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CROSSTALK, DERIVED CIRCUITS AND LOADING.

CONTENTS.

1. INTRODUCTION.

1.1 The intelligibility of telephone conversations depends not only on reducing the attenuation and distortion produced by the characteristics of telephone lines, as discussed in Paper No. 1, but also on the absence of noise and crosstalk introduced along a line from neighbouring circuits. This Paper will deal with the causes of such noise and crosstalk, and the line practices employed to reduce them.

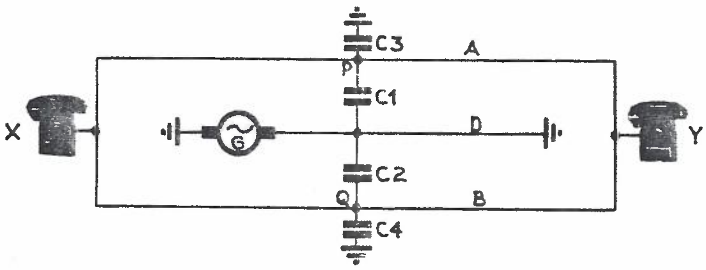
1.2 This Paper also deals with derived circuits and the practice of loading cables.

2. INDUCTIVE CO-ORDINATION.

2.1 If each telephone circuit were completely isolated from all other electrical circuits, no potentials, other than those deliberately introduced for the purposes of telephone transmission, would be present in any telephone circuit. In practice, however, telephone circuits are rarely entirely isolated, as they are in close proximity to other telephone circuits and to other electrical circuits, such as power lines. All electrical circuits set up fields which extend into space, and these fields cause interference in the form of noise and crosstalk in neighbouring circuits. The fields set up by an electrical circuit are electric and magnetic in nature, and, unless circuits (particularly those near to one another) are properly co-ordinated, these fields cause interference by induction. The proper co-ordination of the circuits to minimise interference has been called Inductive Co-ordination. Before proceeding with the methods used to minimise interference, a knowledge of how the two fields produce interference is necessary.

3. INTERFERENCE CAUSED BY ELECTRIC FIELD.

3.1 The potential difference between wires in neighbouring circuits and between those wires and the earth sets up an electric field, because of the dielectric properties of the insulating medium separating the wires. Thus, a number of capacities exist as shown in Fig. 1, which contains a single wire disturbing circuit D (to which an alternating voltage is applied from a generator G) and a metallic telephone circuit, the A and B sides of which connect two telephones, X and Y. If D is equidistant from the A and B sides of the telephone circuit, and the A and B sides are equidistant from the earth, then C1 = C2 and C3 = C4. Equal currents will flow from the generator G to earth via C1 and C3, and via C2 and C4, as well as to earth at the distant end of D, producing equal voltage drops across their reactances. Thus, point P will exhibit the same alternating potential as point Q, and no current from G will flow through the telephones X and Y, which connect these two points.

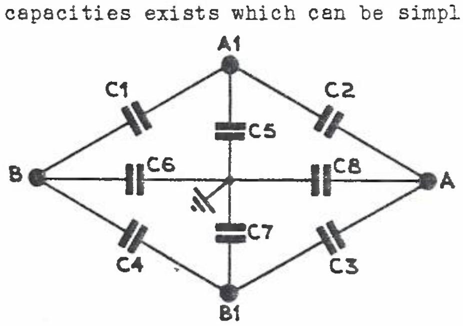


CAPACITANCES EXISTING BETWEEN NEIGHBOURING LINES.

FIG. 1.

3.2 If, now, D is not equidistant from the A and B sides of the telephone circuit and/or the A and B sides of the telephone circuit are not equidistant from the earth, then $C1 \neq C2$ and/or $C3 \neq C4$. Unequal currents, therefore, flow from the generator G to earth via C1 and C3, and via C2 and C4, producing unequal voltage drops across their reactances. Thus, an alternating difference in potential will exist between points P and Q, resulting in disturbing currents flowing through the telephones at X and Y, which connect these two points. If D is carrying a telephone conversation, the result is crosstalk which can be audible if the capacity unbalance is too large, whilst, if D is a power line, the result is noise, not only at the 50 c/s fundamental frequency in the power circuit, but also at harmonics of this frequency, as harmonics are almost invariably present in any power circuit. The same condition will exist if the insulation resistances between D and the A and B sides of the telephone circuit, or between the A and B sides of the telephone circuit and the earth, become unbalanced.

3.3 When the disturbing circuit is metallic, that is, two-wire, a complicated network of capacities exists which can be simplified into a bridge circuit, as shown in Fig. 2.



CAPACITY BRIDGE.

FIG. 2.

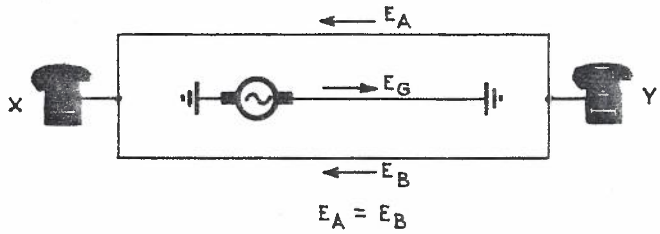
The bridge circuit is a cross section of two circuits, A and B being the two wires of one circuit and A1 and B1 the two wires of the other circuit.

If the four wires are symmetrically disposed, then each of the four capacities between the wires will be equal, these being C1, C2, C3 and C4 in Fig. 2. This, however, is not a balanced condition, as the capacities to earth provide parallel capacities across the wire to wire capacities. For example, C5 and C6 are in parallel with C1, C6 and C7 are in parallel with C4, and so on. Not only must the wire to wire capacities be equal, but also the wire to earth capacities, as in the single wire disturbing circuit case. Under this condition, wires A1 and B1 will act as null points of a balanced bridge when a voltage is applied across A and B, and wires A and B will act as the null points when a voltage is applied across A1 and B1, and no interference results.

/ 4.

4. INTERFERENCE CAUSED BY MAGNETIC FIELD.

4.1 The alternating current flowing through D of Fig. 1 produces an alternating flux which links the two sides of the telephone circuit, E_A of Fig. 3 being the voltage induced across the A side and E_B the voltage induced across the B side.

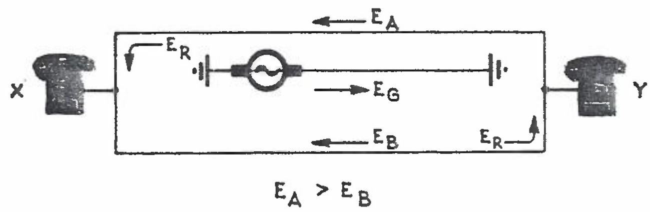


EQUAL VOLTAGES INDUCED BY MAGNETIC FIELD.

FIG. 3.

The directions indicated in Fig. 3 apply for one half-cycle, being reversed during the other half-cycle. When D is equidistant from A and B, then the amount of flux linking the A side equals that linking the B side, so that $E_A = E_B$, leaving no resultant voltage to send a disturbing current around the circuit and through the telephones at X and Y.

4.2 When D is not equidistant from A and B, a resultant voltage sends current through X and Y. The position is indicated in Fig. 4, where D is nearer to A than it is to B.



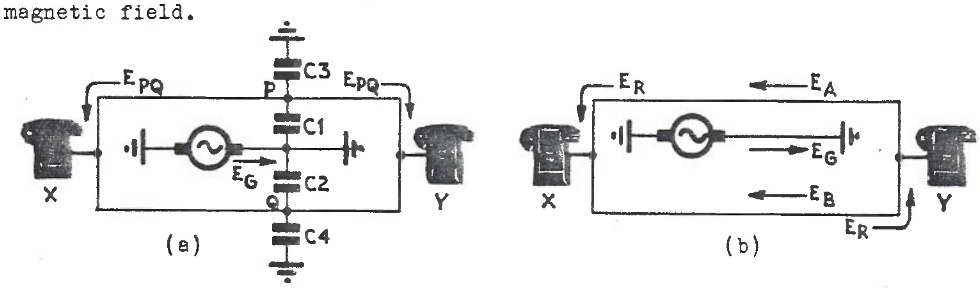
UNEQUAL VOLTAGES INDUCED BY MAGNETIC FIELD.

FIG. 4.

Here, the amount of flux linking A will be greater than that linking B, so that E_A is greater than E_B, leaving a resultant voltage E_R to send a disturbing current in the direction indicated. During the other half-cycle developed by G, all directions are reversed, so that a disturbing alternating current of the same frequency as that developed by G will pass through the telephones X and Y.

5. COMBINED EFFECTS OF ELECTRIC AND MAGNETIC INTERFERENCE.

5.1 Fig. 5 shows what can happen when the interferences caused by the electric and magnetic fields are considered together rather than separately. Here, again, D is nearer to A than to B, Fig. 5a indicating the effect of the electric field during the half-cycle of voltage developed by G, and Fig. 5b indicating the effect of the magnetic field.



COMBINED EFFECTS OF ELECTRIC AND MAGNETIC FIELDS.

FIG. 5.

As D is nearer to A than to B, C1 will be greater than C2, therefore the reactance of C1 will be smaller than that of C2. The voltage drop across C1 will be smaller, therefore, than that across C2, resulting in point P exhibiting a potential above, or positive to, that exhibited by point Q for the half-cycle indicated in Fig. 5. Combining Figs. 5a and 5b, it will be seen that the resultant voltage due to the magnetic field aids the voltage due to the electric field at X, whilst opposing it at Y. A little consideration will show that, during the other half-cycle, the same conditions exist but with all voltages reversed.

/ 5.2

5.2 Thus, cases can arise where one end of a circuit is noisy or where the crosstalk level is high, whilst the other end of the circuit is silent. Under such conditions, it is necessary to specify the end of a circuit to which a crosstalk level refers. In Fig. 5, the crosstalk at X is referred to as "near-end" crosstalk, because it is the end of the disturbed circuit nearest the end of the disturbing circuit to which the disturbing source of supply is connected. The crosstalk at Y is termed "far-end" crosstalk for the opposite reason.

6. PRINCIPLES OF CROSSTALK REDUCTION IN CABLES.

6.1 There are a number of ways of eliminating or, at least, reducing crosstalk. As metallic, that is, two-wire, circuits are almost exclusively used in telephone transmission, one method is to arrange the paralleling wires in such a configuration that the effect of the field of one pair will be the same at both wires of the other pair, and vice versa, thus leaving no resultant voltages to produce interference.

6.2 Fig. 6 shows two possible ways to effect such a non-inductive configuration.

(a)   (b)

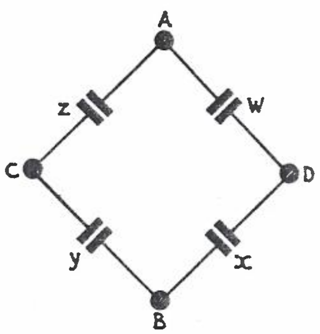
STAR QUAD (a) AND MULTIPLE TWIN (b) FORMATION.

FIG. 6.

It is not possible, because of practical difficulties, to arrange aerial circuits in this manner. Cables, however, can be manufactured with each two pairs arranged as in Fig. 6, each two pairs being known as "QUAD". When the quads are arranged as in Fig. 6a, the cable is termed a Star Quad cable. The arrangement shown in Fig. 6b is closely approximated by the Multiple Twin cable. The Star Quad cable is used almost exclusively, having superseded the Multiple Twin type about 1935.

6.3 In the manufacture of Star Quad cable, it is possible to restrict the capacity unbalances existing between the four wires of a quad to only a minimum value; manufacturing difficulties preclude the complete elimination of unbalance. It is, therefore, necessary to joint together the short lengths of cable which go to make up the whole length of a long cable, in such a manner that the over-all capacity unbalance is reduced to a predetermined minimum.

6.4 To illustrate the principle, Fig. 2 of this Paper is redrawn as Fig. 7. The capacities C5, C6, C7 and C8 of Fig. 2 are included in the capacities w, x, y and z of Fig. 7. This is possible because C5 and C6 shunt C1 in Fig. 2, C6 and C7 shunt C4, and so on. Wires A and B form one pair of the quad and wires C and D form the other pair. For any voltage introduced across A and B, there should be no resultant voltage across C and D, and vice versa. Thus, the following proportion must exist -



CAPACITY BRIDGE.

FIG. 7.

$$w : x :: z : y$$

$$\text{or } w.y = x.z$$

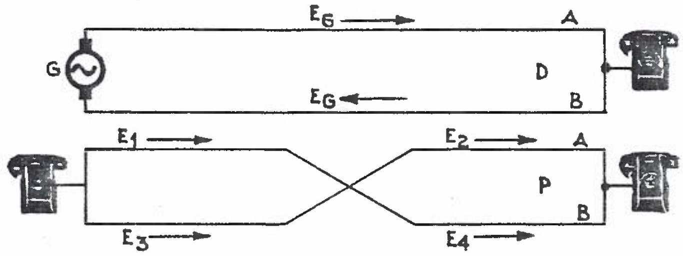
6.5 Assume, now, that in one length of a cable the capacities are measured and that $w.y > x.z$. This unbalance could be corrected by increasing x or z, and this is done in some cases (such as loaded cables, to be dealt with later). Where it is possible to connect together adjacent lengths of cable, the quad discussed above would be connected to a quad in the adjacent length whose measured capacities are such that $w.y < x.z$ by an amount approximately equal to that by which $w.y > x.z$ in the first quad. By providing balancing condensers over each predetermined length of cable in the case of loaded cables, the whole length of cable will exhibit zero unbalance when jointed right through. In the other case, the over-all unbalance is reduced to a minimum, which can be corrected at the end of predetermined long lengths by added capacity in the form of balancing condensers.

The above gives merely the principle used. A later Paper deals more fully with the subject and with the measuring technique employed.

/ 7.

7. PRINCIPLES OF CROSSTALK REDUCTION ON AERIAL LINES.

7.1 Because of practical difficulties, it is not possible to arrange aerial wires in the manner shown in Fig. 6. The scheme used on aerial circuits is one of transposition, and Fig. 8 shows the idea.



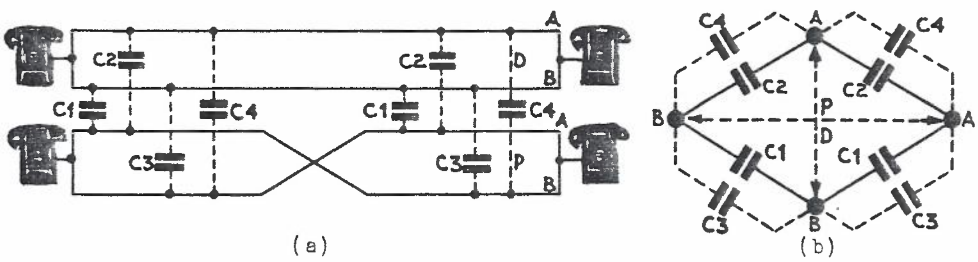
PRINCIPLE OF TRANSPOSITION.

FIG. 8.

A cross-over of the two sides of circuit P, which parallels another circuit D to which an alternating voltage is applied, is made half-way along the length of the line. The direction of the voltage acting in D at some instant is indicated.

7.2 Considering the magnetic interference first, the magnetic interference produced in P by the A side of D will oppose that produced by the B side, because the fields produced by the A and B sides of D oppose. However, as the B side of D is nearer to P than is the A side, the voltage induced across P by the B side of D will be greater than the voltage induced by the A side, producing resultant voltages across the two sides of P in the directions indicated. As the transposition is in the centre of P, then E1 = E2 and E3 = E4, and as E1 + E4 acts in opposition to E3 + E2, then there will be zero voltage acting around P and, therefore, no interference due to the magnetic field.

7.3 Turning now to the wire to wire capacities, the unbalancing of which causes the electric interference, an examination of Fig. 9 will show that a state of capacity balance exists.



CAPACITANCES PRESENT ALONG TRANSPOSED LINE.

FIG. 9.

The actual wire to wire capacities are shown in Fig. 9a whilst an equivalent network is shown in Fig. 9b. Equal capacities carry identical designations, for example, the capacity from one half of the B side of D to one half of the B side of P is designated C1, as is the equal capacity from the other half of the B side of D to the other half of the A side of P. From Fig. 9b it will be seen that a balanced bridge exists both for voltages applied across the A and B sides of D or the A and B sides of P.

7.4 By transposing D and leaving P wired straight through, a similar non-inductive stage will exist between the two circuits. A transposition at the same point in both

/ circuits,

circuits, however, will obviously have no effect in reducing interference.

7.5 Whilst a single transposition, as discussed, is effective in limiting crosstalk in a relatively short length of line, it would not be effective in the case of a long line for two reasons.

7.6 In the first place, because of attenuation, the voltage and current at the energised end of a line are many times as great as near the far end. Thus, the crosstalk voltages and currents induced on the energised side of the transposition will be greater than those on the far side, and they will neutralise in part only and not wholly. As regards near-end crosstalk, this is increased by the fact that the induced voltages and currents coming back from the far side of the transposition are necessarily attenuated to a greater degree than those coming back from the near side. On the other hand, far-end crosstalk is reduced because the slightly higher induced voltages and currents on the near side of the transposition are attenuated more in reaching the far end of the circuit than are those induced on the far side.

7.7 In the second case, the phase shift along the line will mean that the line may be one or a number of wavelengths long at higher frequencies. Thus, not only will the crosstalk voltages and currents induced along the line decrease along the line due to attenuation, but they will also change in magnitude and direction over the transposition sections due to the phase shift. Thus, if one transposition section has a maximum crosstalk voltage induced across it at some instant, that voltage cannot be neutralised by some other section across which the crosstalk voltage is perhaps zero or opposite in phase. It is necessary, therefore, that the transpositions be more frequent for higher frequencies, so that the crosstalk voltages and currents produced in one transposition section can be almost neutralised by approximately equal voltages and currents in the adjacent section.

7.8 In some cases (for example, 140 kc/s, the highest frequency allocation on Type J carrier telephone systems) transpositions as close as every second pole may be necessary.

8. EFFECT OF REFLECTION ON CROSSTALK.

8.1 The transposition scheme outlined above does not eliminate crosstalk - this can only be done by employing an infinite number of transpositions. Similarly, in cables, manufacturing and installation difficulties prevent perfectly balanced quads from being obtained. As described in Long Line Equipment III, unbalance measurements are made on cables when they are laid down and the unbalance correctives applied limit the unbalance, so that, as with a practical transposition scheme, the crosstalk is below the level of audibility when normal voltages are employed. As discussed previously, reflection produces waves whose amplitude is the vector sum of the reflected and incident waves. This means that reflection can increase crosstalk by increasing the amplitude of the voltages and currents in a circuit in which reflection takes place, that is, a circuit which is incorrectly terminated or has any impedance irregularities. Thus, crosstalk is an added reason why circuits should be correctly terminated and uniform in construction.

/ 9.

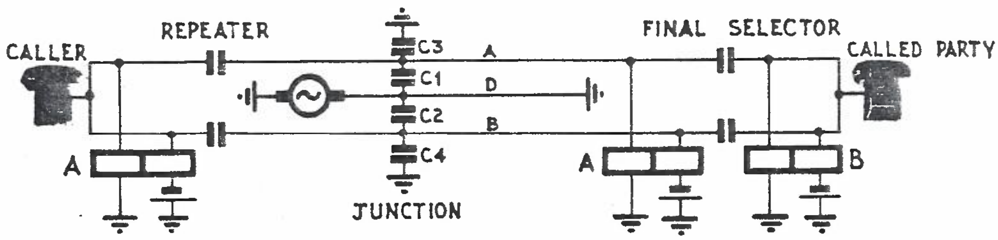
9. EFFECT OF BALANCE.

9.1 Whilst a circuit may be perfectly transposed, interference can still be produced if the linear impedance and metallic impedances to earth are not balanced. A metallic connection to earth exists because all C.B. manual and automatic telephones use an earthed battery for supplying transmitter battery feed current.

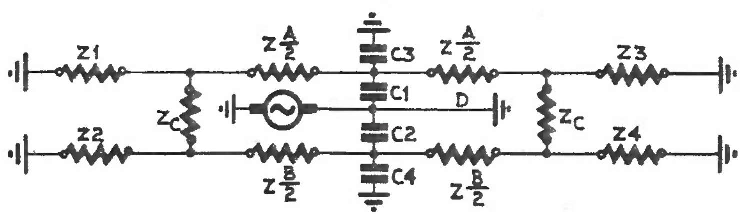
9.2 Fig. 10a shows the through connection between two subscribers connected to different automatic exchanges connected together via a junction, together with a disturbing circuit D equidistant from the A and B sides of the junction.

Fig. 10b is the equivalent circuit with Z1 and Z2 replacing the repeater A relay windings, Z3 and Z4 replacing the final selector A and D relay windings, Z_C replacing the calling and called parties' lines and telephones and Z_A and Z_B replacing the A and B sides of the junction respectively. Currents will now flow to earth via Z1, Z2, Z3, Z4, $Z\frac{A}{2}$ and $Z\frac{B}{2}$ from G, as well as via C3 and C4.

If Z1 $\neq$ Z2, Z3 $\neq$ Z4 and $Z\frac{A}{2} \neq Z\frac{B}{2}$, unequal currents will flow to earth through these impedances, producing unequal voltage drops across them which result in disturbing currents through the two telephones. Thus, accurate linear balance must be maintained, as well as a balance to earth.



(a)



(b)

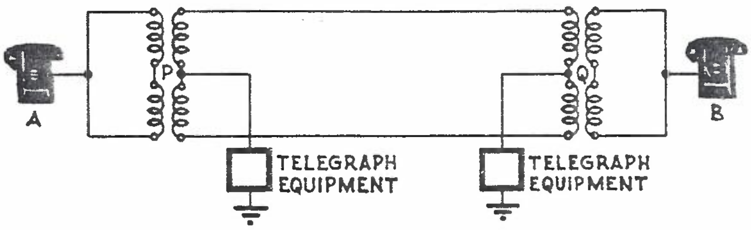
METALLIC IMPEDANCES TO EARTH ON TELEPHONE CONNECTION.

FIG. 10.

10. DERIVED CIRCUITS.

10.1 Where accurately balanced lines are available, additional channels can be derived without having to provide further line plant. Such circuits are termed "Cailho" and "Phantom" circuits. The term "Cailho" usually refers to a derived circuit using an earth return, and the term "Phantom" refers to a completely metallic derived circuit.

10.2 Cailho Circuits. Cailho circuits are generally telegraph circuits, the sensitivity of a telephone receiver precluding the use of earth return telephone circuits because of noise produced by the slight changes in potential which are continually taking place between different points on the earth's surface. These changes in potential are not great enough to produce enough current to operate relays but will make a telephone circuit extremely noisy. Also, it is not possible to transpose a single wire, so that crosstalk would be excessive between neighbouring single wire lines. Fig. 11 shows the principle of the cailho circuit to derive a telegraph channel from an existing physical telephone circuit.

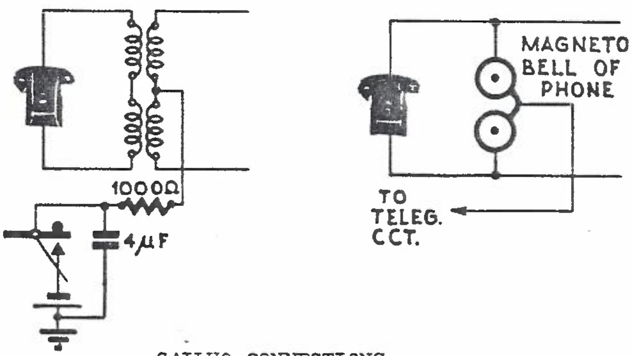


CAILHO CIRCUIT.

FIG. 11.

No interference between the telephone and telegraph circuits will arise, provided the windings of the transformers are accurately differential and the two sides of the physical circuit are balanced as regards both linear impedance and impedance to earth. Under this condition, telegraph signals divide equally at the centre point of the line windings of the transformers to flow through the two halves in opposite directions, producing equal fluxes which neutralise to leave zero resultant flux.

Thus, no voltages can be induced across the transformer windings connected to the telephones by currents from the telegraph equipment passing through the line windings. If the transformer windings or the two sides of the line are unbalanced as regards either linear impedance or impedance to earth, the telegraph currents do not divide equally. Therefore, the two fluxes produced by the line windings of the transformers do not neutralise and interference arises between the circuits, because the resultant flux induces voltages across the windings of the transformers to which the telephones are connected. The unbalance may also cause the telephone circuit to interfere with the telegraph circuit. Under the balanced condition, point P will exhibit the same potential as point Q when A is speaking to B, or vice versa. In the unbalanced condition, however, point P will exhibit a different potential from point Q, so that, whilst speech will be practically unaffected because of the high impedance of the telegraph equipment, 16 cycle ringing current may interfere with the telegraph equipment.



CAILHO CONNECTIONS.

FIG. 12.

In some cases, it is possible to utilise existing magneto bells on a trunk line in order to provide suitable centre points for connecting a cailho telegraph circuit. This is shown in Fig. 12, which contains both the transformer and bell connections to show the similarity.

/ 10.3

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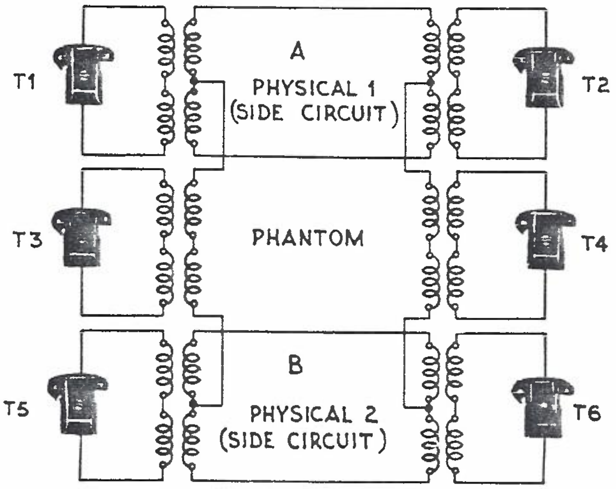
10.3 Phantom Circuits. The principle used in the cailho circuit is used in the phantom circuit, except that the metallic return is supplied by another physical circuit as shown in Fig. 13. Here, again, the circuits must be accurately balanced as regards both linear impedance and impedance to earth, and the transformers must be accurately differential.

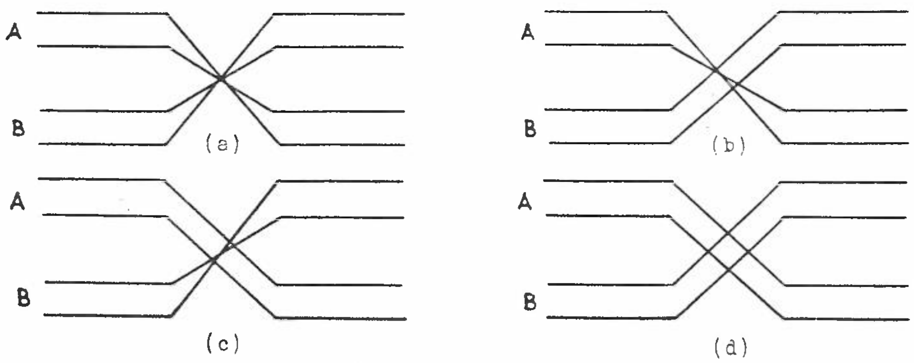
In Fig. 13, the two physical circuits A and B are usually referred to as "side" circuits. Whilst the transformers in the phantom circuit are not necessary for successful operation, they are usually included so that an unbalanced physical circuit will not upset the balance of the phantom when such a circuit is connected to the phantom.



PHANTOM CIRCUIT.

FIG. 13.

10.4 Phantom Transpositions. As each side circuit represents one side of a phantom circuit, it will be necessary to transpose the side circuits of a phantom as well as the two wires of each side circuit. Fig. 14 shows the four types of transpositions necessary to meet all conditions. Fig. 14a shows a transposition in the phantom as well as the side circuits; Fig. 14b shows a transposition in the phantom and the side circuit A; Fig. 14c shows a transposition in the phantom and side circuit B; and Fig. 14d shows a phantom transposition only.



PHANTOM TRANSPOSITIONS.

FIG. 14.

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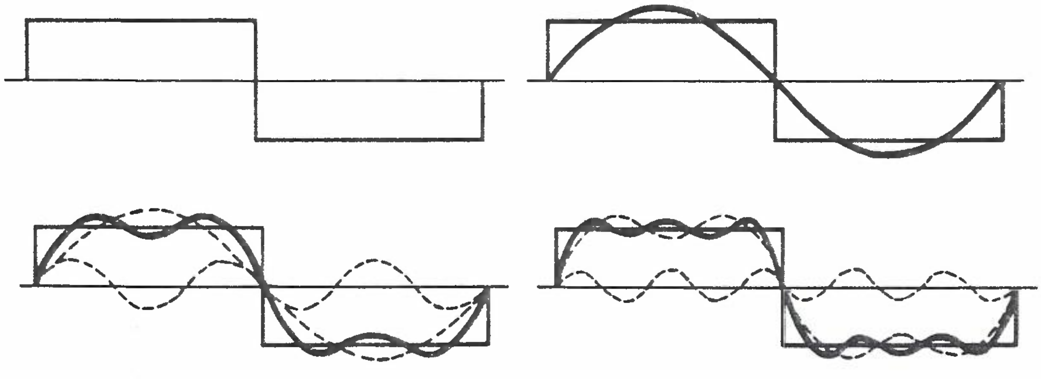
10.5 Composite Circuits. Composite circuits are provided to derive two telegraph channels from a physical telephone circuit. The composite, or C.X., set uses crude low and high pass filters to separate the telegraph and telephone signals simultaneously sent over a physical telephone circuit. Discrimination on a frequency basis can be used, because any telegraph signal can be resolved into a fundamental frequency determined by the signalling speed plus a number of odd harmonics which, when added to the fundamental, produce the "square-topped" telegraph signal.

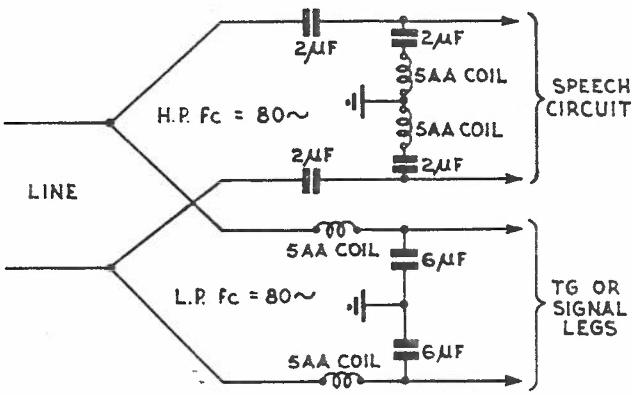
Fig. 15 shows the idea applied to a double current telegraph signal. In order to ensure reasonable signal formation, the third harmonic of the fundamental must be passed into the telegraph equipment so that the signalling speed over a C.X. circuit is fixed by the cut-off frequency of the low-pass filter used to pass the low frequency telegraph signals and block the high frequency telephone signals.



FORMATION OF SQUARE-TOPPED SIGNAL.

FIG. 15.

This cut-off frequency is about 80 c/s in a C.X. set, which fixes the upper limit at 75 c/s, producing a fundamental frequency of 25 c/s. Therefore, the signalling speed over the telegraph circuit is limited to 50 bauds. The high-pass filter, therefore, has a cut-off frequency of 80 c/s, in order to pass the higher frequency telephone signals and reject the lower frequency telegraph signals. Fig. 16 shows the arrangement of one terminal of a composited line.



COMPOSITE SET.

FIG. 16.

As the high-pass filter in the telephone channel will not pass frequencies below 80 c/s, some frequency other than 16 c/s is required for signalling over such circuits. The frequency used is 135 c/s or 1,000 c/s, the operation of these ringing circuits being dealt with later.

10.6 Combined Phantom and C.X. Circuit. In many cases, composite circuits are derived from the side circuits of phantom circuits. Fig. 17 shows a typical circuit, the C.X. sets being connected on the line side of the phantom transformers.

10.7 Fig. 18 shows, in pictorial form, the various methods of increasing the efficiency of line plant as far as telephone channels are concerned.

/ Fig. 17.

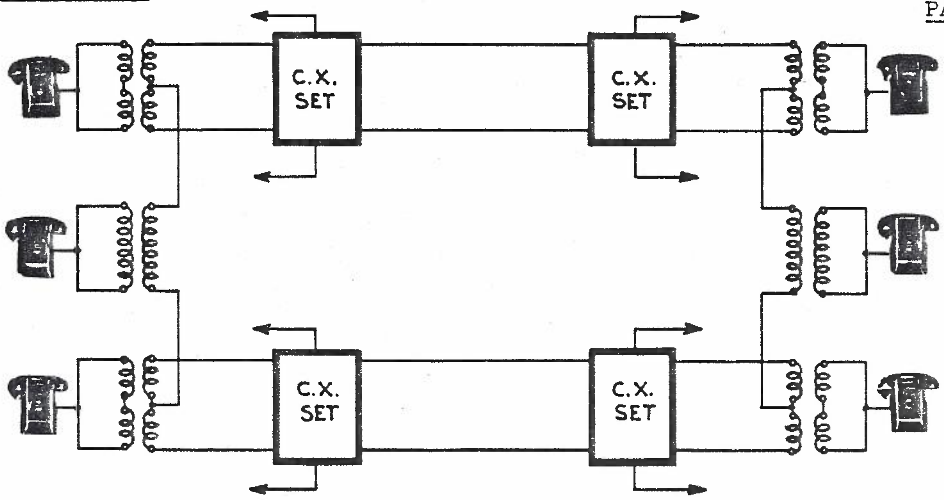


FIG. 17. PHANTOM AND COMPOSITE CIRCUITS COMBINED.

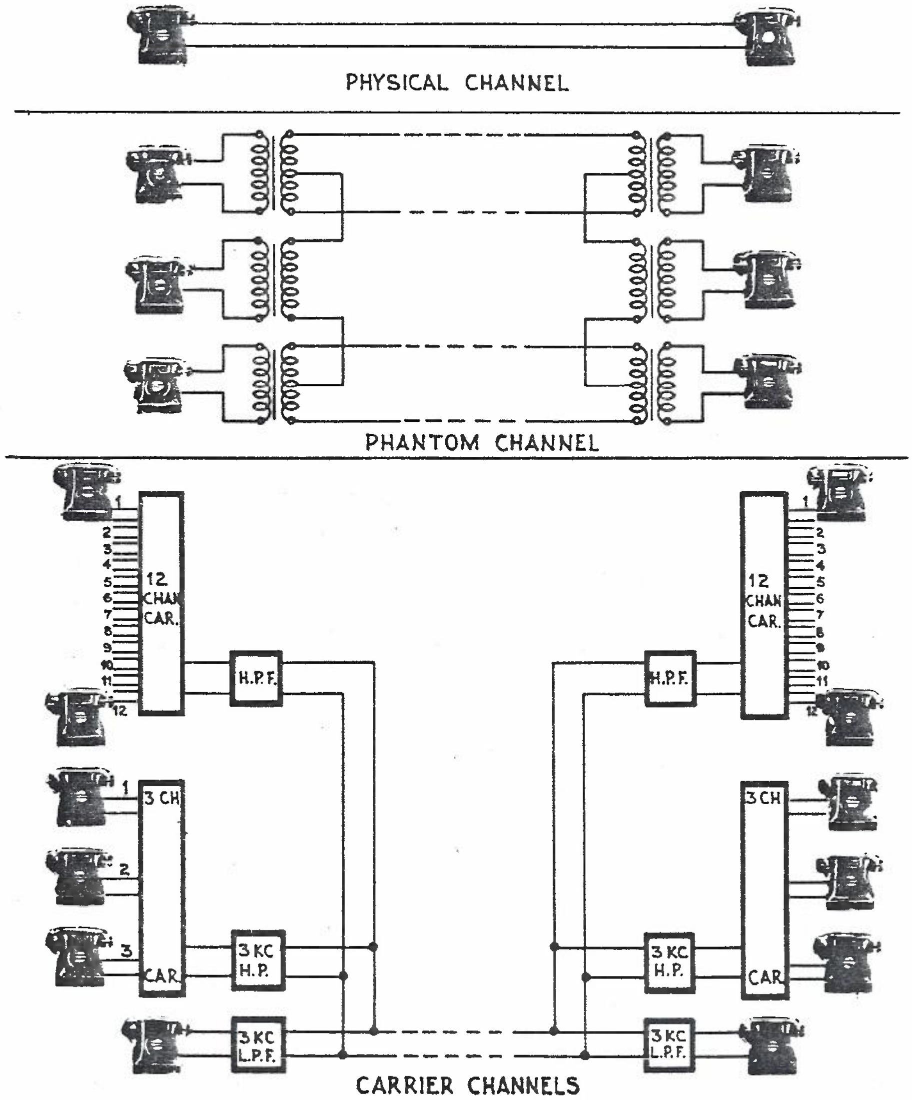


FIG. 18. TELEPHONE CHANNELS.

13. LOADING.

13.1 There are two methods used in loading practice, "Continuous Loading" and "Lumped Loading".

13.2 Continuous Loading. This process involves wrapping the line in a tape of some magnetic material. This treatment is expensive, and the amount of inductance which can be economically provided is small.

13.3 Lumped Loading. This process involves introducing inductance coils at strictly equal intervals along the length of the line. Under these conditions, the performance of the line will be modified from that obtained when the inductance is evenly and continuously distributed. This is because a lumped loaded line constitutes a series of low-pass filter sections, having the lumped inductances of the loading coils as the series inductance and the coil capacity, together with the lines distributed capacity, as the shunt capacity. Loaded circuits, therefore, display a definite cut-off frequency, this being determined by the magnitude of the inductance used and the spacing of those inductances. Thus, the value of the inductance used, together with the spacings, will be determined by the frequencies to be sent over the circuit. Voice frequency circuits are loaded with 88 millihenry coils at 6,000 feet intervals. This produces a cut-off frequency of between 3.5 kc/s and 4 kc/s, depending on the gauge of the conductor used in the cable being loaded. These loading figures are unsuitable for circuits which are required to transmit carrier frequencies or to relay broadcast programmes. "Carrier Loading" employs 3.5 millihenry coils at 750 feet intervals, producing a cut-off frequency of approximately 54 kc/s. "Programme Loading" employs 14 millihenry coils at 3,000 feet intervals, giving a cut-off frequency of at least 12.5 kc/s, depending on the gauge of the cable being loaded. Aerial circuits are not loaded, as their phase angle is normally small. This is shown in Table 2 of Paper No. 1, which indicates that, in their normal condition, aerial circuits are much more nearly non-reactive than are cables.

13.4 Loading also raises the characteristic impedance. This is extremely useful where aerial and cable sections are connected in tandem. The characteristic impedances of cables are much lower than those of aerial lines, but a smooth, continuous circuit can be provided by suitably loading the cable sections to bring their characteristic impedances up to those of the aerial sections. Table 1 shows how V.F. loading increases the characteristic impedance of cables and reduces the phase angle, as discussed above. The frequency employed is 800 c/s.

Type of Cable.	Z_o Unloaded.	Z_o Loaded.
10 lb. S.Q. Cable	366 $\backslash\overline{41^\circ 38'}$ ohms	1085 $\backslash\overline{11^\circ 3'}$ ohms
20 lb. S.Q. Cable	515 $\backslash\overline{43^\circ 16'}$ ohms	1121 $\backslash\overline{5^\circ 40'}$ ohms
40 lb. S.Q. Cable	683 $\backslash\overline{44^\circ 6'}$ ohms	1113 $\backslash\overline{3^\circ}$ ohms

TABLE 1.

13.5 This increase in Z_o also produces the highly desirable effect of decreasing the attenuation. If the same power is applied to a line and its Z_o increased, the input current will decrease. As the power loss along the line is proportional to the square of the current flowing along it, and as Z_o decreases this current, then the power loss will become smaller as Z_o is increased, meaning that the attenuation is decreased. Loading for voice frequency purposes is used mainly for this reason. At carrier frequencies, the aim of loading is not so much to reduce the attenuation as to make the characteristic impedance independent of frequency, this being achieved because the line behaves largely as though non-

/ reactive.

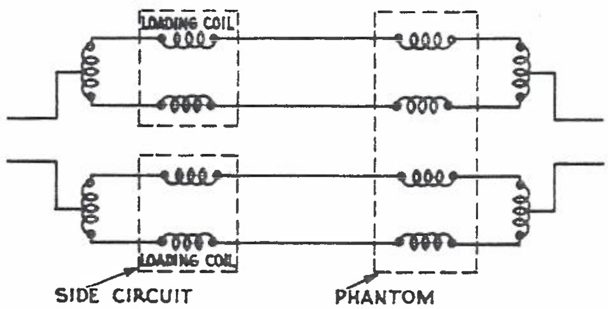
reactive. Table 2 shows how the attenuation constant is reduced by V.F. loading. The change in the phase constant is also included in Table 2. Loading will increase the phase constant, because increasing the series inductance will decrease the velocity of propagation and, therefore, increase the phase constant.

Type of Cable.	Attenuation Per Mile.		Phase Constant.	
	Unloaded	Loaded	Unloaded	Loaded
10 lb. S.Q. Cable	1.56 db	0.803 db	10°34'	33°28'
20 lb. S.Q. Cable	1.021 db	0.386 db	7°6'	26°48'
40 lb. S.Q. Cable	0.703 db	0.202 db	5°12'	26°36'

TABLE 2.

13.6 Loading Coils for Phantom Circuits. Coils for phantom loading usually have lower inductance values than side circuit coils, but they must have four windings.

Fig. 21 shows the connections of a loading point in a phantom group for the side circuits and the phantom.



LOADING COILS FOR PHANTOM CIRCUITS.

FIG. 21.

Phantom loading coils are connected in such a manner as to be non-inductive to the currents circulating in either side circuit, but inductive to the currents in the phantom circuit.

13.7 Half-Coil and Half-Section Terminations. When loading is introduced into a network, such as metropolitan junction network, attention must be given to the conditions possible when two loaded junctions are connected together.

Assume it is decided to load a junction network with 88 millihenry coils at 6,000 feet. It is necessary at a certain point in the network (that is, the main exchange) to space the coils so that, when two junction circuits are connected together, the correct spacing is maintained. This can be done in two ways -

(i) At the main exchange, a half-coil (44 millihenrys) can be used to terminate each junction, whilst 6,000 feet away a full 88 millihenry coil is inserted. This will give conditions of 88 millihenrys at 6,000 feet uniformly, when two junctions are connected together. (Disadvantage. Purchase of special half-value loading coils is necessary.)

/ (ii)

(ii) Place the first coil in each junction only 3,000 feet from the main exchange. When two junctions are interconnected, 6,000 feet spacing is maintained. This method is generally preferred.

The two methods are shown in Fig. 22.

(a) Half-Coil Termination.

(b) Half-Section Termination.

SPACING OF LOADING COILS.

FIG. 22.

14. TEST QUESTIONS.

1. Explain briefly how crosstalk is produced between paralleling telephone lines.

2. Explain how Multiple Twin cable produces a non-inductive relation between the two pairs of a quad.

3. Explain why transpositions on aerial lines have to be closer at higher frequencies than at lower frequencies.

4. Discuss the conditions necessary for preventing interference between a phantom and its side circuits.

5. Describe, with sketches, the use and operation of a composite set.

6. What is meant by "lumped" loading? Discuss the advantages of loading cables.

7. What is meant by "half-coil" and "half-section" terminations?

END OF PAPER.