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EQUIPMENT COMPONENTS (1) - LINE TRANSMISSION

(PREVIOUSLY CP 206)

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1. INTRODUCTION.

1.1 We saw in the course paper 'Equipment Principles - Line Transmission' that line transmission equipment is composed of equipment components, such as filters, modulators, amplifiers, hybrid coils, etc., and that these are assembled on plug-in or panel type units which are interconnected to form the particular types of equipment required.

1.2 An equipment component is a network of electrical elements connected together in such a manner as to provide specific functions. Generally, these networks are classified into 'active' networks and 'passive' networks.

An *active network* is a network of electrical elements in which there is a source of electromotive force. For example, amplifiers and oscillators rely on a D.C. supply for their satisfactory operation.

A *passive network* is also a network of electrical elements, but these contain no source of electromotive force. For example, filters, equalisers and pads have no power supply connected to them.

The electrical elements employed in networks are resistors, capacitors, inductors, electron tubes, transistors, etc. The types of elements used in a particular network, and the method of connecting the elements, depends on the function of the network.

1.3 This paper describes the operation of hybrid coils, pads, attenuators, and filters, all of which are passive equipment components (or networks) employed in line transmission equipment. The operation of equalisers, pre-emphasis and de-emphasis networks, line building out networks, compandors, and voltage limiters, is explained in the paper 'Equipment Components (2) - Line Transmission'.

2. HYBRID COILS.

2.1 BASIC FUNCTIONS. A hybrid coil (sometimes called a hybrid transformer, or more simply a 'hybrid') enables equipment items to be connected in such a manner that transmission paths exist between certain of the items, and isolation exists between the others. This is shown diagramatically in Fig. 1, where the hybrid coil is represented by a square with connections to four equipment items A, B, C and D. The hybrid coil provides a transmission path for signals to pass between the items connected to the adjacent sides, but blocks the passage of signals between the items connected to the opposite sides. For example, signals can pass freely between A and B, B and C, C and D, and D and A, but A is isolated from C, and B is isolated from D.

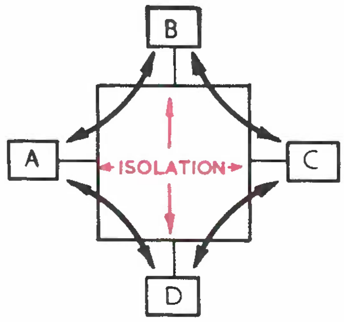


FIG. 1. BASIC FUNCTIONS OF A HYBRID COIL.

2.2 TRANSMISSION PATHS THROUGH A HYBRID COIL. Fig. 2 shows the transmission paths of a signal being injected from items A, B, C and D, in turn, through an ideal hybrid coil. In each case, the signal divides within the hybrid coil and is transmitted to the items connected to the two adjacent sides. None of the signal is transmitted to the equipment connected to the opposite side. For example, in Fig. 2a portion of the signal from A is transmitted to B, and portion to D, but none of the signal is transmitted to C, which is isolated from A.

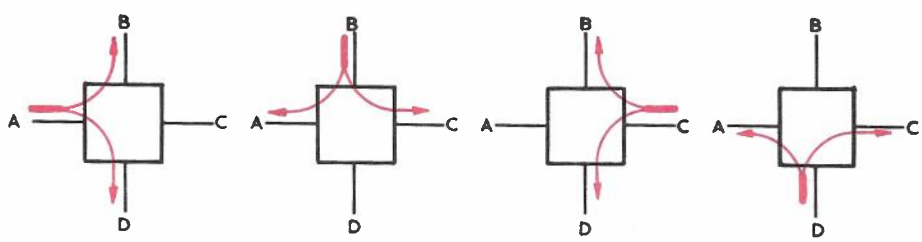


FIG. 2. TRANSMISSION PATHS THROUGH A HYBRID COIL.

2.3 REDUCTION OF SIGNAL LEVEL. A hybrid coil, in achieving the facility of isolation, introduces the disadvantage of reducing the level of a signal passing between any two items interconnected. For example, in Fig. 2a, not all of the signal transmitted from A is received at B; some of the signal is transmitted to D. For this reason the level of the signal at B and D is lower than that transmitted from A. The amount of signal reduction introduced between two items connected through a hybrid coil depends on the type of hybrid and its construction.

2.4 HYBRID COIL – TWO TRANSFORMER TYPE. Hybrid coils have many applications in line transmission equipment, but the most common application is to connect two-wire V.F. lines to four-wire equipment. Fig. 3 shows the circuit of the hybrid coil used for this type of connection. It contains two transformers T1 and T2, and for explanatory purposes, the three windings of each transformer are designated x, y and z. The y and z windings each have the same number of turns and are wound so that they have the same electrical characteristics. The two capacitors block any D.C. which may occur in the circuit.

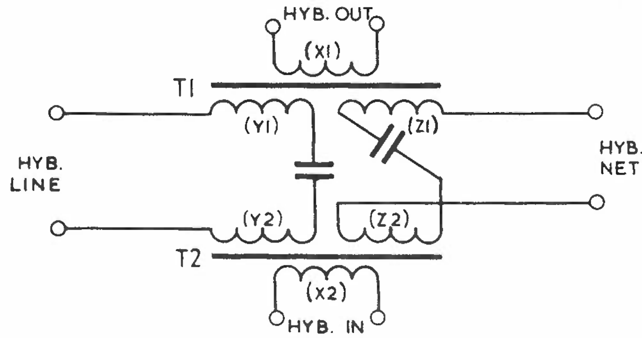


FIG. 3. HYBRID COIL - TWO TRANSFORMER TYPE.

Fig. 4 is a block diagram showing the two transformer type hybrid connecting a two-wire V.F. line to four-wire equipment. In this application the hybrid ensures that:-

- Signals from the two-wire line are connected to the transmit equipment.
- Signals from the receive equipment are connected to the two-wire line.
- The transmit equipment is isolated from the receive equipment.

To ensure that the hybrid coil effectively achieves these functions, a balance network is connected as shown. A balance network is designed to have the same electrical characteristics as the equipment connected to the opposite side of the hybrid coil, which in Fig. 4, is the line.

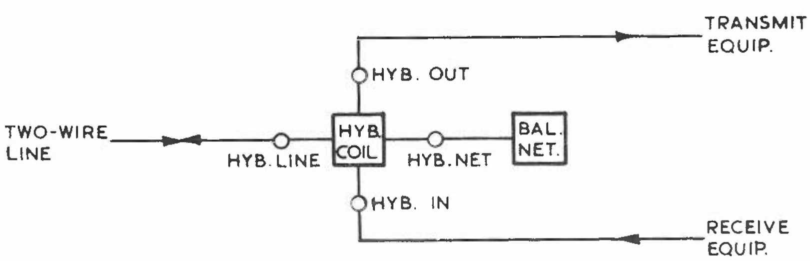


FIG. 4. TYPICAL APPLICATION OF HYBRID COIL.

When directly associated with carrier telephone channelling equipment, the two transformers of the hybrid coil, the transmit pad, the receive pad, and the balance network, are all assembled in the same container, and the total assembly is called a *four-wire terminating set*. (See Fig. 12a).

The hybrid coil shown in Fig. 3 is also used in ARM crossbar trunk switching exchanges to connect two-wire V.F. lines to four-wire switching equipment. In this application the two transformers are mounted separately, and the connection designations may differ from those shown in Fig. 3, but their principle of operation is the same.

2.5 TRANSMISSION FROM LINE TO TRANSMIT EQUIPMENT (Fig. 5). Because the signals transmitted through hybrid coils are alternating in nature, the directions and voltages given in the following descriptions are those existing at the same relative instant.

A signal transmitted from the line causes current through windings Y1 and Y2. The current through Y1 induces e.m.fs. across windings X1 and Z1, and the current through Y2 induces e.m.fs. into windings X2 and Z2. The e.m.f. induced across winding X1 produces current through the input of the transmit equipment, and the e.m.f. induced across winding X2 produces current through the output of the receive equipment. The e.m.fs. induced across windings Z1 and Z2 are equal and opposite, therefore, no current flows in the balance network

Since windings Y1 and Y2 are equal, the signal power transmitted from the line divides equally, half being delivered to the transmit equipment and half to the receive equipment. Theoretically, therefore, the signal level at 'Hybrid Out' is equal to half the signal level applied to 'Hybrid Line'. This represents a power reduction of 2:1, which is equivalent to a 3 dB loss. However, in practice, small transformer losses also occur in the hybrid, and the actual reduction in power between 'Hybrid Line' and 'Hybrid Out' is approx. 3.6 dB. The signal power connected to the receive equipment is dissipated in the output of the receive equipment and therefore, is wasted.

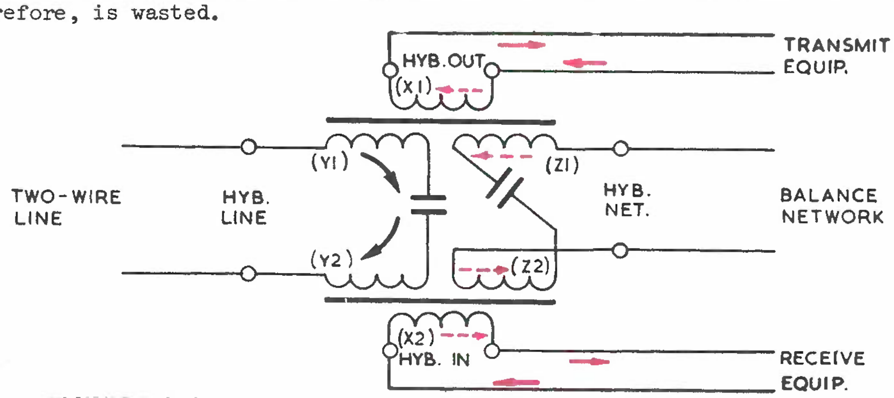


FIG. 5. TRANSMISSION FROM LINE TO TRANSMIT EQUIPMENT.

2.6 TRANSMISSION FROM RECEIVE EQUIPMENT TO LINE (Fig. 6). A signal transmitted from the output of the receive equipment causes current through winding X2. This current induces e.m.fs. of equal value across windings Y2 and Z2. The e.m.f. induced across windings Y2 produces current through the two-wire line and winding Y1. The e.m.f. induced across Z2 produces current through the balance network and winding Z1.

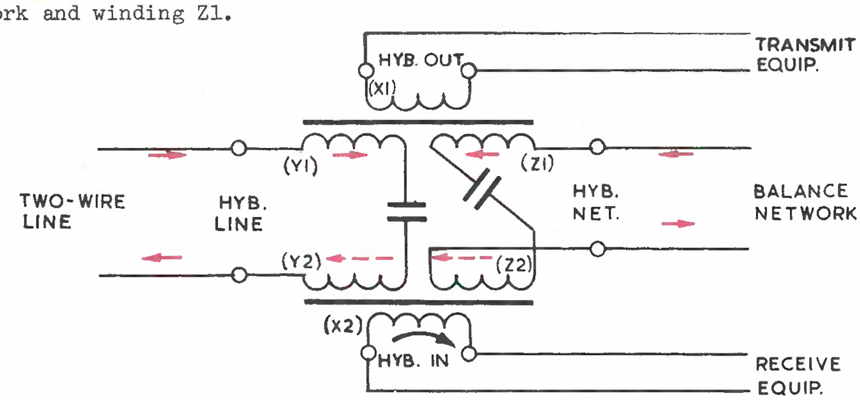


FIG. 6. TRANSMISSION FROM RECEIVE EQUIPMENT TO TWO-WIRE LINE.

The currents produced through the line and balance network are equal, because under ideal conditions, their impedances are equal. Therefore, half the power transmitted from the receive equipment is delivered to the two-wire line, and the other half is delivered to the balance network where it is dissipated and wasted. Since the two-wire line receives only half the power, and a further power loss occurs in the transformers, the signal level at 'Hybrid Line' is approximately 3.6 dB lower than that at 'Hybrid In'.

Because the effects of the current through windings Y1 and Z1 are equal and opposite, no e.m.f. is induced into winding X1, and the transmit equipment is effectively isolated from the receive equipment.

2.7 HYBRID COIL – SINGLE TRANSFORMER TYPE. A hybrid coil consisting of one transformer is shown in Fig. 7. The windings are wound on a common core, and for most applications, windings a-b and b-c have the same number of turns and are wound so that they have the same electrical characteristics. (In some single transformer type hybrid coils, windings a-b and b-c are not equal, but the operation of this type is not described in this paper.)

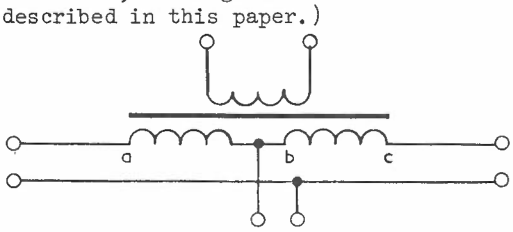


FIG. 7. HYBRID COIL - SINGLE TRANSFORMER TYPE.

For the purposes of explaining the operation of the single transformer type hybrid coil, the connections of a typical application, as shown in Fig. 8, are used. In this application, interconnection exists between equipment items A and B and A and C, and isolation exists between B and C.

2.8 TRANSMISSION FROM A (Fig. 8). A signal transmitted from A produces current through winding d-e. This current induces e.m.fs. across windings a-b and b-c. The induced e.m.fs. produce current through the equipment connected at B and C. Because the potentials at points b and f are equal, no current flows through the balance network.

For example, assume that a signal input from A causes an induced e.m.f. of 1 volt across each of the equal windings a-b and b-c. This induced e.m.f. is a voltage source, and the windings are connected in such a direction that the potentials at b and c are -1 volt and -2 volts respectively, with respect to point a. Since the impedances of the equipment at B and C are equal, 1 volt (half the voltage) is dropped across B, and 1 volt is dropped across C, so the potentials at points f and b are both -1 volt.

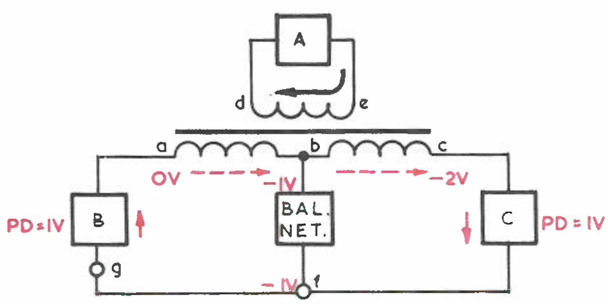


FIG. 8. SIGNAL TRANSMITTED FROM A.

Under these conditions, half the power transmitted from A is delivered to B and half to C, and no power is dissipated in the balance network. The signal levels at B and C are, therefore, 3 dB lower than the level of the signal transmitted from A (neglecting transformer losses).

2.9 TRANSMISSION FROM B (Fig. 9). A signal transmitted from B produces current through winding a-b and the balance network. The current through winding a-b induces e.m.fs. across windings b-c and d-e. The e.m.f. induced across winding d-e produces a current through the equipment connected at A. The e.m.f. induced across winding b-c is in such a direction that it prevents current flow through the equipment connected at C, thus providing isolation between B and C.

For example, assume that at one instant the signal output from B results in a potential of -2 volts at point a, with respect to 0 volts at point g. Current flows, and since the impedances of the balance network and windings a-b are equal, the potential differences across them are equal (1 volt). The voltage values in the circuit are -1 volt at point b, and 0 volts at point f. Windings a-b and b-c are equal and an e.m.f. of 1 volt is induced across b-c. The connections of the windings are such that a potential of -1 volt exists at point b, with respect to 0 volts at point c. Points c and f are therefore at the same potential, and there is no current through the equipment at C.

Under these conditions half the power transmitted from B is delivered to A and half to the balance network; no power is dissipated in the equipment at C. The signal level at A is 3 dB lower than the level transmitted from B (neglecting transformer losses).

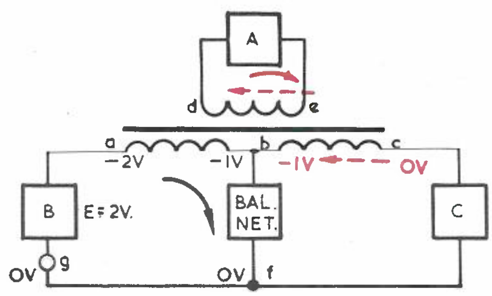


FIG. 9. SIGNAL TRANSMITTED FROM B.

2.10 TRANSMISSION FROM C. The operation of the hybrid for the transmission of a signal from C is the same as that described for the transmission of a signal from B. The signal power divides, half is delivered to A and the other half is dissipated in the balance network. The level of the signal delivered to A is, therefore, 3 dB (plus transformer losses) lower than the level of the signal transmitted from C. Isolation occurs between C and B because, in this case, the induced e.m.f. in winding a-b causes points a and f to be at the same potential, thus preventing current flow through the equipment at B.

2.11 BALANCE NETWORKS. The degree of isolation in hybrid coils depends on how closely the impedance of the balance network is matched to the impedance of the equipment connected electrically opposite to it.

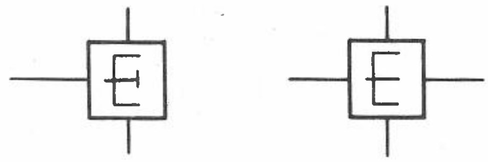
Ideally, this match should be exact over the frequency range concerned. In this ideal case, an infinite loss would exist between the electrically opposite sides of the hybrid, that is, 'across' the hybrid.

In practice, however, a perfect balance cannot be obtained, and a small amount of signal passes across the hybrid coil between the equipment items connected to the opposite sides. The amount of signal which does pass across the hybrid coil is kept below a prescribed value by ensuring that the balance network matches, as closely as possible, the equipment connected opposite to it.

Examples of simple balance networks are shown in Fig. 10. Fig. 10a shows a typical network used to balance a V.F. line, when a hybrid coil is employed to join the two-wire V.F. line to four-wire equipment. When a hybrid coil is used in higher frequency applications, where the impedance is substantially constant over the frequency range transmitted and the phase angle is near enough to zero, a simple non-inductive resistor balance network can be used, as shown in Fig. 10b.

(a) (b)

FIG. 10. TYPICAL BALANCE NETWORKS.



(a) (b)

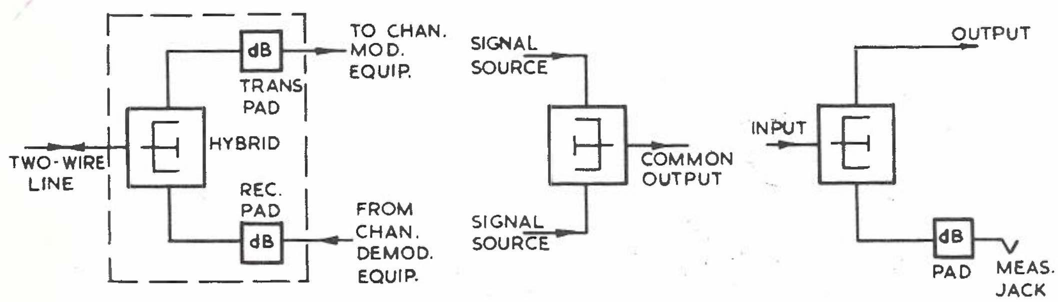
FIG. 11. HYBRID COIL SYMBOLS.

2.12 HYBRID COIL SYMBOL. Since a balance network is usually associated with a hybrid coil, both the hybrid coil and the balance network may be represented in the same symbol, as shown in Fig. 11a. However, should it be necessary to show the balance network separately, or where no balance network is required, the general hybrid coil symbol shown in Fig. 11b is used.

2.13 TYPICAL APPLICATIONS OF HYBRID COILS. Some typical applications of hybrid coils in line transmission equipment are shown in Fig. 12.

Two-Wire to Four-Wire Connection. As stated in para 2.4, the most common application of hybrid coils is to connect two-wire V.F. lines to four-wire equipment. In this application four-wire terminating sets are usually used. Fig. 12a shows a four-wire terminating set connecting a two-wire V.F. line to the four-wire channelling equipment of a carrier telephone system.

Hybrid Decouplers (Combiners). A hybrid coil (usually a single transformer type) is sometimes used to combine two signal sources having different frequency versus impedance characteristics. The hybrid coil combines the two signal sources, applies them to the common output, and at the same time isolates one source from the other to prevent interaction between them (Fig. 12b). This application of the hybrid coil is described in more detail in Section 3.



(a) Four-Wire Terminating Set. (b) Hybrid Decoupler. (c) Measuring Hybrid.

FIG. 12. APPLICATIONS OF HYBRID COILS.

Measuring Hybrids. Measurements must often be taken on the sections of carrier systems containing large numbers of channels, without the possibility of the channels being interrupted by faulty measuring techniques. This is achieved by using a measuring hybrid, connected as shown in Fig. 12c. The windings of the measuring hybrid are arranged so that most of the signal is connected to the output with little reduction in level, but a small portion of the signal is connected to the measuring jack, via a pad. A suitably calibrated measuring instrument is plugged into the measuring jack to indicate the level at that point in the carrier system. Due to the characteristics of the hybrid coil and pad, the measuring point is adequately isolated from the transmission path. Therefore, any impedance changes which may occur across the measuring point, while measurements are being made, have negligible effect on the channels.

3. PADS AND ATTENUATORS.

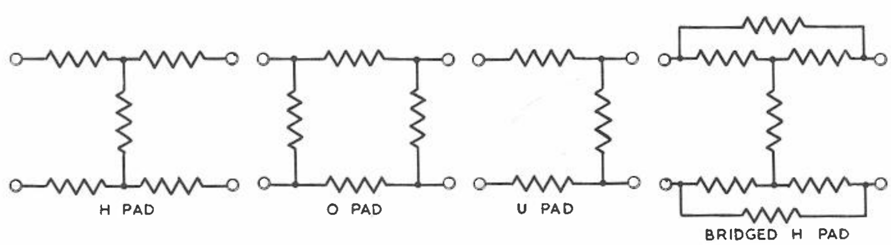
3.1 Pads and attenuators are networks of resistors which introduce known losses into circuits. To ensure that the loss they introduced is independant of frequency, pads and attenuators are always constructed with non-inductive resistors.

Pads. The term 'pad' is generally applied to a resistor network which has a *fixed* value and is designed to introduce a constant loss in a circuit.

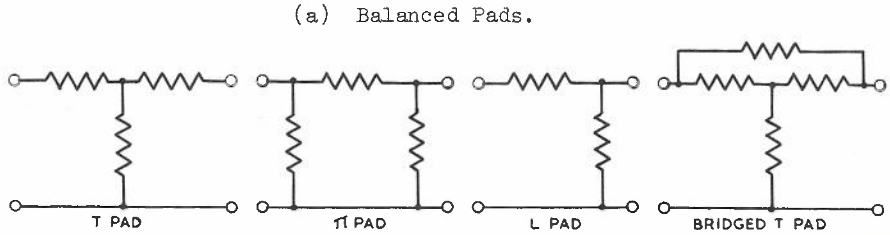
Attenuators. The term 'attenuator' is generally applied to a resistor network, the loss of which can be *varied* in known calibrated amounts by the operation of a key or rotary switch.

3.2 TYPES OF PADS. There are a number of different ways in which resistors can be arranged to form pads. Some of the most common types in general use are shown in Fig. 13. Notice that the configuration formed by the resistors generally determines the name of the pad. Pads are broadly classified into 'balanced pads' and 'unbalanced pads'.

Balanced Pads. A balanced pad contains an equal amount of series resistance in each side (Fig. 13a). They are used in situations where it is essential for the impedance of each side of the circuit to be the same, to prevent noise being introduced by crosstalk.



(a) Balanced Pads.



(b) Unbalanced Pads.

FIG. 13. TYPES OF PADS.

Unbalanced Pads. A pad is unbalanced if it contains more resistance in series with one side than in series with the other side. The pads shown in Fig. 13b contain series resistance in one side only, and are therefore, unbalanced pads. These pads are suitable for use in equipment in which one side of the circuit is earthed, or in situations where an unbalance is not likely to cause noise.

3.3 FUNCTIONS OF PADS. While pads always introduce a loss of power in a circuit, they may not be included in the circuit for this specific purpose. In practice, pads are used for any of the following functions:-

- *Introduce a Known Loss.* The pad is inserted in the circuit for the purpose of lowering the signal level by a fixed amount, without introducing distortion.

- *Impedance Matching.* The pad is used to connect together and match two circuits having unequal impedances.

- *Impedance Masking.* In this application the pad is used to mask the effects of impedance changes in one part of a circuit from affecting another part of the circuit.

3.4 REQUIREMENTS OF PADS. Generally, all pads are designed to fulfill the following requirements:-

- The values of the resistors and the configuration chosen must provide the correct amount of loss.

- The loss provided by the pad must be constant over the entire frequency range transmitted through the pad. For this reason, non-inductive resistors with negligible capacitive effects are used.

- The impedance of the pad must be the same as the impedance of the equipment to which it is connected. If the impedance of the pad is different to the impedance of the equipment, a mismatch occurs, and reflection takes place.

3.5 LOSS INTRODUCED BY PADS. The most common application of pads is to introduce a known loss into a circuit for the purpose of adjusting the signal level to the correct value. For example, in Fig. 14 the output level of equipment item A is +20dBm and the required input level to equipment item B is +14dBm, therefore, it is necessary to attenuate the signal level between A and B by 6dB. A *level adjusting pad,* having a loss of 6dB, has been inserted between A and B for this purpose.

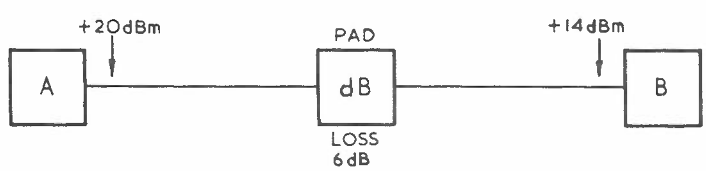


FIG. 14. LEVEL ADJUSTING PAD.

A single series or shunt resistor can be used to attenuate the signal level, but either would produce an impedance mismatch, which in turn causes reflection. The impedance mismatch produced by a single series or shunt resistor can be demonstrated as follows.

Consider an equipment item 'A' with an output impedance of 600 ohms, connected to an equipment item 'B' having an input impedance of 600 ohms, and that A is supplying too much power to B (Fig. 15a). If a resistor of, say, 400 ohms were connected in series with B (Fig. 15b) the power delivered to B would be reduced, but the total impedance connected across the output of A would be increased to 1000 ohms, causing a mismatch between A and B. Also, if the 400 ohms resistor is connected in parallel with B (Fig. 15c), the total impedance connected across the output of A would decrease to 240 ohms, once again causing a mismatch between A and B.

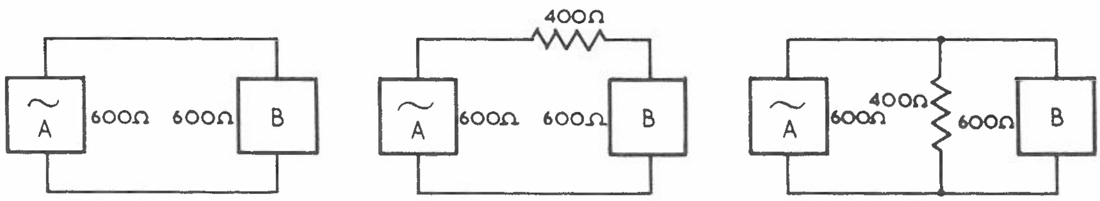
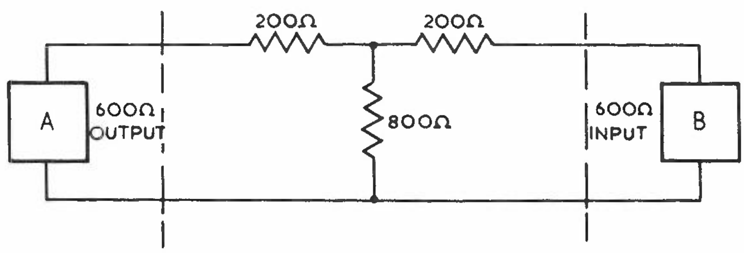


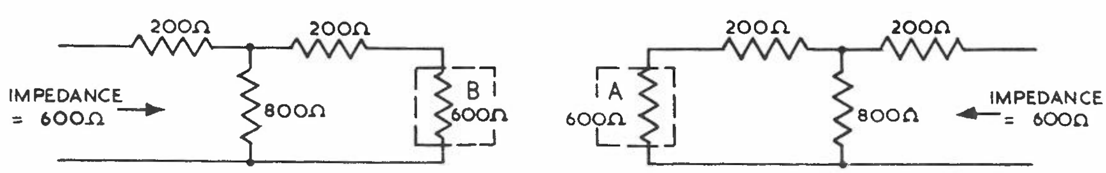
FIG. 15. MISMATCH PRODUCED BY A SERIES OR SHUNT RESISTOR.

Pads always consist of a combination (network) of series and shunt resistors, because these types of networks can be designed to reduce the signal power by the required amount, without producing an impedance mismatch. The series resistors of the pad produce a voltage drop and thus reduce the voltage available to the load, and the shunt resistors shunt current and reduce the current to the load. The reduction in voltage and current produced by the pad effectively reduces the power to the load.

The impedance matching properties of a pad can be demonstrated by using the examples of a T pad (Fig. 16a) which produces a loss of 6dB between the 600 ohm output of A and the 600 ohm input of B. The simplified sketch in Fig. 16b shows that, with B (600 ohms) connected to the pad, the total impedance connected across the output of A is 600 ohms. Similarly, Fig. 16c shows that, with A (600 ohms) connected to the pad, the total impedance connected across the input of B is 600 ohms. Therefore, impedance matching occurs between A and B.



(a) 6dB PAD.

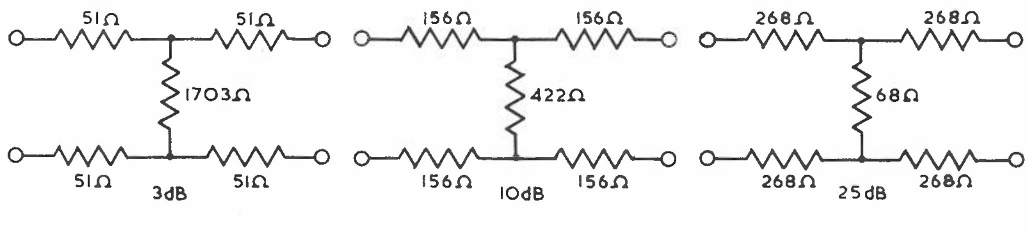


(b) Impedance Across Output of A = 600 ohms.

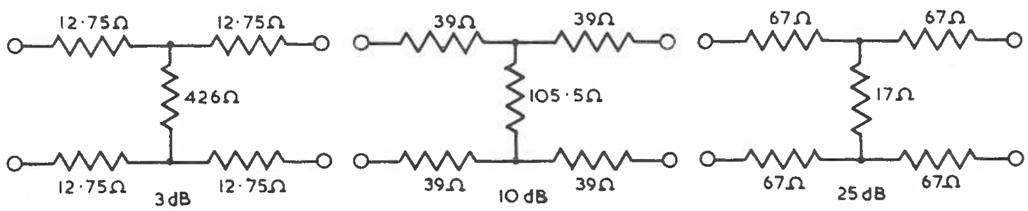
(c) Impedance Across Input To B = 600 ohms.

FIG. 16. TYPICAL T PAD.

Pads may be designed to provide any value of loss. However, a pad must only be used in a circuit having the impedance for which the pad was designed. A pad designed to produce a particular loss, say in a 600 ohms circuit, will not produce the same loss if inserted into a circuit having a different impedance (say 150 ohms). Some examples of H pads, and the losses they produce in the circuit impedances they are designed for, are shown in Fig. 17. Note that different resistor values are required to give the same loss in 600 ohm circuits and 150 ohm circuits.



Pads suitable for 600 ohm Circuits.



Pads suitable for 150 ohm Circuits.

FIG. 17. TYPICAL H PADS.

The particular configuration used for a pad is a matter of circuit design, and is not dealt with in this paper. However, it is possible to obtain the same loss and impedance with a number of different configurations. Examples of pads having different configurations, but designed to produce the same loss in 75 ohm circuits, are shown in Fig. 18.

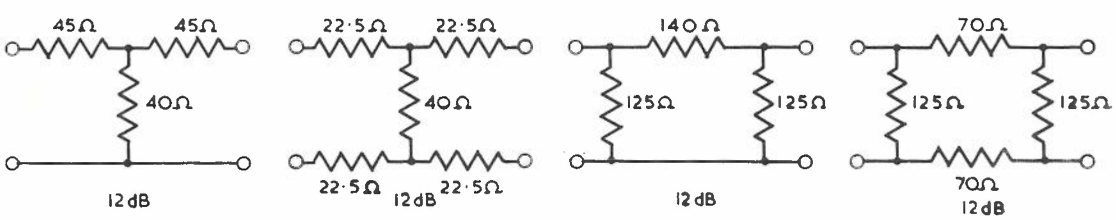


FIG. 18. DIFFERENT CONFIGURATIONS PRODUCING THE SAME LOSS IN 75 OHM CIRCUITS.

3.6 Pads designed to operate with the same value of impedance connected to the input and output, such as those shown in Figs. 16 to 18, are called *symmetrical pads*. Table 1 shows the values of the resistors used to make some of the symmetrical pad configurations used in 600 ohm circuits. To enable the tables to be used to select the correct resistor values for a particular pad it is necessary to know:-

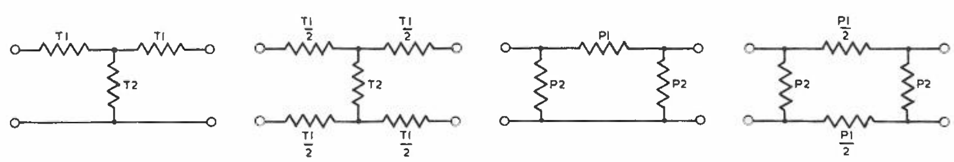
- The amount of loss the pad is to introduce.
- The impedance of the circuit in which the pad is to operate.
- The configuration of the pad.

For example, from Table 1 select the resistor values required in a π pad which is to produce a 10 dB loss in a 600 ohm circuit. Referring to the table, is is found that a 10 dB loss is produced in a π pad when resistors P1 and P2 have values of 854 ohms and 1155 ohms respectively. Fig. 19a shows these resistor values applied to the pad.

An O pad designed to give the same loss (10 dB) as the π pad is shown in Fig. 19b. In this case, half of P1 is included in each side of the pad in order to produce a balanced pad.

FIG. 19. PADS DESIGNED FROM TABLE 1.

To find the values of resistors in pads suitable for 150 ohm circuits, the table is used in a similar manner as for 600 ohm circuits, but the values of the resistors contained in the table are divided by 4 (see Fig. 17). Similarly the resistor values in the table are divided by 8 for pads suitable for 75 ohm circuits, and multipled by 2 for pads suitable for 1200 ohm circuits.



(NOTE. All values in this table are approximate to the nearest whole number)

Loss in dB	T1 (Ohms)	T2 (Ohms)	P1 (Ohms)	P2 (Ohms)
1	35	5 200	69	10 440
2	69	2 583	139	5 235
3	102	1 703	211	3 509
4	136	1 258	286	2 651
5	168	987	365	2 142
6	199	803	448	1 805
7	229	670	538	1 569
8	258	568	634	1 394
9	286	487	739	1 260
10	312	422	854	1 155
15	419	220	1 634	860
20	491	121	2 970	733
25	536	68	5 318	672
30	563	38	9 477	639
35	579	21	16 865	622
40	588	12	29 997	612

TABLE 1. RESISTOR VALUES - SYMMETRICAL PADS SUITABLE FOR 600 OHM CIRCUITS.

3.7 IMPEDANCE MATCHING PADS. Many cases occur in line transmission equipment where equipment items with different impedances have to be connected together. Unless the impedances of the equipment items are matched, reflection will occur. A common method of impedance matching is to use a transformer, which can be designed to match the unequal impedances with little loss over the frequency range. However, where a loss of power is not important, a cheaper method of matching is to use a pad, as shown in Fig. 20. Because impedance matching pads are designed to have different impedance values connected to the input and output, they are referred to as *asymmetrical pads* or unsymmetrical pads.

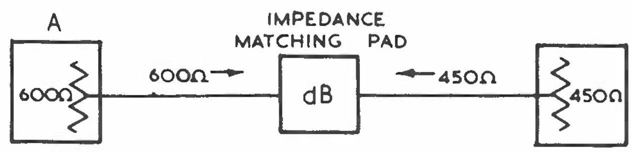
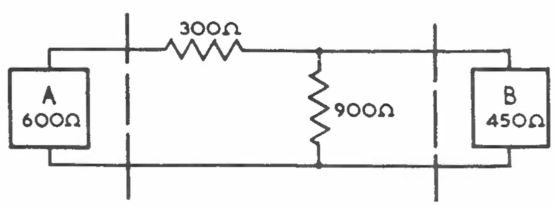
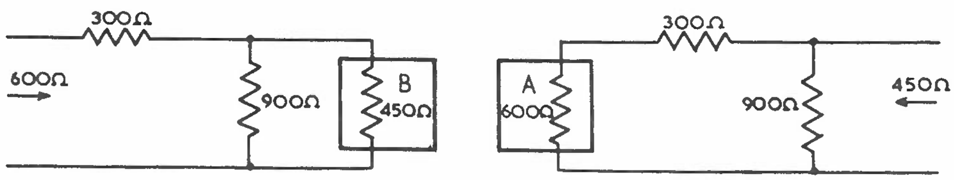


FIG. 20. IMPEDANCE MATCHING PAD.

A pad suitable for matching the 600 ohm output of A to the 450 ohm input of B is shown in Fig. 21a. The impedance matching property of the pad is demonstrated with the aid of the simplified diagrams in Fig. 21b and c. With the 450 ohm input of B connected to the pad (Fig. 21b), the total impedance connected across the output of A is 600 ohms. Similarly, with the 600 ohm output of A connected to the pad (Fig. 21c), the total impedance connected across the input of B is 450 ohms. Since A and B have the correct impedances connected to them, impedance matching exists.



(a) Impedance matching L pad.



(b) Impedance across output of A = 600 ohms.

(c) Impedance across input of B = 450 ohms.

FIG. 21. A PAD SUITABLE FOR MATCHING 600 OHMS AND 450 OHMS.

Minimum Loss Pads. A pad which introduces the minimum possible loss when matching two impedances is called a minimum loss pad. Minimum loss pads are always constructed with an L configuration, or its balanced equivalent, which is the U configuration. The pad shown in Fig. 21 is a minimum loss pad, which provides matching between 600 ohms and 450 ohms with the minimum possible loss of 4.8 dB. It is not possible to design a pad to match these two impedances with a loss less than 4.8 dB.

The minimum loss which must be introduced when matching two impedances with a pad is dependent on the ratio of the impedances. Some examples of minimum loss pads and the loss they introduce when matching impedances having ratios of 2:1, 3:1 and 10:1 are shown in Fig. 22.

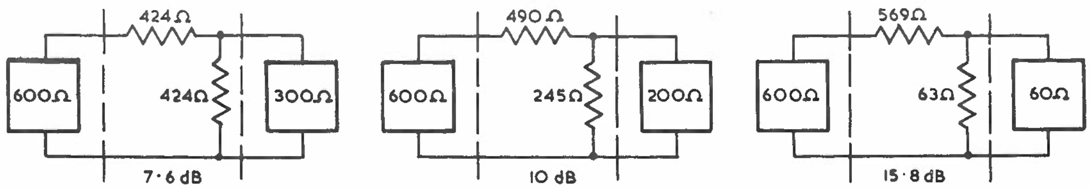


FIG. 22. EXAMPLES OF MINIMUM LOSS PADS.

Where a loss higher than that provided by a minimum loss pad is permissable, or desirable, when matching two impedances, any pad configuration can be used and designed to fulfill the requirements. For example, Fig. 23 shows an H pad which has been designed to match 600 ohms and 300 ohms and provide a loss of 10 dB.

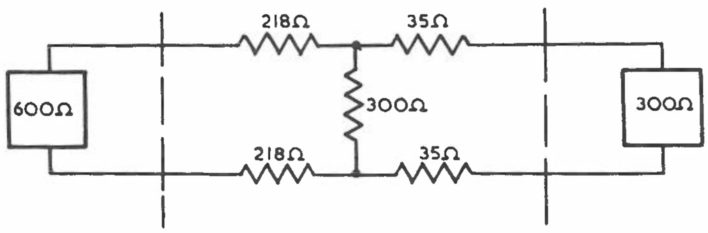


FIG. 23. A 10 dB IMPEDANCE MATCHING H PAD.

3.8 IMPEDANCE MASKING PADS. Some line transmission equipment items, such as filters, are particularly sensitive to impedance changes across their input or output. Variations in the impedance connected to these items cause their characteristics to vary and also produce reflection problems. One method of reducing the effects of impedance variations on an equipment item is to connect a masking pad between it and the point of impedance variation. (Fig. 24).

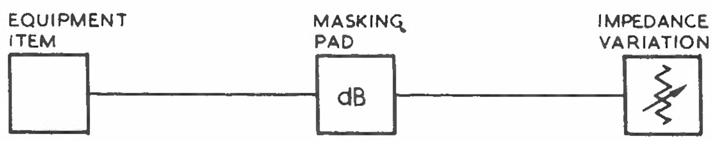


FIG. 24. IMPEDANCE MASKING PAD.

A pad suitable for connecting a 600 ohm equipment item (A) to an impedance (B), which varies between 300 ohms and 900 ohms, is shown in Fig. 25a. With the impedance of B at 600 ohms connected to the pad, the total impedance across the output of A is 600 ohms (Fig. 25b). When the impedance of B is reduced by 300 ohms, the total impedance connected across the output of A only reduces to 584 ohms (Fig. 25c). Similarly, when the impedance of B is increased to 900 ohms, the total impedance connected across the output of A increases to only 610 ohms (Fig. 25d). An impedance variation of 600 ohms (300-900 ohms) occured at B, but the impedance connected across the output of A only varied by 26 ohms (584 to 610 ohms). Therefore, the pad has the effect of masking the impedance changes which occurred at B.

3.9 CALCULATION OF LOSS INTRODUCED BY PADS. The loss introduced by a pad can be calculated by:-

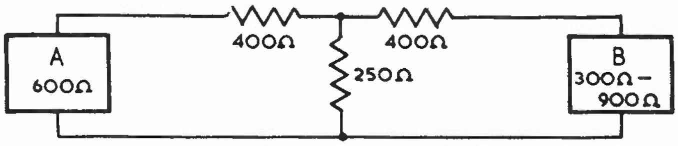
$$\text{Loss in dB} = 10 \text{ Log } \frac{\text{Power In}}{\text{Power Out}}$$

This formula may be applied to both symmetrical and asymmetrical pads.

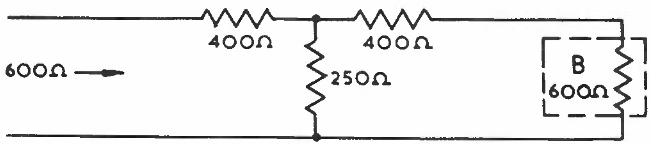
Symmetrical pads may also have the following formulae applied to them.

$$\text{Loss in dB} = 20 \text{ Log } \frac{\text{Current In}}{\text{Current Out}} \quad \text{OR} \quad \text{Loss in dB} = 20 \text{ Log } \frac{\text{Voltage across Input}}{\text{Voltage across Output}}$$

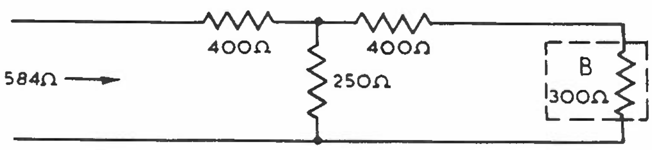
Also, when the levels in dBm at the input and output are known, the loss introduced by the pad is equal to the difference between the two levels (see Fig. 14).



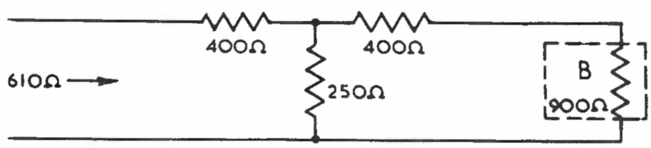
(a) Impedance Masking T Pad.



(b) Impedance across Output of A = 600 ohms.



(c) Impedance across Output of A = 584 ohms.



(d) Impedance across Output of A = 610 ohms.

FIG. 25. AN EXAMPLE OF IMPEDANCE MASKING.

3.10 CALCULATION OF IMPEDANCES TO BE CONNECTED TO PADS. The impedances for which a pad is designed are usually known, but if necessary they may be calculated.

The correct value of impedance (Z) which should be connected to the input of a pad is calculated by:-

$$Z = \sqrt{Zs/c \times Zo/c}$$

where *Zs/c is the input impedance of the pad with the output terminals short-circuited (Fig. 26a) and,*

Zo/c is the input impedance of the pad with the output terminals open-circuited. (Fig. 26b).

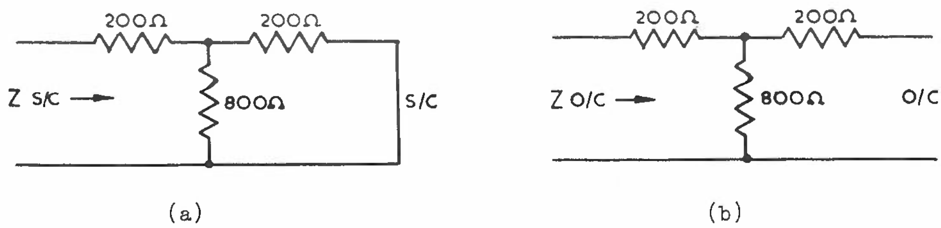


FIG. 26. Zs/c AND Zo/c.

Applying the formula to the pad shown in Fig. 26.

$$Zs/c = 200 + (200 \text{ in parallel with } 800) = 200 + 160 = 360 \text{ ohms}$$

$$Zo/c = 200 + 800 = 1000 \text{ ohms.}$$

$$Z = \sqrt{360 \times 1000}$$

$$Z = \sqrt{360000}$$

$$Z = 600 \text{ ohms.}$$

This pad, therefore, has been designed to operate with an impedance of 600 ohms connected to the input, and because the pad is symmetrical, the impedance connected across the output must also be 600 ohms.

When the pad is asymmetrical, the impedance which should be connected to the output is calculated by applying the formula from the output, with the input terminals short-circuited and open-circuited.

3.11 ATTENUATORS. Attenuators are designed to introduce a known variable loss into a circuit. They find their greatest application in transmission measurements, where they are used to control the levels to or from testing equipment, or for comparison type measurements. Fig. 27 shows an attenuator connected in the output of an oscillator.

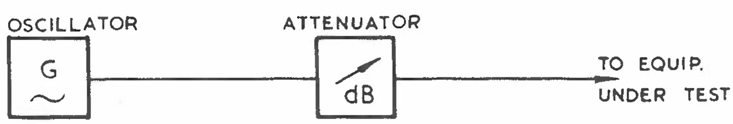


FIG. 27. ATTENUATOR APPLICATION.

Attenuators have similar configuration to pads, that is, they may consist of T, H, O, etc, configurations. To enable an attenuator to introduce a variable loss into a circuit, it is necessary for each resistor in the configuration to be variable, as shown in Fig. 28. The variable arms of the attenuators are all commoned (ganged) and move together, thus giving the required variation in all resistors simultaneously. Even though the losses introduced by attenuators are variable, they are designed so that mismatches are avoided. For example, an attenuator designed to operate in a 600 ohm circuit will always have resistor values suitable for 600 ohm equipment, for all values of loss introduced.

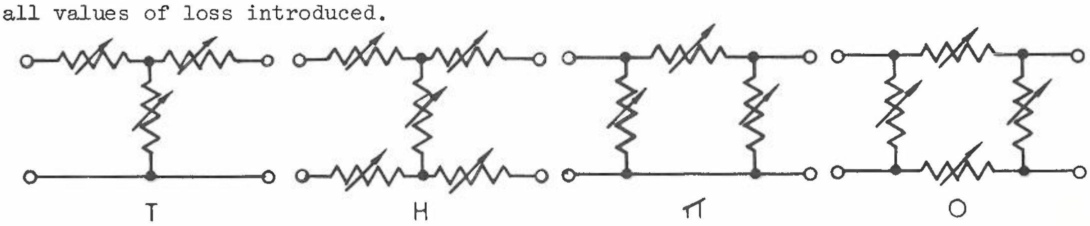


FIG. 28. EXAMPLES OF ATTENUATOR CONFIGURATIONS.

Attenuators used in line transmission equipment are usually constructed to vary the attenuation in steps. One method of achieving this is shown in Fig. 29, where the attenuator is variable in 1 dB steps up to 5 dB. Since the arms are ganged, one shaft, or knob, operates all three switches together. The dotted lines in the figure are the usual method of indicating ganged controls.

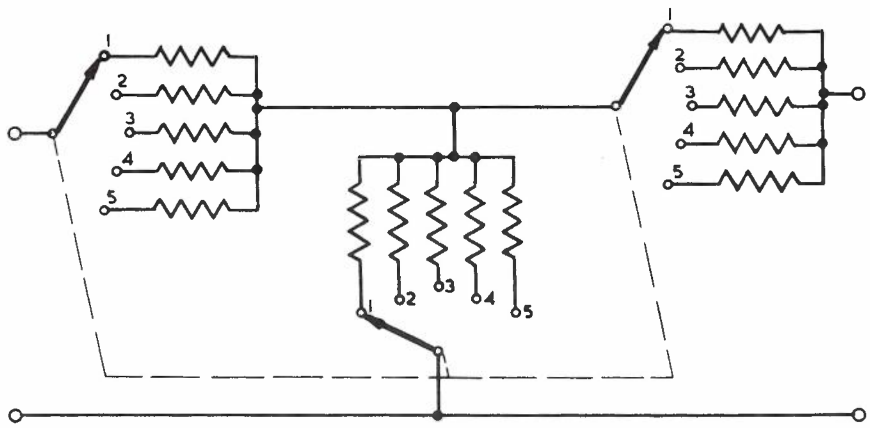


FIG. 29. AN ATTENUATOR, VARIABLE FROM 1 dB TO 5 dB IN 1 dB STEPS.

3.12 Another method of providing variable attenuation is to use fixed pads in series, and keys, as shown in Fig. 30. The keys normally short circuit the pads, so with all keys normal the loss inserted by the attenuator is 0 dB. The keys may be operated singly, or in one of many different combinations, to obtain a variety of losses ranging from 0 dB up to 31 dB, in 1 dB steps. For example, a loss of 28 dB is obtained by operating the 4, 8 and 16 dB keys.

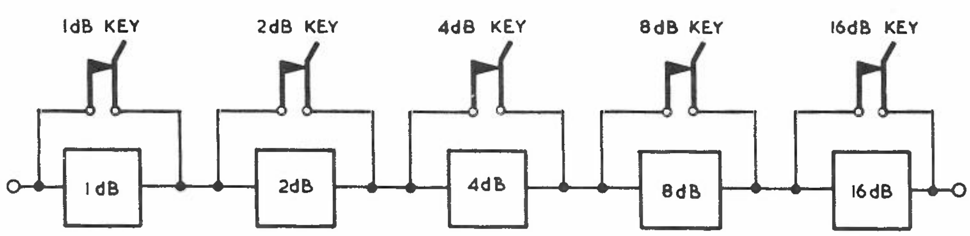


FIG. 30. AN ATTENUATOR USING KEYS AND FIXED PADS.

4. FILTERS.

4.1 In line transmission equipment it is often necessary to allow a selected range of frequencies to pass, or alternatively, to reject certain frequencies from a frequency range. Electrical wave filters or simply 'filters' are used for this purpose.

A *Filter* is a network which allows a selected range of frequencies to pass with little attenuation, and offers a high attenuation to (or 'rejects') all other frequencies.

4.2 TYPES OF FILTERS. The main types of filters used in line transmission equipment are:-

- *Low Pass (L.P.) Filters,* which readily pass all frequencies from zero up to a certain frequency, and reject all frequencies above this range.
- *High Pass (H.P.) Filters,* which readily pass all frequencies above a certain frequency, and reject all frequencies below this range.
- *Band Pass Filters,* which select a given band of frequencies, pass these with little attenuation, and reject all frequencies outside the band.
- *Band Elimination Filters,* which reject a given band of frequencies, and readily pass all frequencies outside the band.

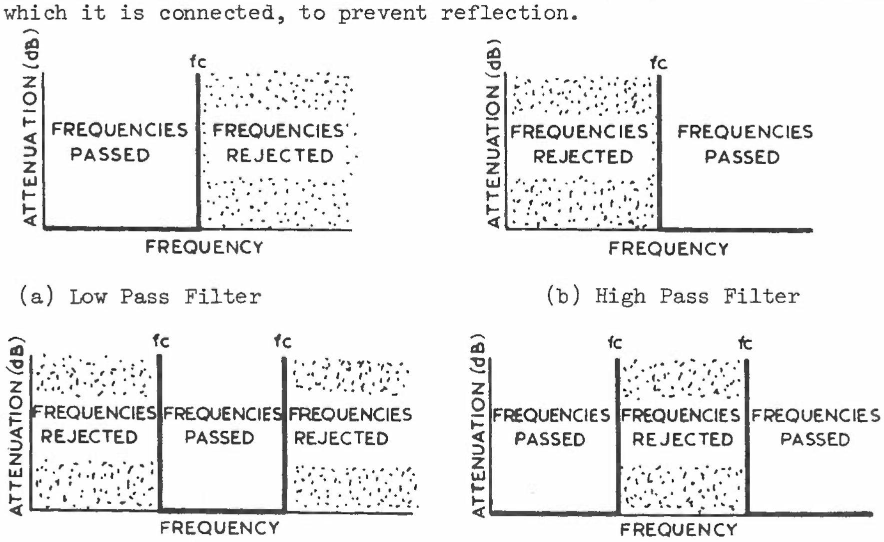
The symbols used to represent these filters are shown in Fig. 31.

Low Pass Filter High Pass Filter Band Pass Filter Band Elimination Filter

FIG. 31. FILTER SYMBOLS.

4.3 REQUIREMENTS OF FILTERS. Filters are designed to have the following characteristics:-

- A low and uniform attenuation in the pass range.
- A high attenuation in the range of frequencies to be rejected.
- A sharp cut-off between the pass range and rejected range of frequencies, to ensure unwanted frequencies are not passed by the filter.
- A uniform impedance versus frequencies characteristic over the pass range.
- The impedance of the filter should match the impedance of the equipment to which it is connected, to prevent reflection.



(a) Low Pass Filter (b) High Pass Filter

(c) Band Pass Filter (d) Band Elimination Filter.

FIG. 32. ATTENUATION VERSUS FREQUENCY CHARACTERISTICS OF 'IDEAL' FILTERS.

Fig. 32 shows the attenuation versus frequency characteristics of ideal filters. Because of the inherent properties of the inductors and capacitors used in filters, these characteristics cannot be obtained in practice, but the object of good filter design is to approach as near as possible to the ideal.

The frequency at which the attenuation of a filter begins to rise sharply is called the 'cut-off' frequency (fc).

4.4 BASIC FILTERS (Prototypes). Most filters in common use are networks of inductors and capacitors. Although practical filter networks are complex, a knowledge of filter operation can be obtained by studying basic filter networks, or 'prototype' filters as they are sometimes called. These basic networks are the basis for all practical filters.

Basic Low Pass (L.P.) Filter. The circuit arrangement of a basic low pass filter is shown in Fig. 33a.

At low frequencies the series inductive reactance (X_L) is low and the shunt capacitive reactance (X_C) is high. Very little of the signal current is shunted by the capacitor, and only a small portion of the voltage is dropped across the inductors. Most of the signal power appears in the filter output, therefore the filter passes the lower frequencies with little attenuation.

As the frequency rises, the inductive reactance increases and the capacitive reactance decreases. A large voltage is dropped across the inductors, and most of the current is shunted by the capacitor. Very little signal power appears in the filter output, therefore the filter offers a high attenuation to the higher frequencies. The frequency versus attenuation characteristic of a basic low pass filter is shown in Fig. 33b.

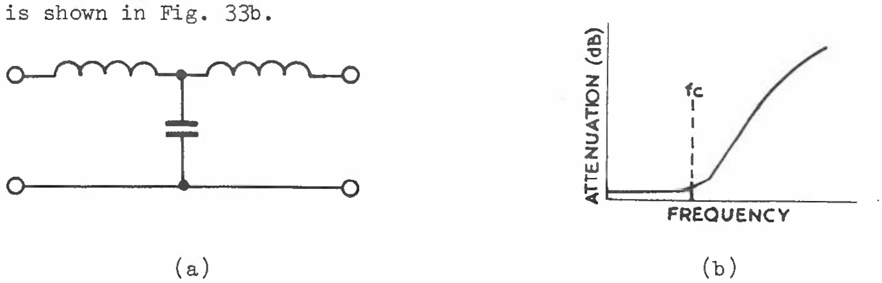


FIG. 33. BASIC LOW PASS FILTER.

Basic High Pass (H.P.) Filter. Figs. 34a and 34b show respectively the circuit of the basic high pass filter and its frequency versus attenuation characteristic. The operation of the high pass filter is exactly the reverse to the operation of the low pass filter.

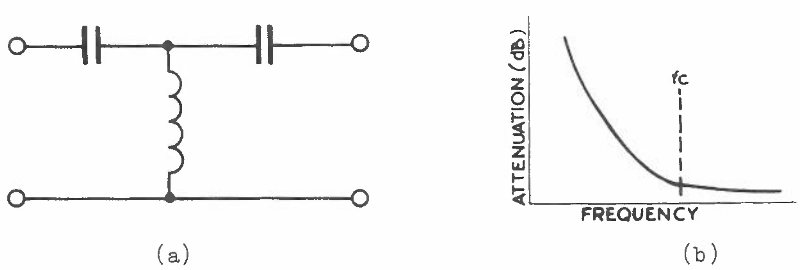


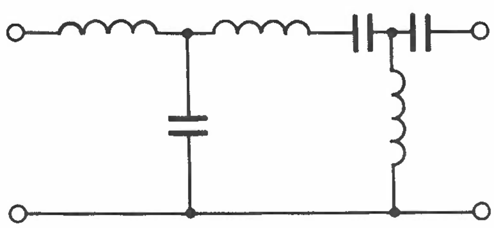
FIG. 34. BASIC HIGH PASS FILTER.

At the lower frequencies, the high reactance of the capacitors produces a high voltage drop, and the low reactance of the inductor shunts most of the current. Very little of the signal power of the lower frequencies appears in the filter output, therefore the filter offers a high attention to these frequencies.

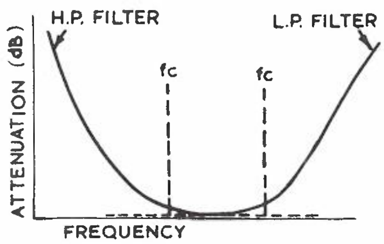
As the frequency rises the capacitive reactance decreases and the inductive reactance increases, resulting in a small voltage drop across the capacitors and a smaller current being shunted by the inductor. Because the filter passes these frequencies with little attenuation, most of the signal power of the higher frequencies appears in the filter ouput.

Basic Band Pass Filter. A band pass filter is essentially a low pass filter in series with a high pass filter (Fig. 35a). The low pass filter has a cut-off frequency equal to the highest frequency of the band to be passed, and the high pass filter has a cut-off frequency equal to the lowest frequency of the band to be passed (Fig. 35b).

All frequencies between the two cut-off frequencies are passed with little attenuation and all frequencies outside the two cut-off frequencies are highly attenuated. For example, if the filter is to pass a frequency band of 8 kHz to 12 kHz, the low pass filter would have a cut-off frequency of 12 kHz, and the high pass filter would have a cut-off frequency of 8 kHz.



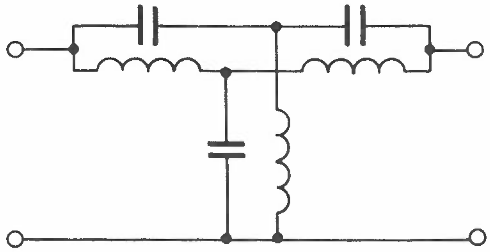
(a)



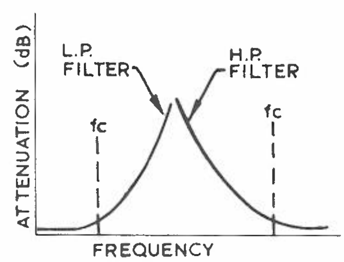
(b)

FIG. 35. BASIC BAND PASS FILTER.

Basic Band Elimination Filter. Band elimination filters consist of a high pass and low pass filter connected in parallel. (Fig. 36a). The low pass filter has a cut-off frequency equal to the lowest frequency of the band to be rejected, and the high pass filter has a cut-off frequency equal to the highest frequency of the band to be rejected (Fig. 36b). All frequencies between the two cut-off frequencies are rejected by the filter, and those frequencies outside the band are passed with little attenuation.



(a)



(b)

FIG. 36. BASIC BAND ELIMINATION FILTER.

For example, if the cut-off frequency of the low pass filter is 10 kHz, and the cut-off frequency of the high pass filter is 12 kHz, the filter will reject all frequencies between 10 kHz and 12 kHz. Band elimination filters constructed with inductors and capacitors are rarely used in line transmission equipment; usually crystal filters are used for this purpose.

4.5 LIMITATIONS OF BASIC FILTERS. Basic filters are suitable for some applications, for example, basic low pass filters are used to smooth D.C. power supplies. However, they are generally unsuitable for use in line transmission equipment because of the following weaknesses in their characteristics:-

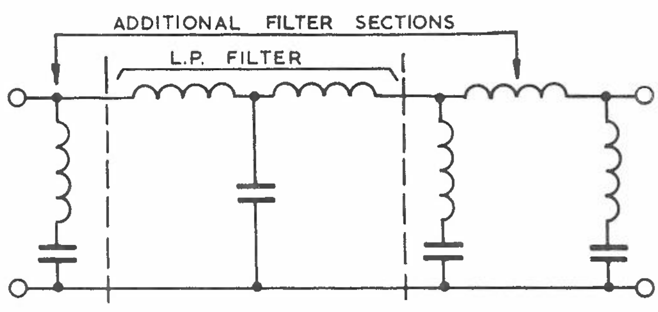
- The cut-off is not sharp enough. The gradual increase in attenuation of a basic filter does not sufficiently attenuate the frequencies to be rejected near the cut-off.

- The impedance varies over the frequency range to be passed. This causes a mismatch between the filter and the equipment to which it is connected, resulting in reflection problems.

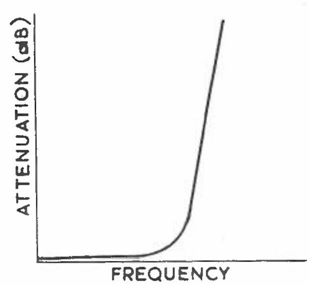
4.6 PRACTICAL LINE TRANSMISSION EQUIPMENT FILTERS. The limitations of basic filters are overcome in practical line transmission equipment filters by making their circuits more complex. An examination of the circuit of practical filters shows that each is composed of a basic filter, plus a number of additional filter sections.

The additional sections are used to modify the basic filter characteristics, to ensure that the practical filter fulfills the necessary requirements. The number of additional sections used, and their complexity, depends on such factors as the sharpness of the cut-off required, the permissable impedance variation with frequency, and whether the filter is to operate singly, or in parallel with others.

An example of a low pass filter used in line transmission equipment is shown in Fig. 37a. Note that the filter consists of a basic low pass filter, plus additional filter sections. The frequency versus attenuation characteristics (Fig. 37b) shows how the additional sections sharpen the cut-off, as compared to the basic low pass filter characteristics shown in Fig. 33b.



(a)

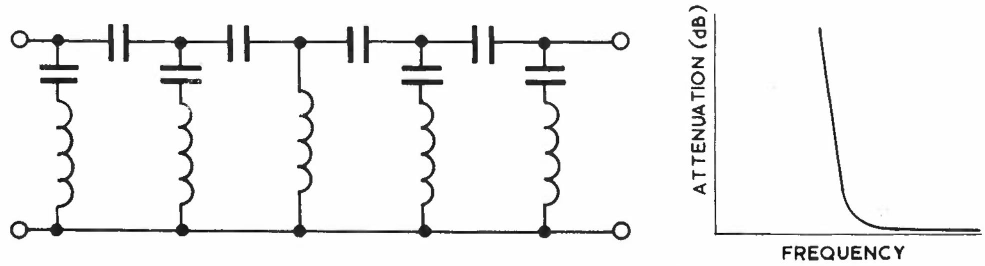


(b)

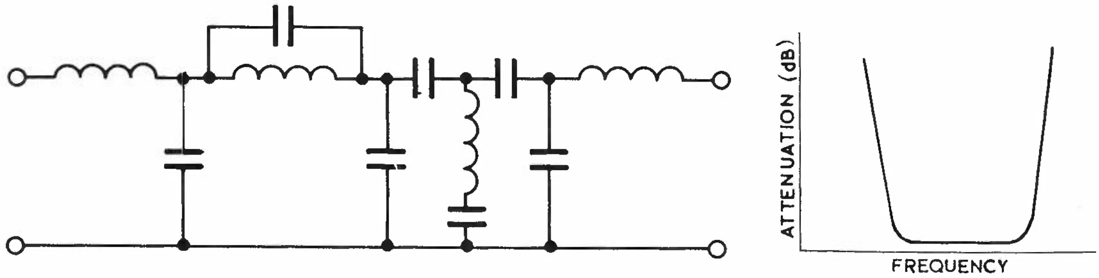
FIG. 37. EXAMPLE OF A PRACTICAL LOW PASS FILTER.

Because of the wide range of filter applications used in line transmission equipment, each type of filter has a large variety of circuits. The configurations used in the practical applications are a matter of circuit design and are not dealt with in this paper, however, the student should be able to recognise the basic filter elements used in each practical filter.

Fig. 38a and 38b show examples of a high pass and a band pass filter and their typical frequency versus attenuation characteristics.



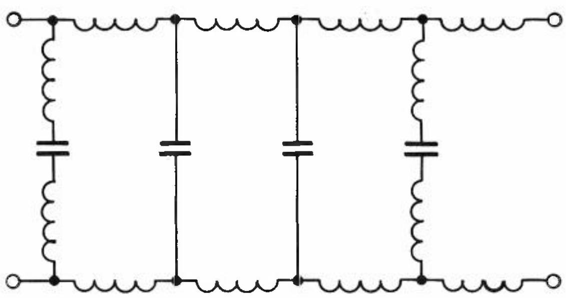
(a) High Pass Filter.



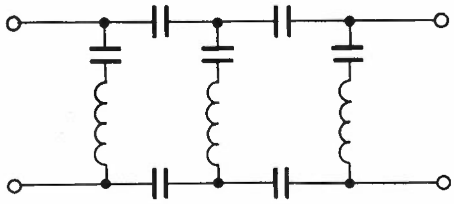
(b) Band Pass Filter.

FIG. 38. EXAMPLES OF PRACTICAL FILTERS.

4.7 BALANCED AND UNBALANCED FILTERS. Like pads and other types of networks, balanced filters contain equal identical elements in series with each side of their circuit, and unbalanced filters contain all the series elements in one side.



(a) Low Pass Filter.



(b) High Pass Filter.

FIG. 39. EXAMPLES OF BALANCED FILTERS.

Since balanced filters require additional inductors and capacitors, their cost is higher than unbalanced filters, and they are used only where technical considerations make the use of unbalanced filters impracticable. In general, balanced filters are used in such applications as line filters, which are connected directly to balanced transmission lines, and unbalanced filters are used in unbalanced carrier equipment circuits. Examples of unbalanced filters are shown in Figs. 37 and 38, and examples of balanced filters are shown in Fig. 39.

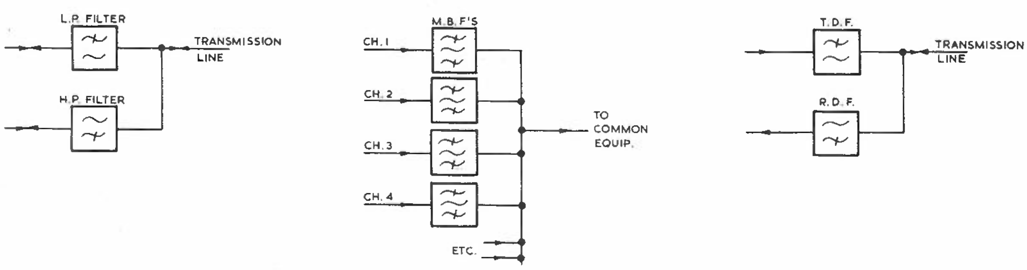
4.8 IMPEDANCE CONSIDERATIONS. For the satisfactory operation of a filter, its input impedance should be the same as the equipment connected to the input, and its output impedance should be the same as the equipment connected to the output. The correct input and output impedances of the filter are only obtained when the filter is correctly terminated (similar to the conditions shown for a pad in Fig. 16). When measurements are made on a filter, it is essential that the correct impedance conditions are maintained, or simulated, otherwise incorrect results will be obtained.

A filter designed to have the same value of impedances connected to the input and output is a *symmetrical filter*.

A filter designed to have different values of impedance connected to the input and output is an *asymmetrical filter*.

4.9 PARALLEL CONNECTION OF FILTERS. Many cases occur in line transmission equipment where it is necessary to operate filters in parallel. Some examples are:-

- *Line Filters* (Fig. 40a), which are used to separate voice frequency signals and carrier system signals (or two carrier system signals) being transmitted simultaneously over the same bearer.
- *M.B.F's and D.B.F's.* Modulator band pass filters and demodulator band pass filters, which are used to separate the channel frequencies of carrier telephone systems. An example of M.B.F's connected in parallel is shown in Fig. 40b.
- *Directional Filters.* (Fig. 40c), which are used to separate the frequencies for each direction of transmission in carrier systems operating over two-wire bearers.

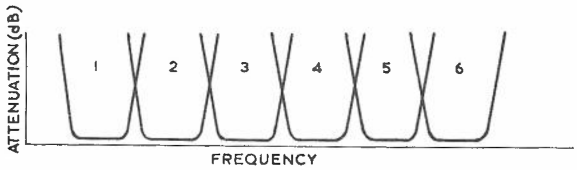


(a) Line Filters (b) M.B.F's. (c) Directional Filters.

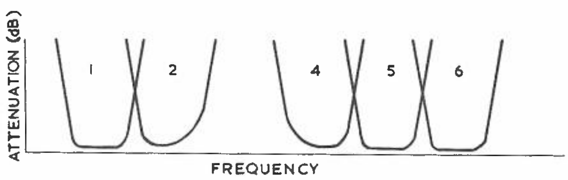
FIG. 40. EXAMPLES OF FILTERS IN PARALLEL.

4.10 EFFECTS OF PARALLEL FILTER CONNECTION. The characteristics of each filter in a parallel group affects the characteristics of the filters electrically adjacent to it. Where relatively large separation bands exist between parallel filters, the effects that adjacent filters have on each other are negligible, and can be ignored. However, where the separation bands are relatively small, adjacent filters have a considerable effect on each other's performance. In this case, for the filters to perform their correct functions, their circuit design is necessarily more complex than where wide separation bands apply.

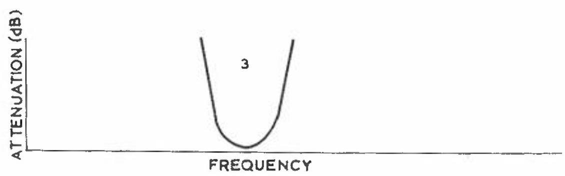
When separation bands are relatively small, parallel filter groups are designed to operate as an integral unit. In effect, the adjacent filters in these groups serve as additional elements for each other. A filter designed to operate in a parallel group does not retain its characteristics if removed from the group. Also, the characteristics of some of the remaining filters in the group are effected when one or more of the filters are removed from the group. For example, the frequency versus attenuation characteristics of six parallel band pass filters with relatively small separation bands are shown in Fig. 41a. When filter 3 is removed from the group (Fig. 41b), the sharpness of the upper cut-off of filter 2 and the lower cut-off filter 4 is reduced considerably. Also, the sharpness of the upper and lower cut-offs of filter 3 is reduced by its removal from the group (Fig. 41c). Therefore, the adjacent filters in a parallel group tend to sharpen each others cut-off. As well as affecting each others cut-off, adjacent filters also effect the impedance versus frequency characteristics.



(a) Frequency / Attenuation Characteristic of a Parallel Filter Group.



(b) Effect When a Filter is Removed.



(c) Effect on The Filter Which Has Been Removed.

FIG. 41. EFFECTS OF ADJACENT FILTERS IN A PARALLEL GROUP.

4.11 COMPENSATING NETWORKS. As shown in Fig. 41, band pass filters designed to operate in parallel, and with small separation bands, are dependent on the presence of an adjacent filter on each side for their satisfactory performance. However, the end filters of a parallel group have an adjacent filter on one side only. Therefore, the sharpness of the cut-off of the extreme frequency sides of the end filters would suffer.

To correct for this, compensating networks are provided to simulate the effects of the adjacent filters which would be required at the extreme ends of the filter group. For example, in the group of three band pass filters shown in Fig. 42a, the compensating networks simulate the effects of filters 0 and 4 which would be required to sharpen the lower cut-off of filter 1 and the upper cut-off of filter 3. These networks are connected in parallel with the filter group and are usually manufactured in separate containers. In block schematic diagrams, both compensating networks are usually represented by the one block, as shown in Fig. 42b.

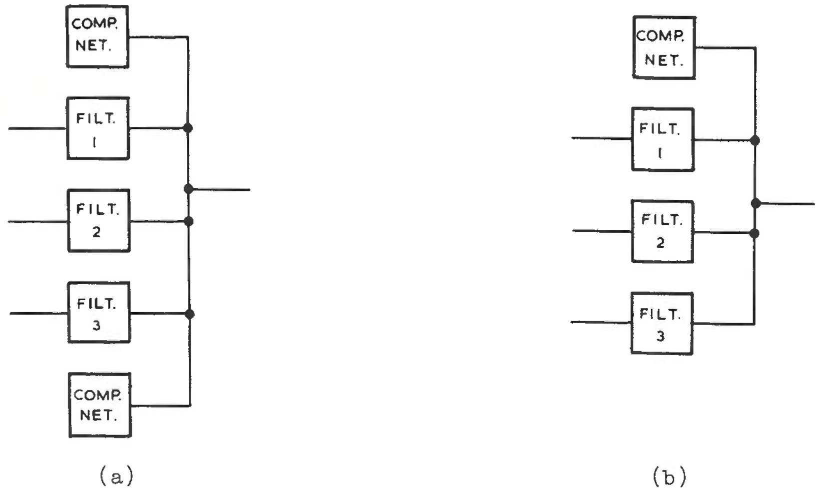
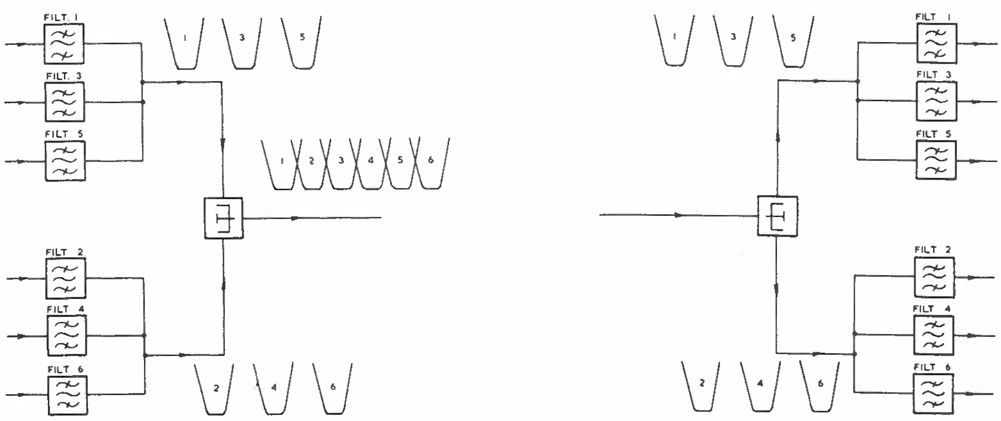


FIG. 42. COMPENSATING NETWORKS.

4.12 FILTER DECOUPLING. In most modern carrier systems, the problems of interaction between adjacent filters, separated by relatively small bands, are reduced by splitting the filters into two separate parallel groups, as shown in Fig. 43. In this arrangement, filters 1, 3 and 5 operate directly in parallel and are connected through a hybrid coil to the transmission path. Similarly, filters 2, 4 and 6 operate directly in parallel and are also connected through the hybrid coil to the transmission path. The hybrid coil provides isolation and prevents the odd and even numbered filters from effecting each other's characteristics. Because of the wide separation bands existing between the filters which are actually in parallel, the use of hybrid decoupling allows for a more simple filter design. For example, in Fig. 43a, filters 1, 3 and 5 have relatively wide separation bands, which results in negligible interaction between them. Similarly filters 2, 4 and 6 are separated by relatively large bands.

The hybrid decoupling arrangements for the transmission and reception of signals are shown in Fig. 43a and 43b respectively. The transmitted signals from the band pass filters are combined in the hybrid coil and applied to the transmission path. At the receiving station, each filter selects its particular frequency band, via the hybrid coil. At both the transmitting and receiving stations, the hybrid coil provides effective isolation between the odd and even numbered filters.



(a) Transmission (b) Reception

FIG. 43. HYBRID DECOUPLING OF FILTERS.

4.13 CRYSTAL FILTERS. Another type of filter used in line transmission equipment is the crystal filter. Some of the main features of this type of filter are:-

- A low attenuation in the pass range.
- A high attenuation in the range of frequencies to be rejected.
- A sharp cut-off.
- Provides sharp cut-offs for very narrow pass bands, and for very narrow rejection bands.
- A higher Q factor, which makes them very stable when used as narrow band pass filters.

However, crystal filters are expensive, and this limits their application in line transmission equipment to those situations requiring their particular characteristics, and where these characteristics cannot be obtained satisfactorily with a more economical filter. For example, extremely narrow bandwidth crystal filters are employed as pilot pick-off and pilot stop filters in carrier systems. Also, crystal filters are used as M.B.F's and D.B.F's in some twelve channel carrier telephone systems using channel carrier frequencies from 64 to 108 kHz.

4.14 The crystals used in filters are carefully cut to the correct size and shape from a substance, such as quartz, which possesses excellent peizoelectric properties. The peizoelectric properties of the crystal cause it to vibrate mechanically when an alternating e.m.f. is applied across the opposite faces. The distortion of the crystal produced by these mechanical vibrations causes it to behave electrically in a similar manner to a series L, C and R circuit.

The equivalent circuit of a vibrating crystal is shown in Fig. 44. The parallel capacitance C1 represents the capacitance between the faces of the crystal, and exists at all times regardless of whether the crystal is vibrating or not.

Crystals possess two resonant frequencies, a series resonant frequency (fr) and a parallel (antiresonant) frequency (fa). The series resonant frequency is determined by the series L and C properties of the vibrating crystal. The parallel resonant frequency is slightly higher than the series resonant frequency, and is determined by the series properties of the crystal in conjunction with the parallel capacitance C1. The values of these resonant frequencies are determined by the size and shape of the crystal.

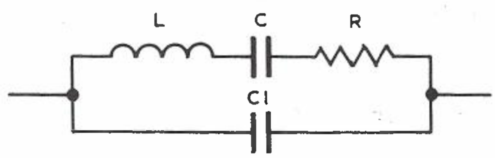
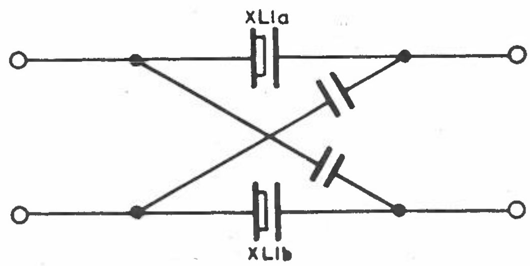


FIG. 44. EQUIVALENT ELECTRICAL CIRCUIT OF A VIBRATING CRYSTAL.

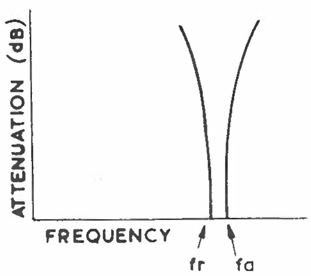
4.15 NARROW BAND PASS CRYSTAL FILTERS. A number of different configurations are used in crystal filters, but the most common is the lattice configuration. The reason for using lattice configurations instead of ladder configurations (that is T, π, H and O) in crystal filters is a matter of circuit design and is not dealt with in this paper. The simplest lattice filter possible, containing two identical crystals, is shown in Fig. 45a. The pass band of the filter is the frequency range between the series resonant frequency (fr) and the parallel resonant frequency (fa) of the crystals (Fig. 45b).

The maximum parallel resonant frequency which can be obtained in a crystal is only 0.36% higher than the series resonant frequency. This means that the maximum pass band which can be obtained in a simple crystal filter is 0.36% of the series resonant frequency. For example, if the series resonant frequency of the crystal is 100,000 Hz, the maximum parallel resonant frequency obtainable with the crystal would be 100,360 Hz, and the maximum possible pass band of the simple filter would be 360 Hz.

By connecting suitable value capacitors in parallel with the crystals the width of the pass band can be reduced further, and very narrow bandwidth filters with extremely good characteristics can be obtained.



(a)

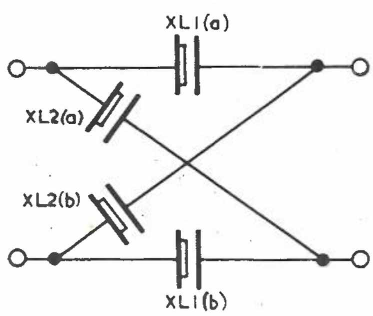


(b)

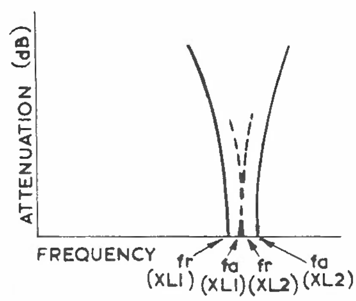
FIG. 45. SIMPLE LATTICE CRYSTAL FILTER.

A bandwidth equal to twice that of the simple lattice arrangement may be obtained by using two pairs of crystal connected as shown in Fig. 46a. The crystals are chosen so that the pass range of one pair, (say XL1), is adjacent to the pass band of the other pair, (XL2). In other words, the anti-resonant frequency of crystals XL1 coincides with the resonant frequency of crystals XL2, as shown in Fig. 45b.

Therefore, crystals XL1 conduct for one half of the pass range and crystals XL2 conduct for the other half. With this arrangement a maximum pass band of 0.72% of the lower resonant frequency may be obtained. Once again the pass band of this arrangement may be reduced by connecting suitable capacitors across the crystals. This lattice arrangement forms the basis for many wider band pass crystal filters.



(a)



(b)

FIG. 46. BASIC LATTICE CRYSTAL FILTER.

4.16 WIDE BAND PASS CRYSTAL FILTERS. To obtain wider pass bands in crystal filters inductors are connected in series with the crystals, as shown in Fig. 47. The inductors do not affect the parallel resonant frequency of the crystals, but alter the series resonant frequency and thus increase the frequency range available between fr and fa. The maximum bandwidth available with this arrangement is approximately 14% of the lowest resonant frequency. This bandwidth can be reduced, when required, by connecting capacitors in parallel with the crystals.

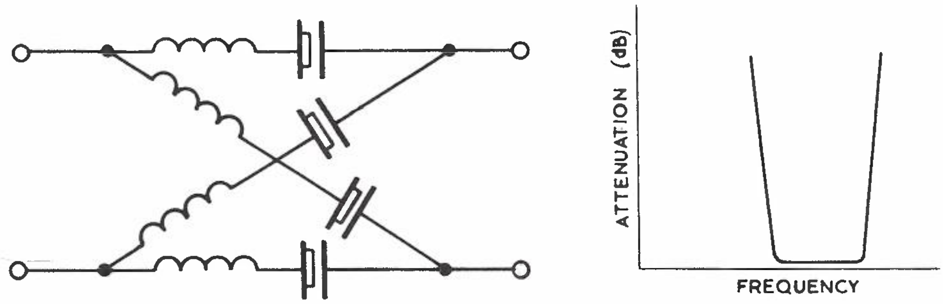
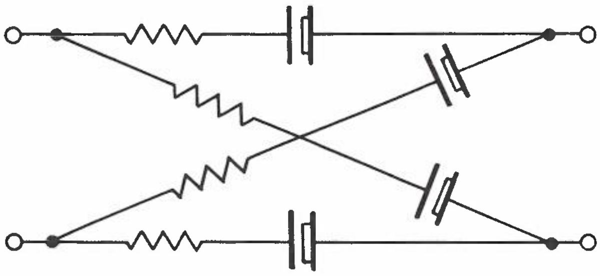
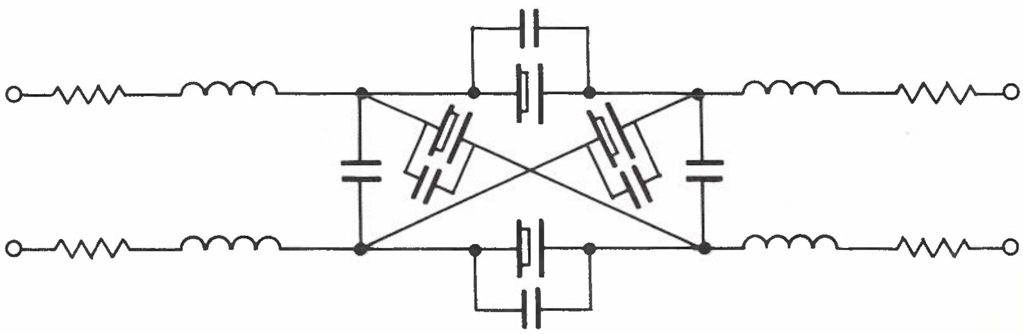


FIG. 47. BASIC WIDE BAND PASS FILTER.

Examples of practical crystal filters are shown in Fig. 48. The narrow band pass filter is used to pick off a pilot frequency in a carrier telephone system. The wide band pass filter (Fig. 48a) is a channel M.B.F. Crystal filters may also be constructed to have low pass, high pass, and band elimination properties. However, the design of these filters varies according to the manufacturer, and since the applications of high pass and low pass crystal filters are very limited, they are not explained in this paper.



(a) Narrow Band Pass Crystal Filter.



(b) Wide Band Pass Crystal Filter.

FIG. 48. EXAMPLES OF PRACTICAL CRYSTAL FILTERS.

4.17 MECHANICAL FILTERS. This type of *band pass filter* has been introduced into some carrier systems, and has the following features:-

- Small in size, which makes them suitable for miniaturised construction.
- High frequency stability; they resist ageing, breakdown, and drift due to extreme temperature variations, or long continuous service.
- Low attenuation to the pass band of frequencies.
- A very high attenuation to the rejected frequencies.
- A very sharp cut-off.
- A high Q factor.

A mechanical filter receives electrical energy, converts it into mechanical vibrations, rejects unwanted frequencies, and then converts the mechanical vibrations back into electrical energy at the output. Basically a mechanical filter can be divided into the three main sections shown in Fig. 49. These sections are:-

- *The Input Transducer.* A transducer is a device which changes electrical energy into mechanical energy, or vice versa. The input transducer changes the electrical energy of the received signal frequencies into mechanical vibrations.
- *The Mechanical Resonant Section.* The vibrations produced by the input transducer are mechanically coupled to the mechanical resonant section. This section contains a device which is designed to vibrate mechanically to all frequencies in the pass range of the filter.
- *The Output Transducer.* This is mechanically coupled to the output of the mechanical resonant section and converts the vibrations back to an A.C. electrical signal.

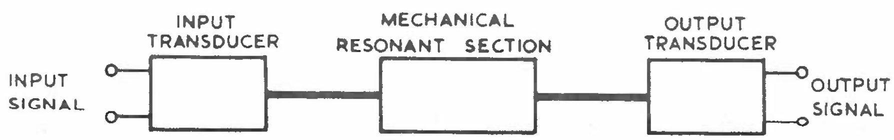


FIG. 49. BASIC PRINCIPLES OF MECHANICAL FILTERS.

4.18 A number of different types of mechanical filters exist, and other types are being developed. The principle of one type is shown in Fig. 50. The transducers consist of a coil and a rod of magnetostrictive material which elongates or shortens when in the presence of a magnetic field. Therefore, when an alternating signal passes through the input transducer coil, the transducer rod vibrates longitudinally. The transducer rod is connected to the first disc in the series of metal discs in the mechanical resonant section. These discs are coupled together with one or more coupling rods, and each disc is designed to mechanically resonate at a different frequency in the pass band of the filter.

The resonant frequencies of the metal discs are spaced evenly over the pass range of the filter to ensure a flat response to the pass band of frequencies. The last disc of the mechanical resonant section transfers the mechanical vibrations to the output transducer rod. This rod vibrates and induces an A.C. electrical signal, corresponding to the range of vibrations passed by the mechanical resonant section, into the coil of the output transducer. The A.C. voltage induced into the output transducer coil is connected to the output terminals of the filter.

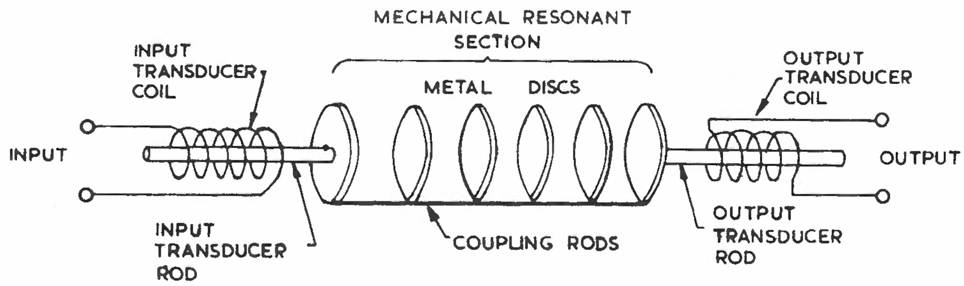


FIG. 50. ELEMENTS OF A MECHANICAL FILTER.

4.19 Another type of transducer used in mechanical filters is the crystal transducer shown in Fig. 51. This type of transducer relies on the peizoelectric property of crystals, which causes crystals to vibrate mechanically when subjected to an A.C. voltage across their faces, or alternatively, when mechanically vibrated to produce an A.C. voltage across their faces. The input and output crystal transducers are connected to the metal discs in a similar manner to the magnetostrictive type. The input A.C. signal is applied across the input crystal transducer causing it to vibrate mechanically. These vibrations are fed through the metal discs of the mechanical resonant section and vibrate the output transducer crystal. The A.C. voltage produced across the faces of the output transducer crystal by these vibrations is connected to the output terminals of the filter.

Some mechanical filters also use crystal elements instead of metal discs and rods in the mechanical resonant section.

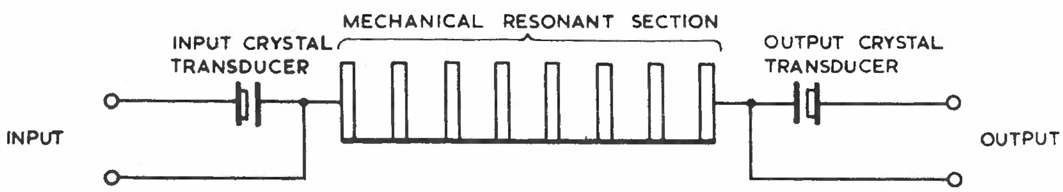


FIG. 51. MECHANICAL FILTER EMPLOYING CRYSTAL TRANSDUCERS.

5. TEST QUESTIONS.

1. *What is an active network?*

2. *What is a passive network?*

3. *State the functions of a hybrid coil.*

4. *Draw the circuit of a two transformer type hybrid coil and explain*

   (i) The operation when a signal is being transmitted from 'Hybrid In' to 'Hybrid Line'.

   (ii) Why the signal level at 'Hybrid Line' is approximately 3.6 dB lower than the signal level at 'Hybrid In'.

   (iii) Why 'Hybrid Out' is isolated from 'Hybrid In'.

5. *What is a four-wire terminating set?*

6. *Draw the circuit of a single transformer type hybrid coil and explain its operation.*

7. *What is a pad?*

8. *What is an attenuator?*

9. *Sketch four types of balanced pad configurations.*

10. *List the main requirements of pads.*

11. *Briefly explain why a single series or shunt resistor is not suitable for introducing a known loss into a line transmission equipment circuit.*

12. *What is*

    (i) A symmetrical pad?

    (ii) An asymmetrical pad?

13. *Using Table 1 design*

    (i) A 30 dB symmetrical H pad suitable for 600 ohm equipment.

    (ii) A 20 dB symmetrical T pad suitable for 150 ohm equipment.

    (iii) A 15 dB symmetrical O pad suitable for 75 ohm equipment.

14. *An L pad has a 300 ohm resistor in the series arm and a 900 ohm resistor in the shunt arm. Explain how this pad matches 600 ohm equipment to 450 ohm equipment.*

15. *Explain the function of an impedance masking pad.*

16. *What is a minimum loss pad?*

17. *The impedances which should be connected to the input and output of a pad are not known. Explain how they could be determined.*

18. *State the functions of the four types of filters and sketch the symbol used to represent each.*

5. TEST QUESTIONS (CONTD).

19. *List the requirements of filters.*

20. *Draw the circuits and frequency versus attenuation characteristics of the four basic inductor-capacitor type filters.*

21. *What are the limitations of basic filters?*

22. *Draw typical frequency versus attenuation characteristics of practical high pass and low pass filters.*

23. *Briefly explain why parallel filters with small separation bands are designed to operate as an integral unit.*

24. *What are composite networks and why are they used?*

25. *With the aid of a sketch explain the principles of hybrid decoupling. What is the advantage of hybrid decoupling?*

26. *Sketch the equivalent electrical circuit of a vibrating crystal.*

27. *List the main features of crystal filters.*

28. *Sketch a basic lattice crystal filter.*

29. *How does the cut-off of a crystal filter compare with the cut-off of an inductor-capacitor type filter?*

30. *Describe the principle of operation of a mechanical filter.*

END OF PAPER

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