

March 7, 1939.

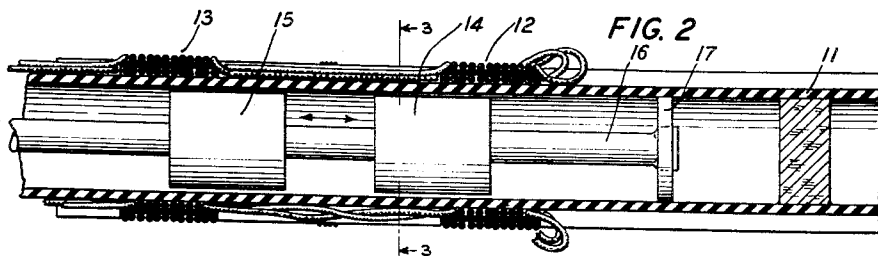
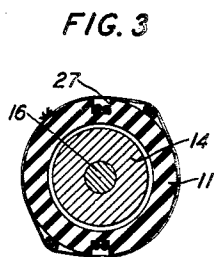
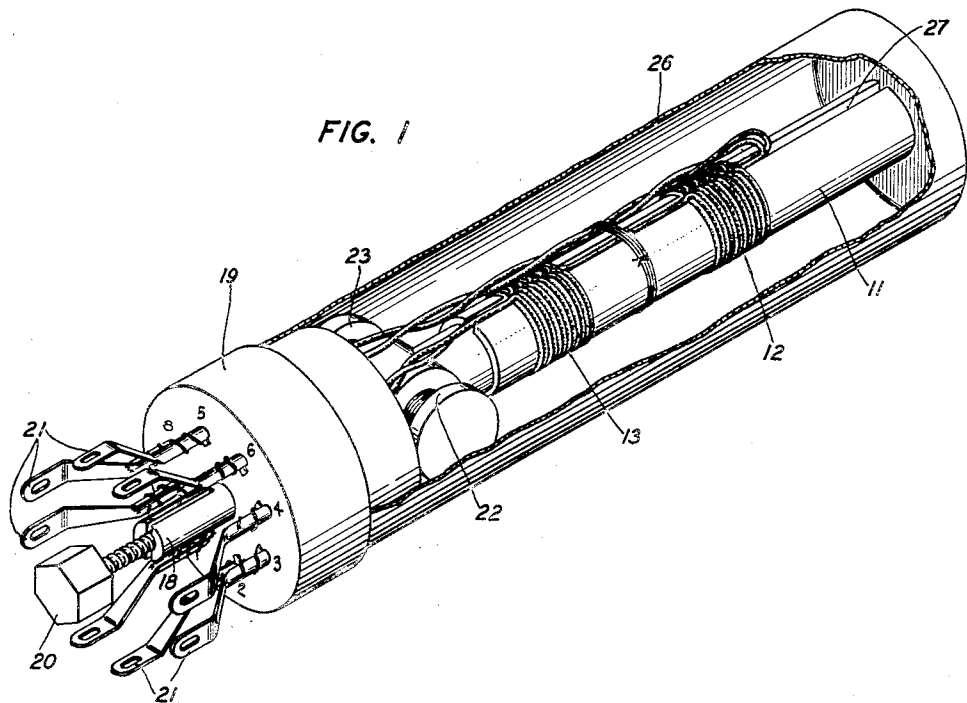
P. S. DARNELL

2,149,336

INDUCTIVE DEVICE

Filed Sept. 30, 1937

3 Sheets-Sheet 1



INVENTOR
P. S. DARNELL

BY
T. H. Jackson

ATTORNEY

March 7, 1939.

P. S. DARNELL

2,149,336

INDUCTIVE DEVICE

Filed Sept. 30, 1937

3 Sheets-Sheet 2

FIG. 4

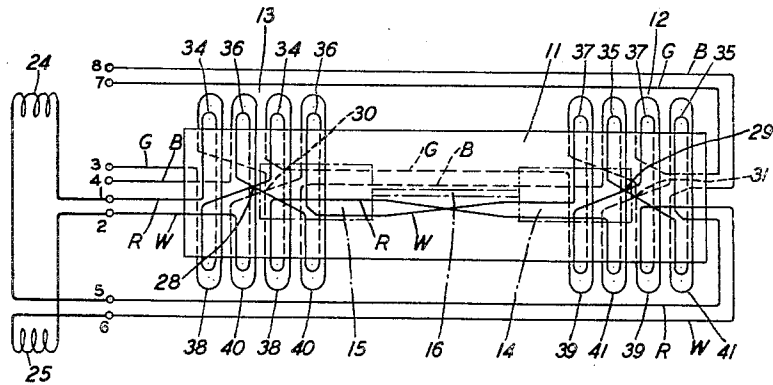
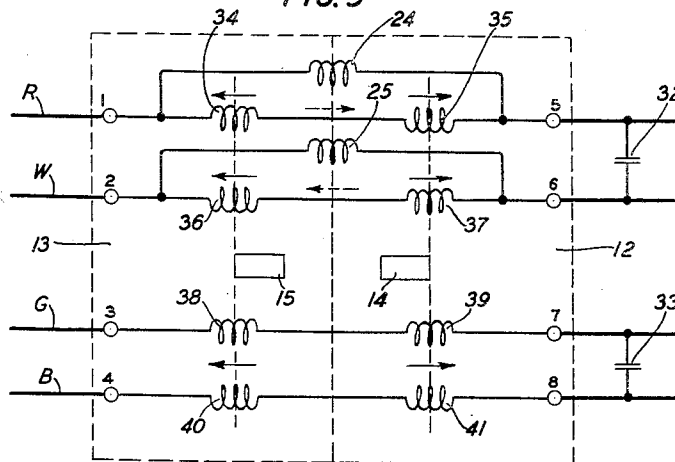


FIG. 5



INVENTOR
P. S. DARNELL
BY
T. H. Jackson
ATTORNEY

March 7, 1939.

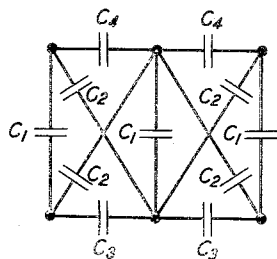
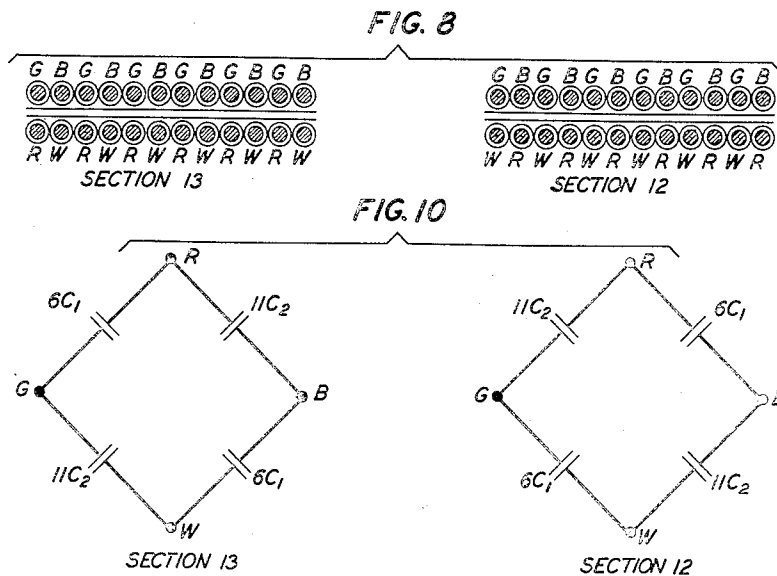
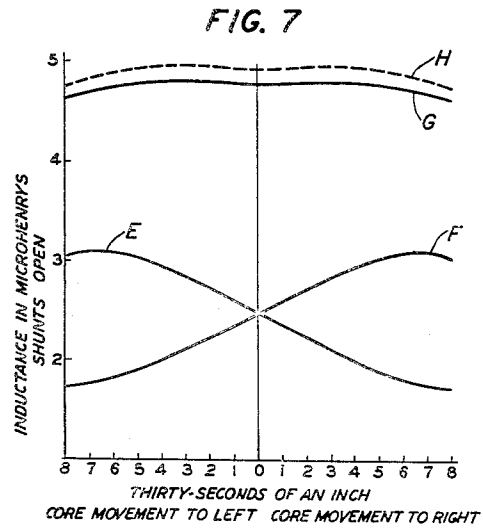
P. S. DARNELL

2,149,336

INDUCTIVE DEVICE

Filed Sept. 30, 1937

3 Sheets-Sheet 3



INVENTOR
P. S. DARNELL
BY *T. H. Jackson*
ATTORNEY

UNITED STATES PATENT OFFICE

2,149,336

INDUCTIVE DEVICE

Paul S. Darnell, South Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application September 30, 1937, Serial No. 166,514

19 Claims. (Cl. 179-80)

This invention relates to systems for the transmission of intelligence and more particularly to inductive devices or coils having adjustable magnetic material cores and fixed windings associated therewith which are used in such systems.

In the art of the transmission of intelligence by electric currents one of the features which may impair the quality of the transmission is the interference caused in one circuit due to currents in another adjacent circuit. An extreme case probably occurs in transmission by carrier currents applied to cables where the individual pairs constituting the circuits are close together. This interference between adjacent circuits has been given the general term "cross-talk" and as used in this specification the term cross-talk will include all types of interference in electric current transmission of intelligence caused in one circuit by currents in another circuit. Cross-talk is, therefore, one of the characteristics of a transmission line which reduces the efficiency thereof as to clarity and distinctness of the received signal.

One of the objects of this invention is to improve the transmission of intelligence by electric current.

Another object of this invention is to reduce cross-talk in transmission lines.

Another object of the invention is an inductive device adapted for incorporation in transmission lines to aid in balancing out cross-talk voltages in said lines.

A further object is an inductive device having a plurality of fixed windings and adjustable cores of magnetic material so arranged that the mutual inductance between the sets of windings entering into the circuit pairs may be varied while the inductive reactance of these sets of windings remains substantially constant.

These and other related objects will be apparent and the invention will be better understood from the following description and drawings forming a part thereof, in which

Fig. 1 is a perspective drawing of the inductive device of this invention with a part of the cover removed;

Fig. 2 is a longitudinal section of the winding spool showing the windings and adjustable cores;

Fig. 3 is a section of the spool, etc., taken on line 3-3 of Fig. 2;

Fig. 4 is a wiring diagram showing in detail the windings on the spool;

Fig. 5 is a schematic showing how the windings are related when the device is inserted in two cable pairs;

Figs. 6 and 7 are curves which will be used in explaining the operation of the device; and

Figs. 8, 9 and 10 illustrate where capacities exist between turns of the device and how such capacities are balanced out.

A number of suggestions have been made relative to cross-talk elimination based upon balancing out the interfering voltages. Reference is here made to two patents which have issued in this connection: Coolidge et al. Patent 2,008,061 which discloses a transmission system designed for cross-talk elimination and providing a scheme of cross connections between cable pairs which may be extended as more pairs of the cable are utilized for carrier transmission and Weaver Patent 2,080,217 which is an improvement over the system of Coolidge et al. This present invention is a further improvement over the Weaver patent in that it is directed to an improved inductive device which may be incorporated in the system of Weaver.

The inductive device of this invention as illustrated in Figs. 1, 2, 3 and 4 comprises a hollow tube 11 of insulating material on which windings are mounted in two sections 12 and 13. The tube on which the windings are mounted may be of any satisfactory insulating material; in practice phenol fibre tubing has been found satisfactory.

Within the tube 11 are two cylindrical magnetic material cores 14 and 15 fixedly mounted on a non-magnetic material rod 16. The cores are preferably of molybdenum permalloy dust in accordance with U. S. Patent 1,768,443 to Elmen. This dust may be prepared in accordance with U. S. Patent 1,669,649 to Beath et al. and ground to a sufficient fineness to pass through a 400-mesh sieve. After the proper degree of fineness is attained the particles are insulated and pressed into the cylindrical forms.

The non-magnetic rod 16 is preferably brass supported at one end in an insulating washer 17. The other end of rod 16 is screw-threaded through a metallic bushing 18 which is inserted in insulating head 19. Rod 16 is equipped with a detachable hexagonal head 20 whereby the rod may be turned to adjust the position of cores 14 and 15 relative to the windings 12 and 13. It is understood that the hexagonal head may be replaced by any convenient means of turning rod 16.

The terminals 21 of the windings are inserted in holes which extend through insulating head 19 to facilitate connection to the windings. These terminals are staked to the head near the outside surface and are of such a length that they may be bent to contact with and be soldered to terminals

of an adjacent coil when required, thereby making unnecessary the use of separate strapping wires between units disposed as indicated in Weaver Patent 2,080,217.

- 5 On tube 11 near head 19 are mounted two auxiliary spools 22 and 23 on which are mounted two inductive resistance windings 24 and 25 which are connected in shunt to certain of the main windings for a purpose which will appear later.

10 An aluminum or other light metal non-magnetic shield or container 26 fits over a reduced portion of head 19 to form an enclosure for the tube 11, windings, etc. Wax or other insulating compound is introduced into the container to prevent the entrance of moisture.

15 The windings are mounted on tube 11 in two sections of two layers each and each layer of each section contains two individual windings or coils. These individual windings are so wound that the wires cross only once per turn. This winding arrangement will be seen more particularly in Fig. 4 wherein block 11 represents the tube or winding spool, 14 and 15 the cores 20 and 16 the rod upon which the cores are mounted.

25 Before proceeding with a description of the manner of winding shown in Fig. 4 it may be noted from the circuit diagram of Fig. 5 that section 13 comprises four separate windings or coils 34, 36, 38 and 40; and section 12 comprises four separate windings or coils 35, 37, 39 and 41. Coils 34, 37, 38 and 39 are wound in one direction and coils 35, 36, 40 and 41 are wound in the opposite direction. Still considering both Figs. 4 and 35 5 and as viewed from the left of the figures, coil 34 consists of alternate turns of the inner layer of section 13 wound in a counter-clockwise direction, while coil 36 consists of the remaining turns of the inner layer of section 13 but wound in a clockwise direction. Coil 38 consists of alternate turns of the outer layer of section 13 wound in a counter-clockwise direction, while coil 40 consists of the remaining turns of this outer layer wound in a clockwise direction. Similarly, 40 in the other section coil 35 consists of alternate turns of the inner layer of section 12 wound in a clockwise direction and coil 37 consists of the remaining turns of the inner layer wound in a counterclockwise direction. Coil 39 comprises alternate turns of the outer layer of section 12 wound in a counter-clockwise direction and coil 41 comprises the remaining turns of the outer layer wound in a clockwise direction.

45 Starting from terminal 1 and following wire R it will be seen that this wire is wound counter-clockwise viewed from the left-hand end of the spool and constitutes alternate turns of the inner layer. From terminal 1 it proceeds to the right, then up and behind the spool to the lower edge, 50 then up and diagonally to the right and again around the spool for the required number of turns in this section. The wire W is wound clockwise (viewed from the left) and proceeds from terminal 2 to the right, then down and behind the spool, then up and to the front and then diagonally to the right and again around the spool as required.

55 Wires R and W then pass to the second section 12 in a groove corresponding to groove 27 (Fig. 1) cut in the diametrically opposite side of tube or spool 11. These wires are twisted an odd number of times in passing from section 13 to section 12 and are wound in reverse direction in section 12 to that of section 13. That is, wire 60 R is wound in clockwise direction as viewed from

the left end while wire W is wound in a counter-clockwise direction. The method of winding is the same in section 12 as in section 13 and is such that the wires of each pair cross but once 5 for each turn. Wires R and W have a typical point of crossing at point 28 in section 13 and at point 29 in section 12. Wire R is brought out to terminal 5 and wire W is brought out to terminal 6.

10 In practice the wires of one pair are wound one turn at a time to give only the single crossing. For example, wire R is given one turn in one direction and then wire W is crossed over wire R and given one turn next to wire R but in the opposite direction. Then wire R crosses 15 over wire W as at 28 and again wire R is given another turn next to wire W. This process is continued until windings 34 and 36 are completed.

20 Wires G and B from terminals 3 and 4 are placed in the second layer but start on the side of tube 11 opposite the point at which wires R and W start and cross at the completion of each turn as at typical point 30 in section 13 outer layer and at typical point 31 in section 12. The crossing points are of course on the opposite side 25 of tube 11 to the crossing points of wires R and W. In passing from section 13 to section 12 in groove 27, wires G and B retain their same relative positions, that is, they are twisted an even number of times, and are wound in the same 30 direction in section 12 as in section 13. Wires G and B are brought out to terminals 7 and 8, respectively.

35 Inductive resistance 24 is shunted across the windings of wire R between terminals 1 and 5 while inductive resistance 25 is shunted across the windings of wire W between terminals 2 and 6.

40 The manner in which this unit operates will be seen more clearly from Fig. 5 which shows two cable pairs of a transmission system. Each pair constitutes a circuit over which communication may be had.

45 To describe the operation of the device it will be assumed that signals are being transmitted over the pair comprising conductors 1—5 and 2—6 of Fig. 5 and that due to conditions elsewhere in the circuit between the two pairs involved there is induced in the pair comprising 50 conductors 3—7 and 4—8 a voltage which arises from the signal current in the pair of which conductors 1—5 and 2—6 are parts. This induced voltage will tend to cause current to flow in the pair of which conductors 3—7 and 4—8 are parts and this current would give rise to 55 disturbance in transmission in the latter pair.

60 The device operates as follows to neutralize this voltage: At a given instant assume that current is flowing in conductor 1—5 from 1 to 5 and in conductor 2—6 from 6 to 2, as indicated by the dotted arrows. The magnetic flux set up in the individual coils will then be as shown by the solid arrows. The flux due to coil 34 will be from right to left as viewed in the drawings. Since the winding of coil 35 is reversed relative 65 to that of coil 34 the flux will also be reversed. In coil 37 current is passing from right to left and since the direction of winding is reversed relative to that of coil 35 the flux in coils 35 and 37 will be in the same direction. For a similar 70 reason the flux in coil 36 will be in the opposite direction to that of coil 37 but in the same direction as that of coil 34.

75 Coil 34 is spaced at such a distance from coil 35 and coil 36 is spaced at such a distance from

coil 37 that there is substantially no threading of the flux due to coils 34 plus 36 with coils 35 plus 37, nor of the flux due to coils 35 plus 37 with coils 34 plus 36; that is, substantially no mutual inductance exists therebetween. The flux due to coils 34 and 36 will thread coils 38 and 40 in the direction of the solid arrow associated with coils 38 and 40 since the latter coils are superimposed on the former. Also, the flux due to coils 35 and 37 will thread coils 39 and 41 in the direction shown by the solid arrow associated with coils 39 and 41. The conditions as just recited exist when the movable cores are in their midpositions, as indicated in Figs. 2, 4 and 5.

The cross-talk voltages induced in the pair with which conductors 3—7 and 4—8 are associated due to conditions external of the device and due to the signal current present in the cable pair associated with wires 1—5 and 2—6 may be in a direction to cause current to flow in the same direction as the signal current in the pair with which conductors 1—5 and 2—6 are associated or they may be in the opposite direction.

Assume, first, that these voltages are in a direction which would cause current to flow in the same direction as the signal currents, that is, the induced voltages external of the device are such as to tend to cause current to flow from 3 to 7 and from 8 to 4. Since coil 34 is wound in the same direction as coil 38 and coil 36 is wound in the same direction as coil 40 and the flux due to coils 34 and 36 threads coils 38 and 40 in the same direction as that of coils 34 and 36, the induced voltages in coils 38 and 40 will be in a direction to oppose those set up externally of the device. In the other section of the device coils 35 and 37 are wound in opposite directions and the flux due to coils 35 and 37 threads coils 39 and 41 in the same direction. The voltages induced in coils 39 and 41 due to the currents in coils 35 and 37 are such as to aid the voltages set up externally of the device. To neutralize the cross-talk voltages the coupling between coils 34 and 36 and coils 38 and 40 must be increased, while the coupling between coils 35 and 37 and coils 39 and 41 must be decreased. This is accomplished by moving cores 14 and 15 from their mid position toward the left, as shown in Fig. 5; that is, the cores must be moved out of the field of coils 35, 37, 39 and 41 and into the field of coils 34, 36, 38 and 40. The opposing flux is therefore increased in accordance with the assumed conditions while the aiding flux is decreased. Tests of the pair including conductors 3—7 and 4—8 will indicate when the cores have been moved a sufficient distance to neutralize the undesired voltages.

If the voltages induced externally of the device are in the opposite direction to that assumed in the preceding discussion, then the voltages due to coils 35 and 37 must dominate and this is accomplished by moving cores 14 and 15 to the right, as shown in Fig. 5; that is, the cores must be moved out of the field of coils 34, 36, 38 and 40 and into the field of coils 35, 37, 39 and 41.

Fig. 6 shows by means of a curve the manner in which the total mutual inductance between the pair 1—5 and 2—6 and the pair 3—7 and 4—8 reverses as the cores are moved. The ordinates of the curve are mutual inductances in microhenries measured with a current having a frequency of 1 kilocycle while the abscissae in-

dicate positions of the core in thirty-seconds of an inch to the right or left of the mid position. When the cores are in the mid position indicated at position zero, the net or resultant mutual inductance of the device is zero because the mutual inductance in section 12 is equal and opposite to the mutual inductance in section 13.

As the cores are moved from the mid position the resultant mutual inductance changes. This resultant mutual inductance as the cores are moved toward the left is indicated as positive. Therefore, the resultant mutual inductance when the cores are moved to the right will be negative, as will be readily understood from the previous discussion in which it was shown that the flux which dominates changes as the cores move through the mid position. The cores may therefore be adjusted as to position to neutralize the cross-talk voltages no matter which direction they tend to cause current to flow and no matter what their magnitudes within the limits of operation of the device. It is readily seen from this curve that the absolute or numerical values of mutual inductance are substantially equal for an equal movement of the cores in either direction from the mid position.

Fig. 7 illustrates graphically how, as the mutual inductance in sections 12 and 13 varies, the inductive reactance in the pair composed of conductors 1—5 and 2—6 remains substantially constant. In this figure, the ordinates are inductances in microhenries measured with a current having a frequency of 1 kilocycle while the abscissae indicate the positions of the cores in thirty-seconds of an inch to the right or left of the mid position. The effective inductance of coils 34 plus 36 is shown in curve E. This curve is the same type of curve as that of Fig. 6 except that curve E shows the variation in total inductance, that is mutual plus self, for coils 34 plus 36, whereas the curve of Fig. 6 shows the variation in the resultant mutual inductance only of all the coils. Curve E shows that with the cores in the mid position the total inductance of coils 34 and 36 is about 2.45 microhenries and that as the cores move to the left the total inductance reaches a peak of about 3.20 microhenries. When the cores are moved to the right the total inductance of coils 34 plus 36 falls to about 1.20 microhenries. Similarly, curve F shows the variation in total inductance of coils 35 plus 37 with movement of the cores.

The maximum and minimum values for coils 35 plus 37 are the same as for coils 34 plus 36, the minimum for curve F occurring at the position of the cores for the maximum of curve E and the maximum for curve F occurring at the position of the cores for the minimum of curve E. At the mid position of the cores, the total inductance of coils 34 plus 36 is equal to the total inductance of coils 35 plus 37.

Curve G of Fig. 7 shows the measured variation in total inductance of the loop 1—5—6—2 which includes coils 34, 35, 36 and 37 with change in position of the cores for the full effective movement of the cores. It will be noted that this curve is substantially flat.

Curve H of Fig. 7 shows the variation in total inductance of loop 1—5—6—2 as determined from curves E and F, that is, curve H is derived from curves E and F by adding the ordinates of E and F. Curve H is given for purposes of comparison to show that the shape of the curve of the measured values is substantially the same as the derived values. The difference in absolute values

of curves G and H is due to a slight mutual inductance which exists between the coils of section 12 and the coils of section 13. To separate sections 12 and 13 far enough to eliminate this slight mutual inductance would make the device too long for a desirable design. This small amount of mutual inductance is insufficient to interfere with the efficient operation of the device in its practical application.

Curves E, F and G show that as the total inductance of coils 34 and 36 increases with the cores moving to the left the total inductance of coils 35 and 37 decreases and that the amount of increase is substantially equal to the amount of decrease. Also, since these coils are wound with wire of uniform dimensions and characteristics and since the diameters of the coils are equal, the increase of inductance of coil 34 equals the decrease of inductance of coil 35; hence, the total inductance of coil 34 plus that of coil 35 remains substantially constant. This is also true with respect to coils 36 and 37. Therefore, the inductive reactance of line 1-5 is equal to that of 2-6 and this inductive reactance remains substantially constant with varying mutual inductance due to the movement of the cores.

The conditions discussed with reference to loop 1-5-6-2 are also true of loop 3-7-8-4. There is, therefore, no inductive unbalance in the event of longitudinal currents and no cross-talk resultant therefrom. Longitudinal currents may occur due to noise or like interference. If power current to energize repeaters is transmitted over the signal cable it probably will be impressed as longitudinal currents, that is, the pair comprising conductors 1-5 and 2-6 may constitute one power conductor while another pair, such as 3-7 and 4-8, may constitute the other conductor. With the device of this invention adjusted for neutralizing side-to-side cross-talk there will therefore be no cross-talk due to longitudinal currents which might be considered a type of phantom-to-side cross-talk.

As noted earlier in the specification, inductive resistance winding 24 is connected in shunt to coils 34 and 35 and inductive resistance winding 25 is connected in shunt to coils 36 and 37. The purpose of these inductive resistance windings is to make the mutual inductance characteristic of the coils 34 to 41, inclusive, simulate the mutual inductance existing between any two cable pairs. Representing the mutual inductance of coils 34 to 41, inclusive, by m_1 and the mutual inductance existing between cable pairs by m_2 , theoretical conditions which have been checked by measurements show that m_2 , due to proximity effect, is complex in character and may be represented by the formula $m_a + jm_b$, where m_a is the in-phase component and jm_b is the component 90 degrees out of phase as indicated by j which is

$$\sqrt{-1}.$$

The inductive resistance windings are so designed that the mutual inductance m_1 is so modified by the shunts that the proper $m_a + jm_b$ relationship is effective between the two pairs.

Coils inserted in transmission lines for loading, etc., are likely to give rise to cross-talk because of the capacities which exist between the wires of the coils. This is well understood by those skilled in the art and efforts are made in designing such coils to maintain what is known as side-to-side capacitance unbalance at a minimum since the greater this unbalance the greater is the cross-talk arising from this type of unbalance.

Figs. 8, 9 and 10 illustrate how in the present device this type of cross-talk is kept at a minimum by reducing the side-to-side capacity unbalance to substantially zero. In Fig. 8, the relation of the individual turns of the sections of the device are shown. In section 13 the first turn of wire G is shown as being directly over the first turn of wire R in accordance with the wiring diagram of Fig. 4. The first turn of wire B is over the first turn of wire W and next to the first turn of wire G, while the first turn of wire W is next to the first turn of wire R. The second turn of wire G is next to the first turn of wire B and is over the second turn of wire R which is next to the first turn of wire W. This is continued throughout section 13 for the six turns of each wire in each layer.

In section 12, due to the odd number of turns given to wires R and W in passing from section 13 to section 12, the first turn of wire G is over the first turn of wire W and the first turn of wire B is over the first turn of wire R. This arrangement is continued for the six turns of each wire in section 12.

Fig. 9 shows the main or significant capacities that exist between individual turns. Assuming uniformity of conductor diameter and insulation thickness, the capacity between each turn of wires G and R and between each turn of wires B and W in section 13 and between each turn of wires G and W and between each turn of wires B and R in section 12 will be equal and may be represented by C_1 . The capacity between each turn of wires G and W and each turn of wires B and R in section 13 and between each turn of wires G and R and between each turn of wires B and W in section 12 are equal and may be represented by C_2 .

In Fig. 10 are shown bridge arrangements of capacities C_1 and C_2 for the two sections. For a section of six turns of each individual wire there will be a total capacity of $6C_1$ between wires R and G and $6C_1$ between wires B and W, while between wires G and W and between wires R and B there will be $11C_2$ in each case in section 13. In section 12 there will be $6C_1$ between wires R and B and between wires G and W and $11C_2$ between wires R and G and between wires B and W.

In telephone practice, side-to-side capacitance unbalance between two conductor pairs is defined in terms of the pairs forming the present device as

$$[\text{Capacity } (R \text{ to } B) + \text{capacity } (W \text{ to } G)] - [\text{capacity } (R \text{ to } G) + \text{capacity } (W \text{ to } B)]$$

Therefore, from the bridge arrangement for section 13 the capacitance unbalance is $22C_2 - 12C_1$ and for section 12 the capacitance unbalance is $12C_1 - 22C_2$. The two sections are connected in series, thus putting the interwinding capacities in parallel and when these two unbalances $22C_2 - 12C_1$ and $12C_1 - 22C_2$ are added together the result is zero.

For a device of n turns of each wire per layer there will be a capacitance unbalance in one section of $[2(2n-1)C_2 - 2nC_1]$ and in the other section an unbalance of $[2nC_1 - 2(2n-1)C_2]$. These unbalances when added together give a resultant unbalance of zero. There are other capacities existing between the turns of the wires but such capacities are so small that they may be disregarded.

The capacity C_3 in Fig. 9 of wire R to wire W and C_4 of wire G to wire B does not enter into the side-to-side capacitance unbalance but contributes to the capacity loading required to neu-

tralize the inductive reactance added to the transmission line by the insertion of the device of this invention. The capacity loading added by these inherent capacities is normally not sufficient and must be augmented by external capacities. Condensers 32 and 33 of Fig. 5 supply this additional loading capacity in connection with the present device.

This invention has been described in connection with a transmission line in which two cable pairs are shown for the sake of simplicity but the invention is adaptable to many applications and to transmission lines in which many pairs are involved requiring a large number of the inductive devices specifically described. The invention is therefore to be limited only as defined in the appended claims.

What is claimed is:

1. An inductive device comprising an insulating tube, a winding of a plurality of turns surrounding one section of said tube, a second winding of a plurality of turns surrounding a second section of said tube, said windings being spaced apart on said tube a distance sufficient to reduce to substantially zero the mutual inductance between said windings, a pair of magnetic cores within said tube, one for each winding, said cores being separated from each other by a relatively large non-magnetic gap, and means for adjusting the positions of said cores relatively to said windings.

2. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being separated into sections of a plurality of layers, one of said windings comprising non-contiguous turns in one layer of one section, a second of said windings comprising other non-contiguous turns in said one layer of said one section, one turn of said one winding lying in the space between adjacent turns of said second winding, magnetic material in a plurality of concentrated masses within said tube, and means to adjust the position of said masses in relation to said windings.

3. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being separated into sections of a plurality of layers, one of said windings comprising non-contiguous turns in one layer of one section, a second of said windings comprising other non-contiguous turns in said one layer of said one section, one turn of said one winding lying in the space between adjacent turns of said second winding, the turns of said one winding and the turns of said second winding being wound in opposite directions, magnetic material in a plurality of concentrated masses within said tube, and means to adjust the position of said masses in relation to said windings.

4. An inductive device comprising an insulating tube, a plurality of windings on said tube, and means to vary the mutual inductance between said windings while maintaining the inductive reactance of said device substantially constant, comprising compressed magnetic material cores spaced apart and which are adjustable in relation to said windings but fixed in relation to each other.

5. In a transmission system, pairs of conductors grouped in a cable, an inductive device comprising a plurality of windings, a plurality of spaced magnetic material cores movable in relation to said windings, certain of said windings adapted for connection into one of said pairs, certain others of said windings adapted for con-

nection in another of said pairs, and means to move said magnetic material cores whereby the mutual inductance between said windings may be varied while the inductive impedance of the windings in any one pair remains substantially constant.

6. In a transmission system, pairs of conductors grouped in a cable, an inductive device comprising a plurality of windings, separated cores of compressed finely divided magnetic material movable in relation to said windings, means whereby said windings may be connected to said conductors, and means to move said magnetic material cores to vary the mutual inductance between said windings, whereby voltages in one pair of conductors due to currents in another pair of conductors may be substantially neutralized.

7. In a transmission system, pairs of conductors grouped in a cable, an inductive device comprising a plurality of windings, cores of magnetic material spaced from each other and movable in relation to said windings, means whereby said windings may be connected to said conductors and means to move said magnetic cores whereby the mutual inductance between said windings may be varied while the total inductance in any one conductor of any pair remains substantially constant.

8. An inductive device comprising an insulating tube and a plurality of windings on said tube separated into sections each of a plurality of layers, one of said windings comprising non-contiguous turns in one layer of one section, a second winding comprising non-contiguous turns of one layer of a second section, said non-contiguous turns in said one section and said non-contiguous turns in said second section being wound on said tube in opposite directions, a third of said windings comprising other non-contiguous turns of said one layer of said one section and a fourth winding comprising other non-contiguous turns of said one layer in said second section, said other non-contiguous turns in said one section and said other non-contiguous turns in said second section being wound in opposite directions.

9. An inductive device comprising an insulating tube and a plurality of windings on said tube separated into sections each of a plurality of layers, one of said windings comprising non-contiguous turns in one layer of one section, a second winding comprising non-contiguous turns of one layer of a second section, said non-contiguous turns in said one section and said non-contiguous turns in said second section being wound on said tube in the same direction, a third of said windings comprising other non-contiguous turns of said one layer of said one section and a fourth winding comprising other non-contiguous turns of said one layer in said second section, said other non-contiguous turns in said one section and said other non-contiguous turns in said second section being wound in the same direction.

10. An inductive device comprising an insulating tube, a plurality of windings on said tube, a plug in the end of said tube, a threaded bushing in said plug approximately centrally thereof, a non-magnetic rod passing into said tube through said bushing, a threaded portion on said rod adapted to coact with the threads in said bushing, and a plurality of magnetic cores fixed to said rod and separated from each other.

11. An inductive device comprising an insulating tube, a plurality of windings on said tube

arranged in sections, a plurality of discontinuous magnetic bodies within said tube fixed relatively to each other but movable relatively to said windings, said windings being grouped in pairs and each winding of each pair being wound to a helix of substantially the same diameter as that of the other winding of the pair.

12. An inductive device comprising an insulating tube, a plurality of discontinuous magnetic bodies within said tube fixed relatively to each other and a plurality of pairs of windings on said tube, each pair comprising a single layer, succeeding turns of one winding separating the succeeding turns of the other winding of the pair.

13. An inductive device comprising an insulating tube, individual cores within said tube, said cores comprising extremely fine insulated particles of magnetic material pressed together, a non-magnetic rod supported at both ends in said tube, said cores being fixedly mounted on said rod and separated from each other, a plurality of windings on said tube, each of said windings comprising spaced turns of a single layer, the spaced turns of one winding filling the spaces between the turns of another winding in the same layer.

14. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being located in a plurality of sections and each section comprising a plurality of layers, each individual winding comprising one-half the total turns of one layer of one section, the remaining turns of each layer of each section being included in a different winding, and a plurality of magnetic bodies associated with said windings.

15. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being separated into sections of a plurality of layers, compressed cores of finely divided and insulated particles of a magnetic material, said cores being separated from each other and fixed in their positions relatively to each other but movable relatively to said windings, and a metallic shield surrounding said device.

16. An inductive device comprising an insulating tube, a plurality of windings wound along

said tube, other windings mounted on spools whose axes are perpendicular to the axis of said insulating tube, said spools being mounted on said tube, connections from said other windings to certain of said plurality of windings to connect said other windings in shunt to said certain of said plurality of windings, spaced magnetic cores associated with said plurality of windings movable relatively thereto, and a metallic shield surrounding said windings, tube and cores.

17. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being separated into sections of a plurality of layers, a plug of insulating material at one end of said tube, a threaded bushing in said plug, a non-magnetic rod within said tube, said rod having a threaded portion adapted to coact with said threaded bushing, magnetic material cores on said rod separated from each other but fixed to said rod, elongated terminals of flexible conducting material mounted in holes in said plug and staked to said plug, and a metallic shield surrounding said tube, said windings, said cores, and a part of said plug.

18. An inductive device comprising an insulating tube, grooves cut on said tube in certain parts and in diametrically opposite portions, a plurality of windings on said tube, said windings being separated into sections, connections between said windings in said sections, said connections being placed in said grooves, individual magnetic cores in said tube movable relatively to said windings but fixed relatively to each other, a non-magnetic rod joining said cores, and a metallic shield surrounding said windings, said tube and said cores.

19. An inductive device comprising an insulating tube, a plurality of windings on said tube, said windings being separated into sections of a plurality of layers, each winding comprising one-half the turns of one layer of one section, separated magnetic cores within said tube movable relatively to said windings, plugs in the ends of said tube, a metallic shield surrounding said tube and windings, and an insulating moisture-repellent compound filling said shield and surrounding said tube but kept from entering said tube by said plugs.

PAUL S. DARNELL.