April 6, 1937. A. E. BOWEN 2,075,927

SHIELDING SYSTEM

Filed April 25, 1936

FIG. 1

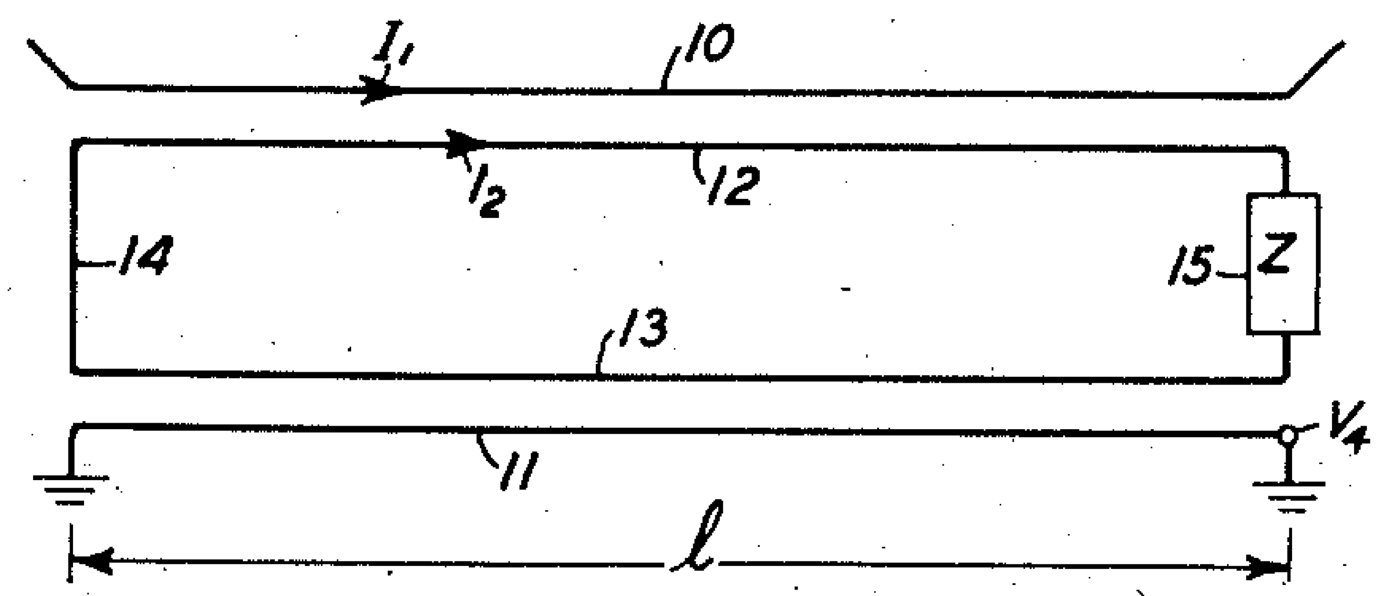


FIG. 2

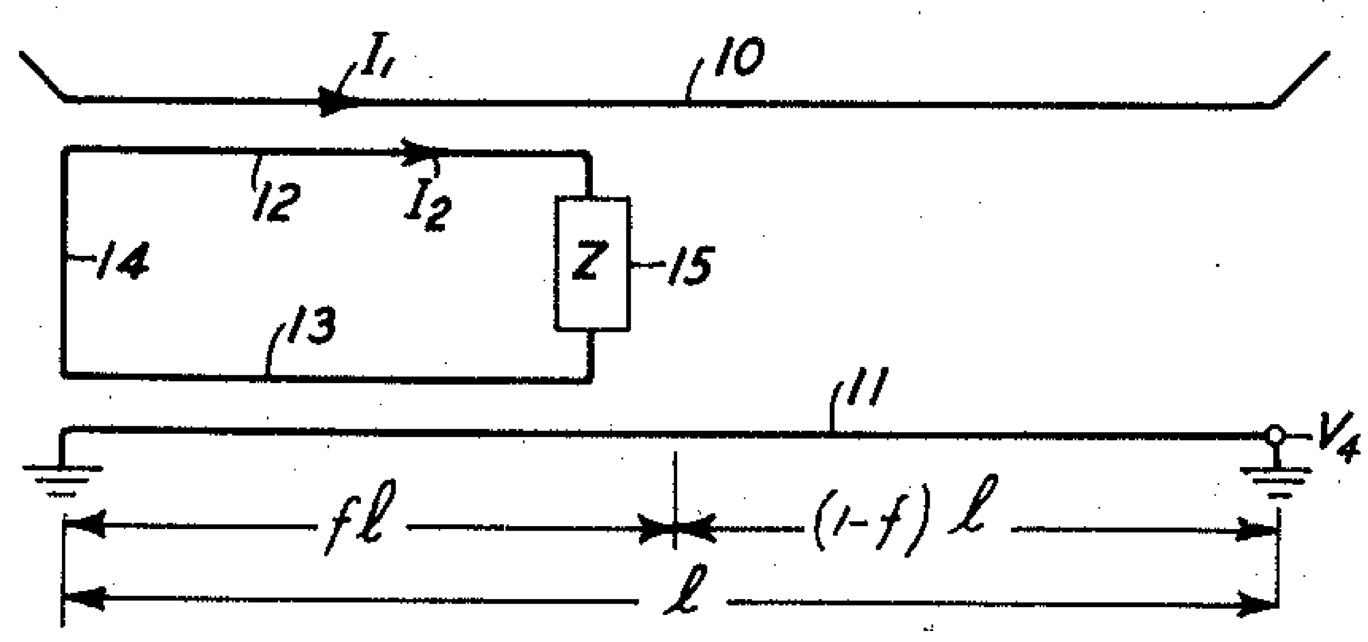


FIG. 3

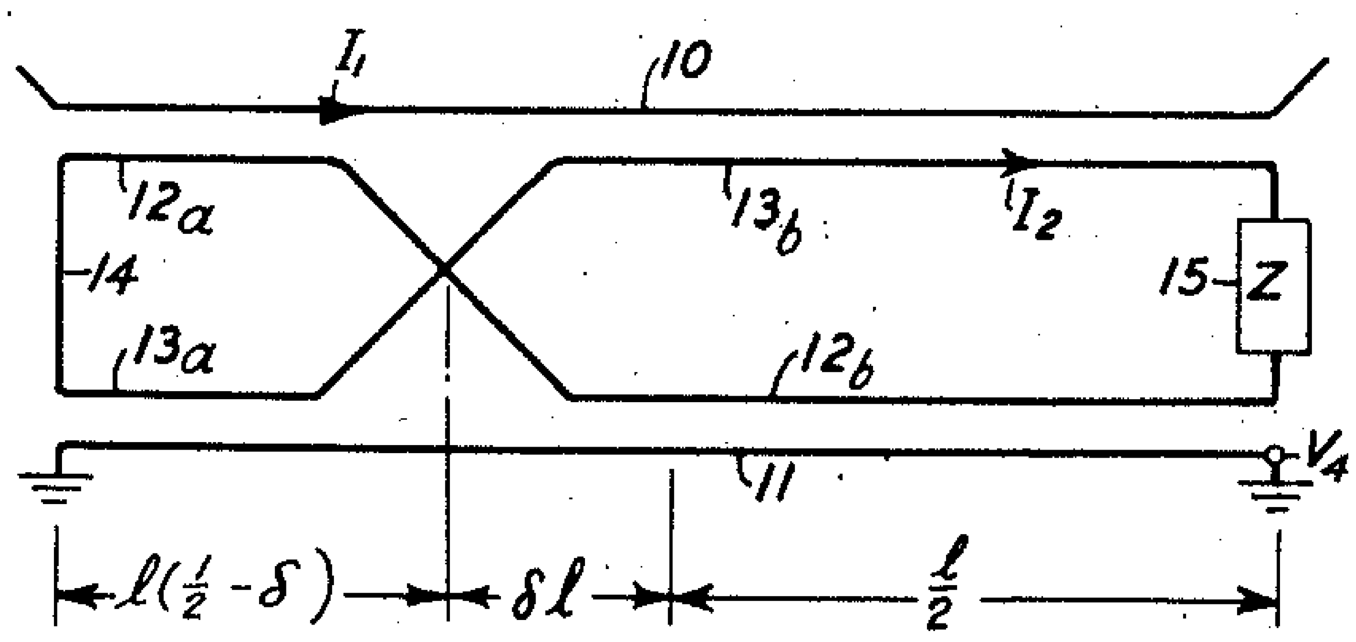


FIG. 4

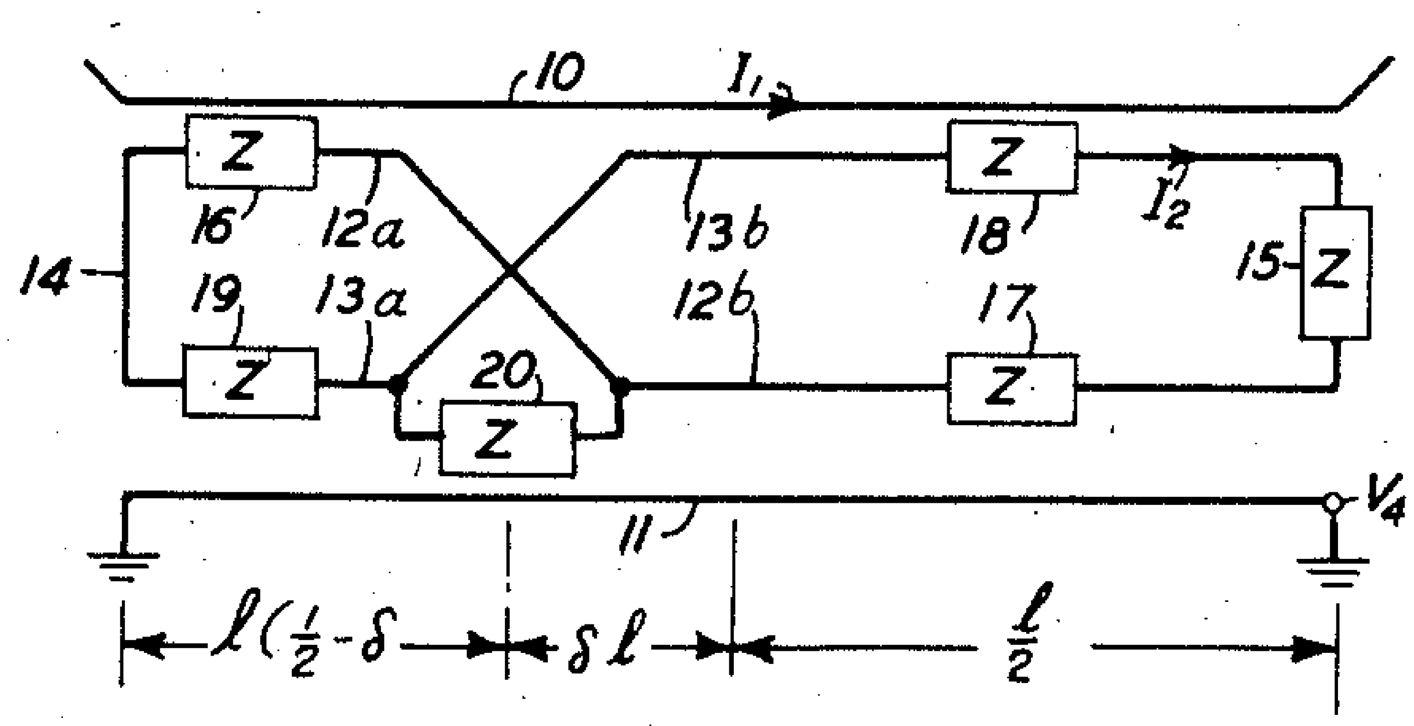
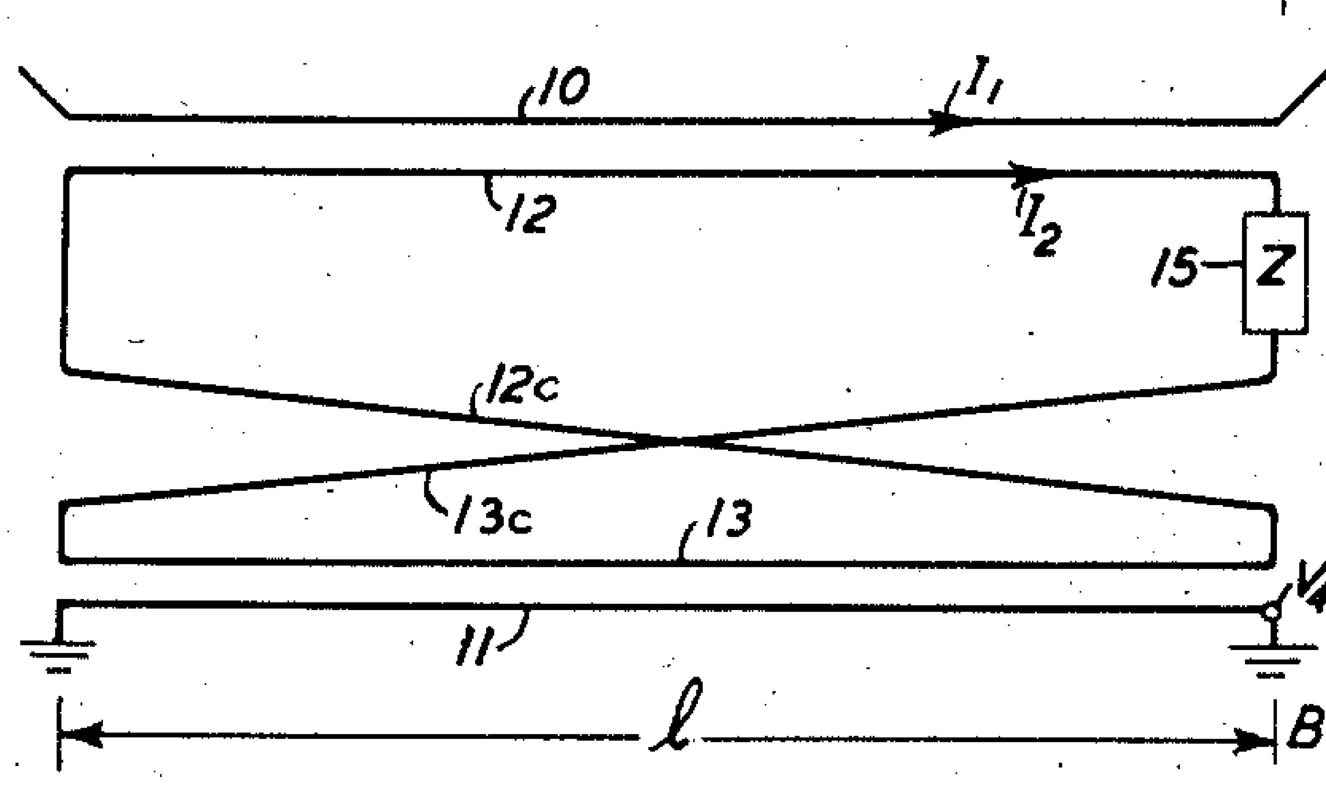


FIG. 5



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SHIELDING SYSTEM

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12 Claims. (Cl. 171—97)

This invention relates to shielding systems for intelligence transmitting circuits and more particularly to systems for shielding telephone and telegraph lines from a power line in proximity thereto.

As is known in the art, it frequently occurs that a telephone or telegraph line is positioned in the vicinity of a transmission line, the lines, for example, being substantially parallel to one another for a material distance. As a result of such physical relation of the lines and the consequent electromagnetic association thereof, highly undesirable voltage and current disturbances appear in the telephone or telegraph line due to periodic variations in the power line and also due to unbalances and short circuits in the power system. Consequently, the transmitting characteristics of the telephone or telegraph line are materially affected and altered so that unfaithful transmission of speech and music or signals obtains.

One general object of this invention is to effectively shield one transmitting system from another transmitting system in proximity thereto. More specifically, one object of this invention is to substantially eliminate interference between a power line and a telephone line heretofore resulting from longitudinal inductive effects extant because of continuous or transient variations in the currents flowing in the power line.

Another object of this invention is to minimize or completely eliminate ground connections to a shielding system associated with a power line and a telephone or telegraph line whereby the facile attainment of a low resistance shielding circuit is enabled.

In accordance with one feature of this invention, a shielding system is composed of a closed metallic loop having a wire portion adjacent and substantially parallel to the disturbing power line and another wire portion adjacent and substantially parallel to the disturbed telephone or telegraph line. The wire portions may be coextensive with the proximate portions of the power and telephone or telegraph lines or may occupy but point in the exposure between the two lines.

In a modification, the closed loop may comprise two conductors each having a portion adjacent the disturbing line and another or transposed portion adjacent the disturbed line. The two portions may be cross-connected at a suitable point in the exposure between the two lines.

Suitable impedances, which may be resistive or reactive or a combination thereof, may be introduced at suitable points in the shielding system to provide the requisite impedance and phase relationships to insure substantially perfect shielding in any particular instance.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Figure 1 is a diagrammatic view showing a shielding system illustrative of one embodiment of this invention and the relation thereof to a disturbing and a disturbed line;

Fig. 2 illustrates a modification of the shielding system shown in Fig. 1 in which conductors forming a part of the system are adjacent only portions of proximate sections of the disturbing and disturbed lines;

Fig. 3 is another diagrammatic view showing another shielding system in accordance with this invention, comprising transposed conductors;

Fig. 4 illustrates a modification of the shielding system shown in Fig. 3 wherein suitable impedances are provided in the shielding circuit; and

Fig. 5 illustrates another modification of the shielding systems shown in Fig. 3.

Referring now to the drawing, there is illustrated in each of the figures a disturbing system **10**, which may be, for example, a power line, and a disturbed system **11**, which may be, for example, a telephone or telegraph line. The two lines may extend in proximity to each other and may be substantially parallel to each other to form an exposure of length l. The telephone or telegraph line may be grounded at one end as shown. In order to shield the disturbed line against longitudinal induction, a shielding system is provided in the enclosure formed by proximate conductors in the disturbed and disturbing systems.

In one illustrative embodiment shown in Fig. 1, the shielding system comprises a conductor **12** positioned adjacent and substantially parallel to the disturbing or power line **10**, and another conductor **13** positioned adjacent and substantially parallel to the disturbed or telephone or telegraph line **11**. The conductors **12** and **13** may be connected at one end of the exposure by a cross conductor **14** and at the other end by a cross-connection including an impedance **15**. This impedance may be a resistance, an inductance or a capacitance or a combination of two or all of these.

As shown in Fig. 2, the shielding system need not be coextensive with the exposure between the disturbing and disturbed lines **10** and **11**, respectively. That is, the conductors **12** and **13** may extend only from one end of the exposure to a distance fl from this end.

It will be understood, of course, that the shielding effect of the shielding circuit is dependent upon a variety of factors among which are the size of the conductors 12 and 13, the length of these conductors, the frequency of the currents in the disturbing system and the space relationship of the disturbing and disturbed lines. The requisite parameters for the shielding system in order to produce substantially perfect shielding may be ascertained in the manner set forth hereinafter.

If the current in the disturbing line 10 is designated as I_1 and the current in the shielding system is designated as I_2, and the length of the shielding conductors 12 and 13 is large in comparison with the distance between the lines 10 and 11, as it is in actuality, the electromotive forces extant around the shielding and disturbed circuits in Figs. 1 and 2 may be expressed, respectively, by the equations

$$I_1(Z_{10-12}-Z_{10-13})+2I_2(Z_{12-12}-Z_{12-13})=0 \quad (1)$$

and

$$I_1Z_{10-11}l+I_2(Z_{12-11}-Z_{13-11})fl=V_4 \quad (2)$$

where V_4 is the terminal voltage on the disturbed circuit 11.

Eliminating I_2 from Equations 1 and 2,

$$V_4=I_1Z_{10-11}l\left[1+\frac{f}{2}\frac{(Z_{10-12}-Z_{10-13})(Z_{13-11}-Z_{12-11})}{Z_{10-11}(Z_{12-12}-Z_{12-13})}\right] \quad (3)$$

The voltage which would have been induced in the disturbed circuit 11 in the absence of shielding circuit 12–13 is given by $V_4'=I_1Z_{10-11}$, so that the shield factor

$$\eta=\frac{V_4}{V_4'},$$

which represents the effect of adding the shielding conductor, is obtained by dividing Equation (3) by I_1Z_{10-11}, and may be expressed as

$$\eta=1+\frac{f}{2}\frac{(Z_{10-12}-Z_{10-13})(Z_{13-11}-Z_{12-11})}{Z_{10-11}(Z_{12-12}-Z_{12-13})} \quad (4)$$

In any particular situation, the frequency of the current I_1, the earth resistivity and the distances between the several conductors 10, 11, 12 and 13 will be fixed so that consequently the several mutual impedances Z_{10-12}, Z_{10-13}, Z_{12-13}, Z_{12-11}, Z_{13-11} and Z_{10-11} are fixed. Hence, the fixed quantities in Equation 4 may be represented conveniently by a single symbol, for example p which is equal to

$$2\frac{(Z_{10-12}-Z_{10-13})(Z_{13-11}-Z_{12-11})}{Z_{10-11}} \quad (5)$$

Equation 4 may then be written as

$$\eta=1+\frac{pv}{Z_{12-12}-Z_{12-13}} \quad (6)$$

where

$$v \text{ is } \frac{f}{4}$$

Inasmuch as the several mutual impedances above-mentioned are complex quantities, p will be complex and may be written as

$$p=P_1+jP_2 \quad (7)$$

where both P_1 and P_2 are real.

To ascertain the requisite parameters of the shielding circuit to give substantially perfect shielding, the shield factor η is made 0 and, expressing p, Z_{12-12} and Z_{12-13} in rectangular form, Equation (6) may be written thus:

$$0=1+\frac{(P_1+jP_2)v}{R_{12-12}-R_{12-13}+j(X_{12-12}-X_{12-13})} \quad (8)$$

from which it is determinable that

$$P_1v=(R_{12-12}-R_{12-13}) \quad (9)$$

and

$$P_2v=(X_{12-12}-X_{12-13}) \quad (10)$$

Equations 9 and 10, it will be seen, involve three variables, namely, v, R_{12-12} and X_{12-12}. Hence, if any one of these three is fixed the equations may be solved for the remaining two.

As an illustration there may be considered a situation wherein the spacing between lines 10 and 11, 10 and 13, 12 and 11, and 12 and 13 is 400 feet, and wherein the shielding conductors 12 and 13 are spaced three feet from the lines 10 and 11, respectively. The conductors 12 and 13 may be No. 4/0 AWG copper wire, the frequency of the current in the disturbing or power line 10 may be 60 cycles, and the earth resistivity may be approximately 10 meter-ohms. Under these conditions, $P_1=-.56$, $P_2=.36$, $R_{12-12}=.066$, $R_{12-13}=.014$ and $X_{12-13}=.020$, each being expressed in ohms per kilo feet. Under these conditions the values of v and X_{12-12} requisite for perfect shielding may be obtained from Equations 9 and 10, to wit:

$$v=\frac{R_{12-12}-R_{12-13}}{P_1}=.093$$

and

$$X_{12-12}=X_{12-13}-P_2v=-.060$$

Inasmuch as X_{12-12} as determined above is negative, it follows that the series impedance 15 in the shielding system of Figs. 1 and 2 must be a condenser. If the reactance of the wire parts of the shielding circuit, with ground return, be designated as X_{12-12w} ohms per kilo feet, the requisite capacitance, C, for perfect shielding may be ascertained from the relation

$$cl=\frac{1}{2wf(X_{12-12w}-X_{12-12})} \quad (11)$$

where $w=2\pi$ times the frequency. Under the conditions assumed, $X_{12-12w}=0.197$ ohm per kilo foot so that

$$cl=\frac{1}{2.377\times0.37\,(.197+.060)}=.0136 \text{ farad kilo feet}$$

Hence, if the exposure between the power line 10 and the telephone or telegraph lines were 20 kilo feet in length, the series impedance 15 would need to be a condenser having a capacitance of 680 microfarads.

The various specific parameters given heretofore are, of course, merely illustrative of one particular application of this invention and it will be understood that the invention may be practiced in instances where the distance between the disturbing and disturbed lines is greater or less than 400 feet, and also that various size wires may be employed for the shielding conductors 12 and 13. It may be pointed out, for example, that with a 4/0 AWG copper shielding conductor for spacings of the disturbing and disturbed lines of 200 feet or less it is desirable that the shielding conductors be coextensive with the exposure, that is that $f=1$, although even this length of shielding conductor will not suffice to reduce the voltages to zero. However, with this wire size and for separations greater than 200 feet, perfect shielding can be had, and it has been found that f decreases rapidly with increasing separation and that, for example, for a separation of 1000 feet the shielding system need extend through only about one-tenth of the exposure to obtain perfect shielding. As illustrative of specific instances, it may be noted that for a separation of about 50 feet it has been ascertained that the product cl should be about 7,000 microfarad kilo feet and that for separations of 200 feet and 1,000 feet this product should be about 4,000 and 60,000 microfarad kilo feet, respectively.

It may be pointed out also that, in general, if the distance between the disturbing and disturbed lines is decreased, the size of the shielding wires and of the series capacitance must be increased in order to secure perfect shielding. For example, it has been ascertained that with the distance between lines **10** and **12**, and **11** and **13** of the order of 3 feet and for a shielding system extended through the whole exposure ($f=1$), for relatively small separations of the order of 100 feet or less, the shielding conductors should be of the order of 1,000,000 circular mils in cross-section for satisfactory shielding, and that this cross-section decreases rapidly with increasing separations until at a separation of 1,000 feet, a No. 8 AWG shielding conductor will enable perfect shielding. It has been ascertained also, for example, that for separations of the order of 50 feet the requisite value of cl is approximately 6,500 microfarad kilo feet and for separations of about 1,000 feet the necessary value is about 1,600 microfarad kilo feet.

In the foregoing specific illustration, the calculations have been based upon a power line-shield conductor spacing of three feet. Although such spacing is satisfactory for relatively low potential lines, it will be appreciated that for higher potential lines greater spacings will be necessary. The requisite parameters for the shielding system to assure the desired high degree of shielding may be ascertained in the manner set forth heretofore. It may be noted, however, that it has been ascertained that as the separation between the shielding conductor and the power line is increased, the resistance of the shielding wire required to assure perfect shielding decreases and the series capacitance becomes larger. Neither, however, varies rapidly with separation.

In another embodiment of this invention shown in Fig. 3, the shielding system may comprise cross-connected transposed shielding wires. In this figure, the shield wire **12** includes a portion **12**a adjacent the disturbing or power line **10** and a portion **12**b adjacent the disturbed or telephone or telegraph line, the two portions being transposed at a distance from one end of the exposure between the disturbing and disturbed lines, the point of transposition being displaced materially from the longitudinal midpoint of the enclosure. Similarly, the shielding wire **13** includes transposed portions **13**a and **13**b, the former portion being adjacent the telephone or telegraph line **11** and the latter portion being adjacent the power line **10**. The shielding wires **12** and **13** are connected at one end by a cross wire **14** and at the other end by a series impedance **15**, which preferably is adjustable in both magnitude and phase angle.

The particular parameters required to secure desired shielding may be ascertained in a manner similar to that set forth heretofore with reference to the shielding systems illustrated in Figs. 1 and 2. For convenience in analysis, the point of transposition of the shielding conductors **12** and **13** is represented as being a distance δl from the longitudinal midpoint of the enclosure between the lines **10** and **11**. Other lengths or distances are, then, as indicated in Fig. 3. If the current in the disturbing power line **10** is represented as I_1 and the resulting current in the shielding circuit is represented as I_2, according to Kirchoff's law:

$$-I(Z_{10-12}-Z_{10-13})2\delta l-I_2(Z_{12-12}-Z_{12-13})2l=0 \quad (12)$$

and

$$I_1Z_{10-11}l-I_2(Z_{13-11}-Z_{12-11})2\delta l=V_4 \quad (13)$$

From Equations 12 and 13 it follows that the shield factor

$$\eta=1+2(\delta^2)\frac{(Z_{10-12}-Z_{10-13})(Z_{13-11}-Z_{12-11})}{Z_{10-11}(Z_{12-12}-Z_{12-13})} \quad (14)$$

Equation 14, it will be seen, is identical with Equation 4 if

$$\delta^2=\frac{f}{4}.$$

Consequently Equation 14 may be rewritten as Equation 6 above if in the latter $v=\delta^2$. Hence the requisite parameters for the shielding system illustrated in Fig. 3 may be ascertained in the same manner as heretofore given in the discussion of Figs. 1 and 2.

As a specific illustration, the case may be considered wherein the several factors, that is, size of shielding conductor, frequency, earth resistivity and separations are the same as in the specific illustration described heretofore with reference to Figs. 1 and 2. In this case, for perfect shielding v should be .093 and X_{12-12} should be $-.060$ as ascertained heretofore. δ may then be ascertained from the relation

$$\delta l=l\sqrt{v}=.303l$$

and the necessary capacitance for the series impedance **15** in the shielding circuit shown in Fig. 3 may be calculated from the relation

$$cl=\frac{1}{2w(X_{12-12w}-X_{12-12})} \quad (15)$$

For perfect shielding in Fig. 3, then

$$cl=\frac{1}{2.377\,(.197+.060)}=.00503 \text{ farad kilo feet,}$$

so that if the length of the exposure were 20 kilo feet, in Fig. 3, the capacitance required for perfect shielding would be 252 microfarads. This value, it will be seen, is less than half that required in a shielding system of the types shown in Figs. 1 and 2.

The requisite value of this capacitance and also the magnitude of the current I_2 in the shielding system may be reduced, if desired, by the insertion in the shielding system of lumped impedances **16**, **17**, **18** and **19** connected in series with the shielding conductors **12** and **13** and another lumped impedance **20** cross-connected between the shielding conductors as shown in Fig. 4. These impedances may be resistive, inductive, or capacitive or a combination of two or more of these.

It will be understood, of course, that the specific parameters above-determined for the shielding system of Fig. 3 are merely illustrative of one particular application of this invention. It may be pointed out also that, in general, variations in such factors as the wire size, separations of the disturbing and disturbed lines, and spacings between these lines and the shielding conductors result in variations in the parameters of the shielding system shown in Fig. 3 commensurate with the variations mentioned hereinabove in the discussion of the systems shown in Figs. 1 and 2.

In another embodiment of this invention illustrated in Fig. 5, the closed metallic shielding circuit comprises, in addition to the shielding conductors 12 and 13 located adjacent the disturbing line 10 and the disturbed line 11, respectively, two conductors 12*c* and 13*c* disposed closely adjacent and substantially parallel to each other and positioned between the conductors 12 and 13. A series impedance 15 is connected as shown and may be a resistor, inductor, or capacitor or any combination of the three. The parameters of the shielding system necessary for perfect shielding may be ascertained in the same manner as described in detail heretofore in connection with Figs. 1 to 4, inclusive.

Although several embodiments of this invention have been shown and described, it will be understood, of course, that the shielding systems thus shown and described are but illustrative of the invention and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. In combination, a pair of transmitting lines disposed in the vicinity of each other and a shielding circuit comprising a closed metallic loop having a portion adjacent one of said transmitting lines and another portion adjacent the other of said lines.

2. In combination, a power line, a telephone line subject to inductive interference from said power line, and a shielding circuit comprising a closed metallic loop having a wire portion adjacent and substantially parallel to said power line and another wire portion adjacent and substantially parallel to said telephone line.

3. In combination, a power system including a line, a telephone system including a line in the vicinity of said first line and forming an inductive exposure therewith, and a shielding system comprising a closed metallic loop having a wire adjacent said power line and another wire adjacent said telephone line, said wires being of such length that the shield factor is substantially zero.

4. In combination, a transmission line, a second transmission line subject to inductive disturbance by said first line and forming an exposure therewith, and a closed metallic loop shielding system including a pair of wires each adjacent one of said lines, said wires being of less length than said exposure.

5. In combination, a transmitting line, a second transmitting line in the vicinity of and subject to inductive disturbance by said first line, and a closed metallic shielding system including a pair of conductors each having a portion adjacent said first line and another portion adjacent said second line.

6. In combination, a power line, a telephone line in the vicinity of said power line and forming an inductive exposure therewith, and a closed metallic shielding circuit including a pair of conductors each transposed intermediate the ends of said exposure, each of said conductors having a portion adjacent said power line and a portion adjacent said telephone line.

7. In combination, a power line, a telephone line in the vicinity of said power line and forming an inductive exposure therewith, and a shielding system comprising a closed metallic loop including a pair of wires each having a portion adjacent said power line and a transposed portion adjacent said telephone line, said wires being transposed at a common point intermediate one end of said exposure and the longitudinal midpoint thereof.

8. In combination, a pair of transmitting lines disposed in the vicinity of each other and forming an inductive exposure, and a shielding system adjacent said exposure including a closed metallic circuit having a portion adjacent each of said lines and means including a pair of adjacent conductors cross-connecting opposite ends of said portions.

9. In combination, a power line, a telephone line in the vicinity of said power line and forming an inductive exposure therewith, and a closed metallic shielding circuit comprising a wire adjacent and substantially parallel to said power line, a wire adjacent and substantially parallel to said telephone line, and conductors including closely adjacent substantially parallel portions cross-connecting opposite ends of said wires.

10. In combination, a pair of transmitting lines one subject to disturbance by the other and a closed metallic shielding circuit comprising a pair of wires each disposed adjacent one of said lines, and an impedance in series with said wires of such magnitude that the shield factor is substantially zero.

11. In combination, a power line, a telephone line in the vicinity of said power line and forming an inductive exposure therewith, and a closed metallic shielding circuit comprising a pair of wires each transposed intermediate the ends of said exposure and each having a portion adjacent said power line and a portion adjacent said telephone line, and an impedance of predetermined phase angle and magnitude connecting said wires at one end.

12. In combination, a power line, a telephone line in the vicinity of said power line and forming an inductive exposure therewith, and a closed shielding system comprising a wire adjacent said power line, a wire adjacent said telephone line, a conductor connecting one pair of opposite ends of said wires, and a connection between the other opposite ends of said wires including a conductor adjacent said first conductor and a series impedance of predetermined magnitude and phase angle.

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