplifier A2, there is a nominal loss of 3 dB in passing from the output of A1 to line, a fraction i'/i of the current sent to line is returned with a further loss of 20 $\log_{10}$ (i/i') dB and finally there is another nominal loss of 3 dB in the hybrid coil as the returned current passes into the input of amplifier A2. Iron and copper losses in the hybrid coil add roughly another 1 dB to this total, so that to a good approximation the loss across the hybrid coil, which is what determines the stability of the circuit, is given by

$$= 20 \log_{10} \frac{i}{i'} + 7 \text{ dB} \qquad (9)$$

$$= 20 \log_{10} \frac{Z_1 + Z_2}{Z_1 - Z_2} + 7 \text{ dB} \qquad (10)$$

Overall Loss in a 4-wire Circuit

Fig. A.9 shows in block form a 4-wire circuit with a number of intermediate repeaters and with hybrid coils or 4-wire terminating sets at the ends to convert to the 2-wire condition. The algebraic sum of the line losses and amplifier gains in each leg of the 4-wire part of the circuit is represented by G,

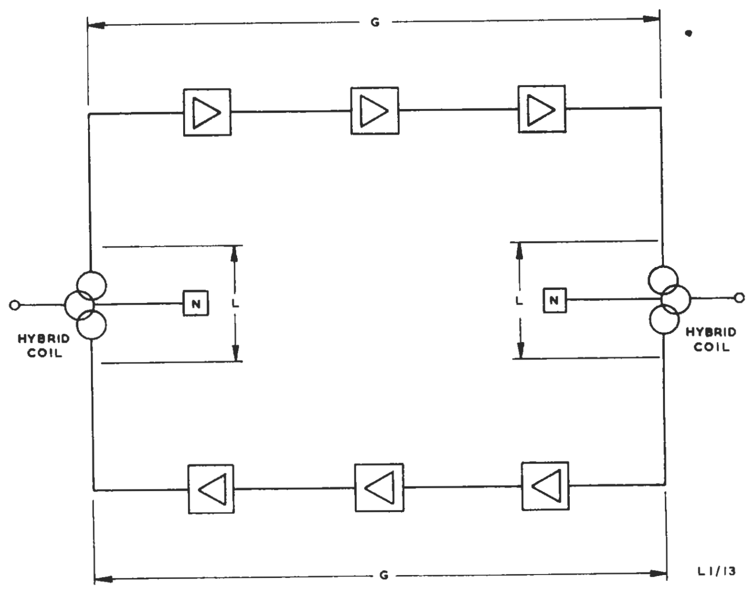


Fig. A.9. 4-wire Circuit with Intermediate Repeaters the loss across the 4-wire terminating set is L at each end and N, N are the networks intended to simulate the impedance of whatever circuit may be connected to the 2-wire ends of the main circuit. The networks N can only be very roughly designed, since a very great variety of local circuits may be connected to the trunk line; in most instances they consist of a 600-ohm resistor in series with 1 or 2 μF.

If the algebraic sum of the gains and losses round the 4-wire loop is positive, i.e., if there is more gain than loss, the whole circuit will oscillate and will be not only useless in itself, but liable to cause disturbance in neighbouring channels. It is important therefore that the 4-wire circuit shall be stable even when the conditions of maximum unbalance occur across the 4-wire terminating sets. Maximum unbalance occurs when the circuit is idle, i.e., unconnected, because in this condition there may be an open circuit at the 2-wire point of the 4-wire terminating set.

If this condition exists, equation (8) shows that the return loss, $20 \log_{10} (i/i')$ dB, is zero; consequently, the loss across the 4-wire terminating set from the output of the incoming line amplifier to the input of the outgoing line amplifier is only 7 dB, from equation (10). It follows therefore that the limit of stability is reached when

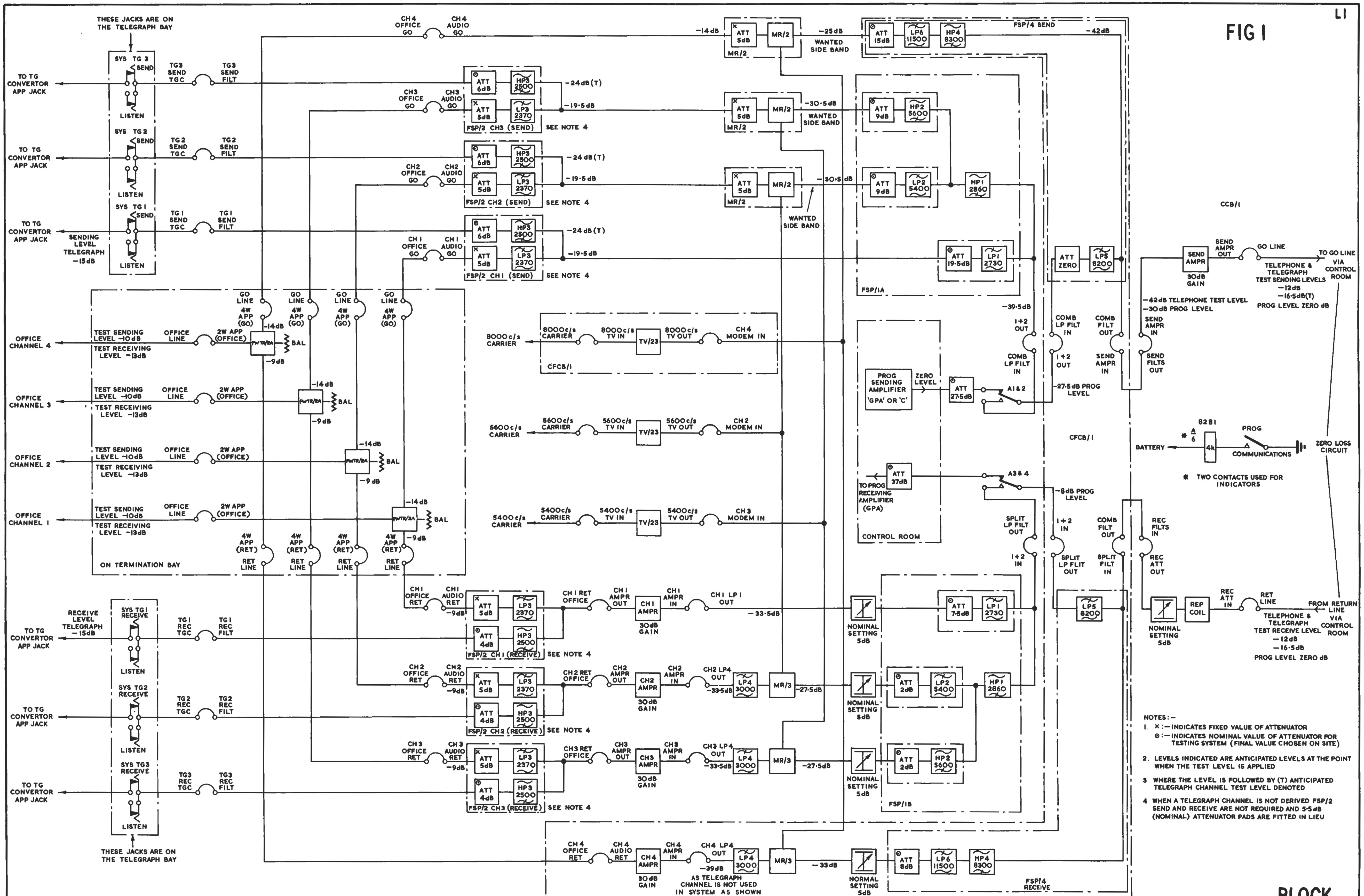
$$2G = 2L = 14 \text{ dB} \qquad (11)$$

This means that the overall gain in each leg of the 4-wire part of the circuit may not exceed 7 dB. This in turn leads to an overall loss, 2-wire to 2-wire, of zero, because the gain G in the 4-wire leg is exactly offset by the $3\frac{1}{2}$-dB loss in the passage of each 4-wire terminating set. In practice such circuits are not worked at zero overall loss because some margin must be left as a precaution against instability, and it is therefore customary to line them up to an overall loss of 3 dB.

60/WG/126/DJE
DK5890

L1

FIG 1



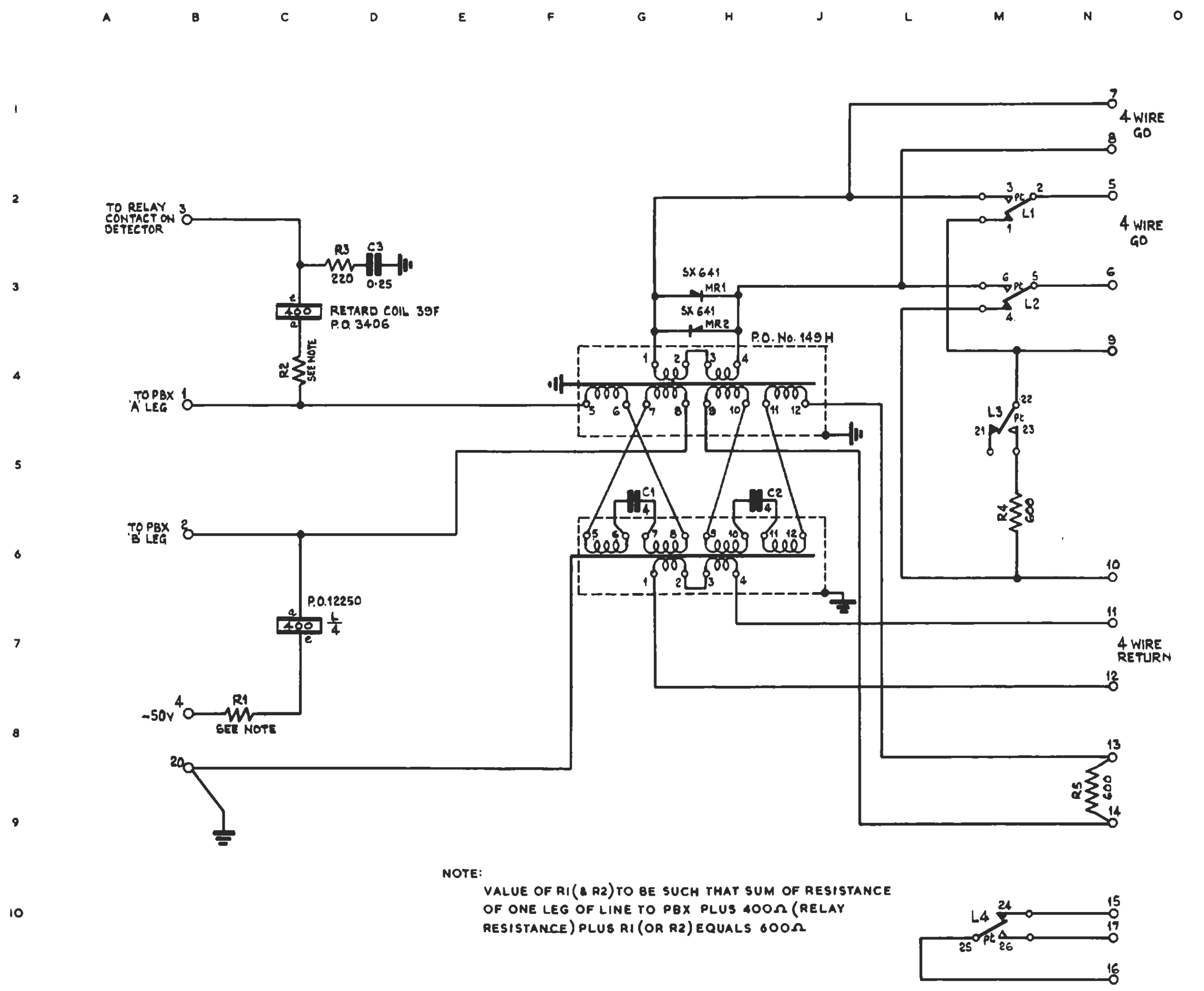
NOTES:–

1. X :– INDICATES FIXED VALUE OF ATTENUATOR
   ⊙ :– INDICATES NOMINAL VALUE OF ATTENUATOR FOR TESTING SYSTEM (FINAL VALUE CHOSEN ON SITE)
2. LEVELS INDICATED ARE ANTICIPATED LEVELS AT THE POINT WHEN THE TEST LEVEL IS APPLIED
3. WHERE THE LEVEL IS FOLLOWED BY (T) ANTICIPATED TELEGRAPH CHANNEL TEST LEVEL DENOTED
4. WHEN A TELEGRAPH CHANNEL IS NOT DERIVED FSP/2 SEND AND RECEIVE ARE NOT REQUIRED AND 5·5dB (NOMINAL) ATTENUATOR PADS ARE FITTED IN LIEU

B B C 1+3 CHANNEL CARRIER SYSTEM (OR 1 PROGRAMME + 1 TELEPHONE): BLOCK DIAGRAM

BLOCK DIAGRAM

64/JHH/128
EB 10170



4-WIRE TERMINATING AND RINGING SET FWTR/2A: CIRCUIT

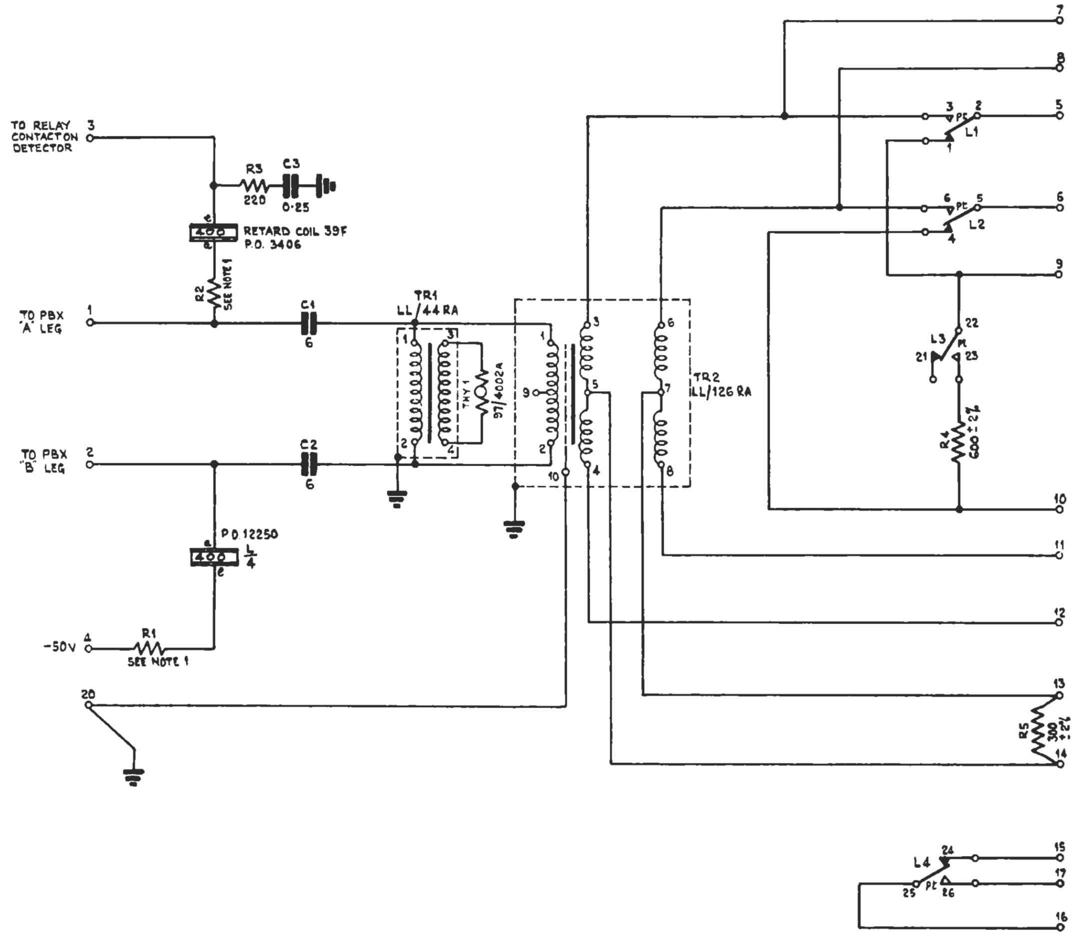
FIG 2

L1

64/JHH/123
DB 3110

L.1

FIG 3



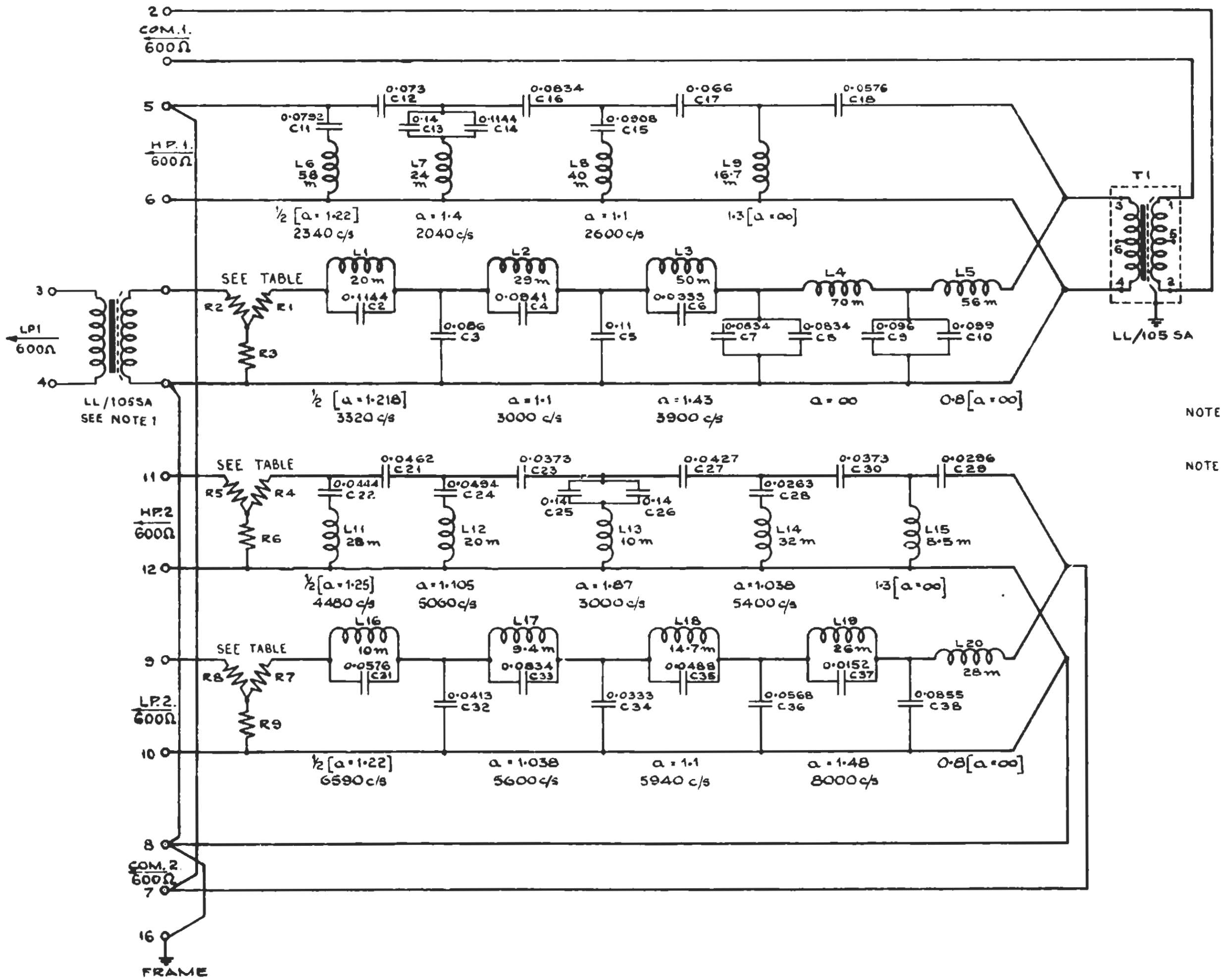
NOTE:-

1. VALUE OF R1 (& R2) TO BE SUCH THAT SUM OF RESISTANCE OF ONE LEG OF LINE TO PBX PLUS 400Ω (RELAY RESISTANCE) PLUS R1 (OR R2) EQUALS 600Ω

FOUR-WIRE TERMINATING & RINGING SET FWTR/2 : CIRCUIT

LOSS-PAD TABLE: FIG. 4

Unit	*Conditions*	*Loss*	*Resistors*	*Ohms*
FSP/1A	Telegraph Channel Derived	21·5 dB	R1, R2	507
			R3	102
		11 dB	R4, R5, R7, R8	336
			R6, R9	367
	Telegraph Channel NOT Derived	27 dB	R1, R2	546
			R3	56
		16·5 dB	R4, R5, R7, R8	434
			R6, R9	184
FSP/1B	Telegraph Channel Derived	10 dB	R1, R2	312
			R3	422
		5 dB	R4, R5, R7, R8	168
			R6, R9	988
	Telegraph Channel NOT Derived	15·5 dB	R1, R2	428
			R3	207
		10·5 dB	R4, R5, R7, R8	324
			R6, R9	393



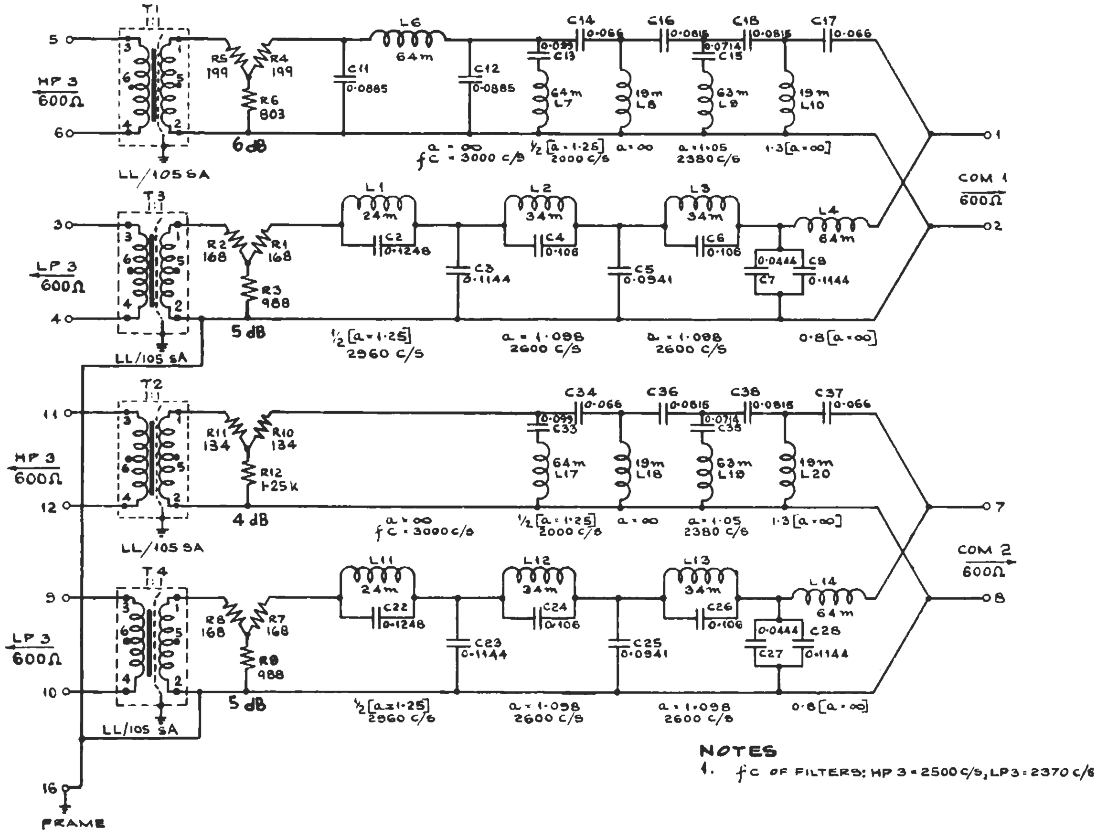
NOTE 1 :- T2 REQUIRED ONLY ON FSP/1A

NOTE 2 :- f_c OF FILTER :
HP1 = 2860 c/s
HP2 = 5600 c/s
LP1 = 2730 c/s
LP2 = 5400 c/s

FIG 4

SPLITTING FILTER PANELS FSP/IA & FSP/IB : CIRCUIT

LI



NOTES

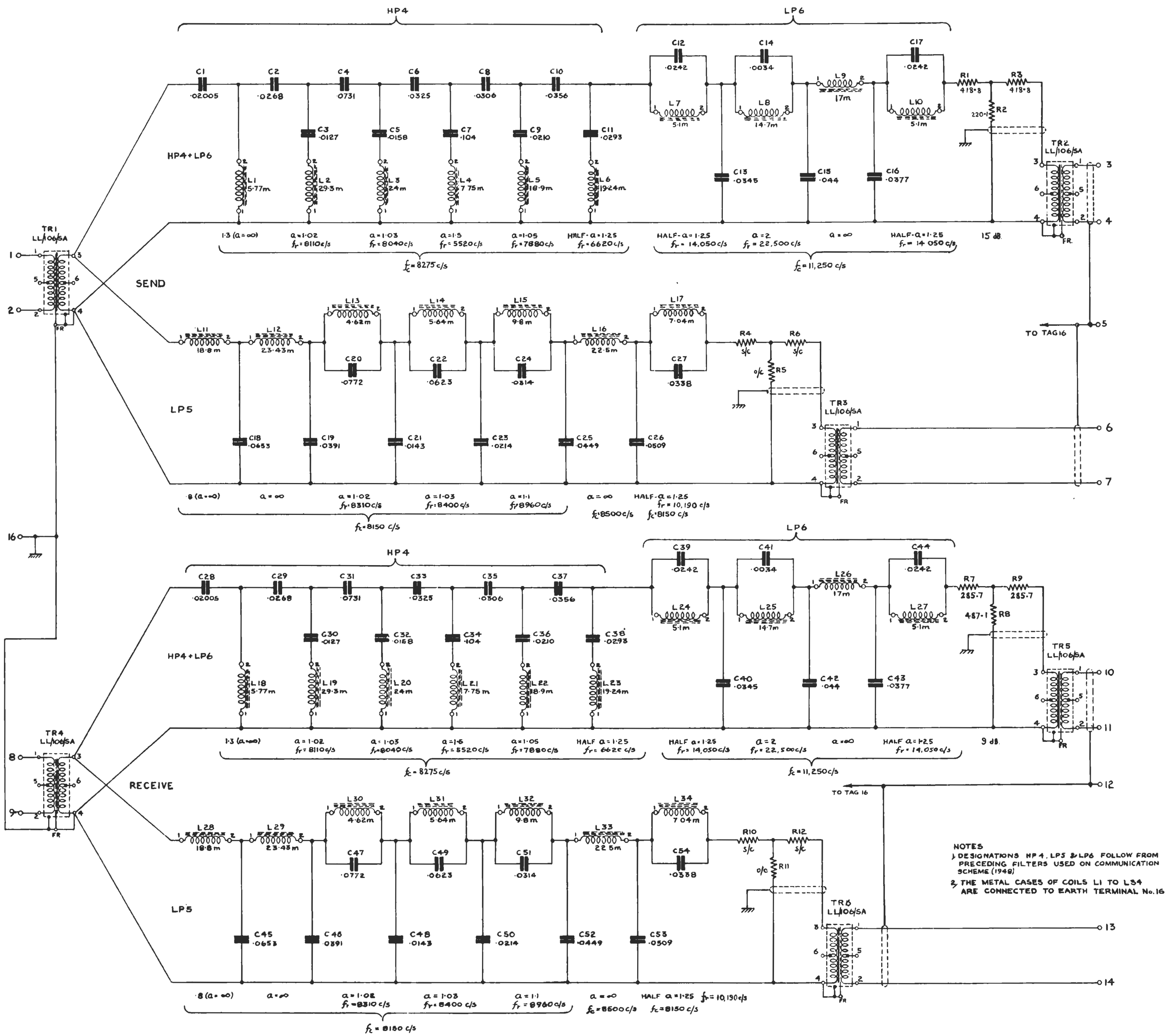
1. fc of filters: HP 3 = 2500 c/s, LP 3 = 2370 c/s

SPLITTING FILTER PANEL FSP/2 : CIRCUIT

FIG 5

L1

FIG 6



NOTES
1. DESIGNATIONS HP4, LP5 & LP6 FOLLOW FROM PRECEDING FILTERS USED ON COMMUNICATION SCHEME (1948)
2. THE METAL CASES OF COILS L1 TO L34 ARE CONNECTED TO EARTH TERMINAL No. 16

SPLITTING FILTER PANEL FSP/4 : CIRCUIT DIAGRAM