May 21, 1935. L. L. LOCKROW 2,001,847

SYSTEM FOR THE NEUTRALIZATION OF INDUCTIVE INTERFERENCE

Filed April 15, 1933

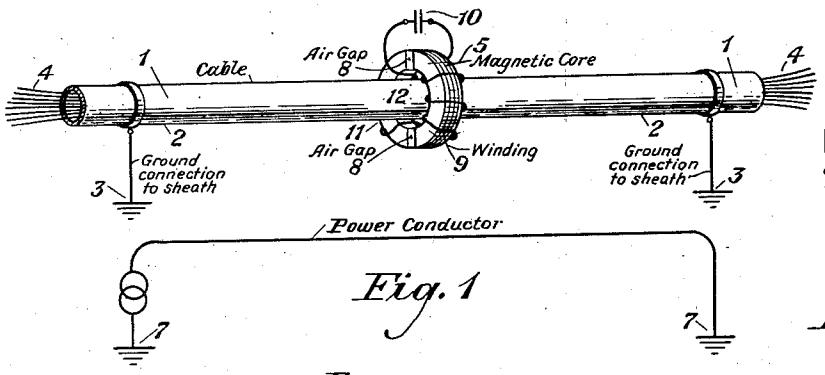


Fig. 1

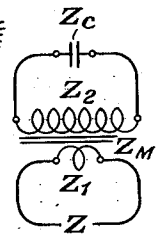


Fig. 2

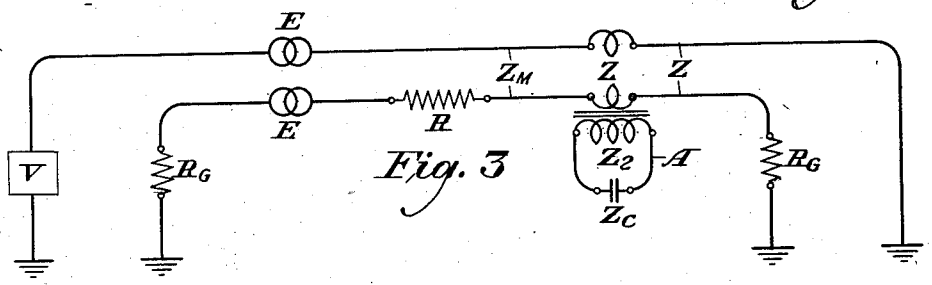


Fig. 3

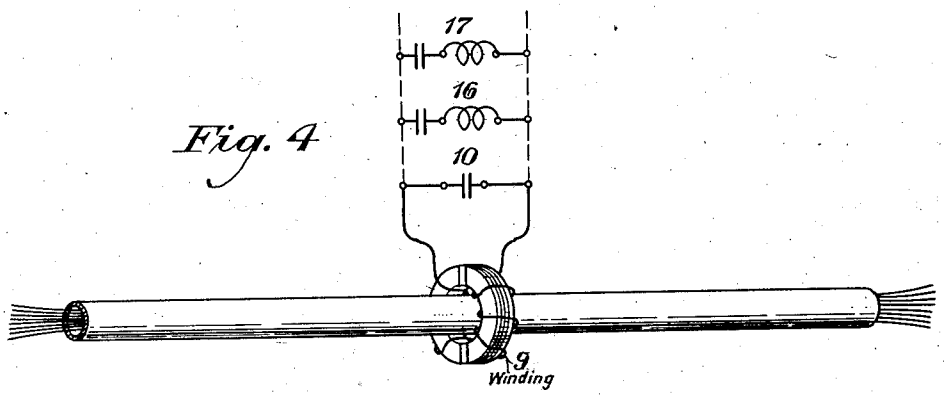


Fig. 4

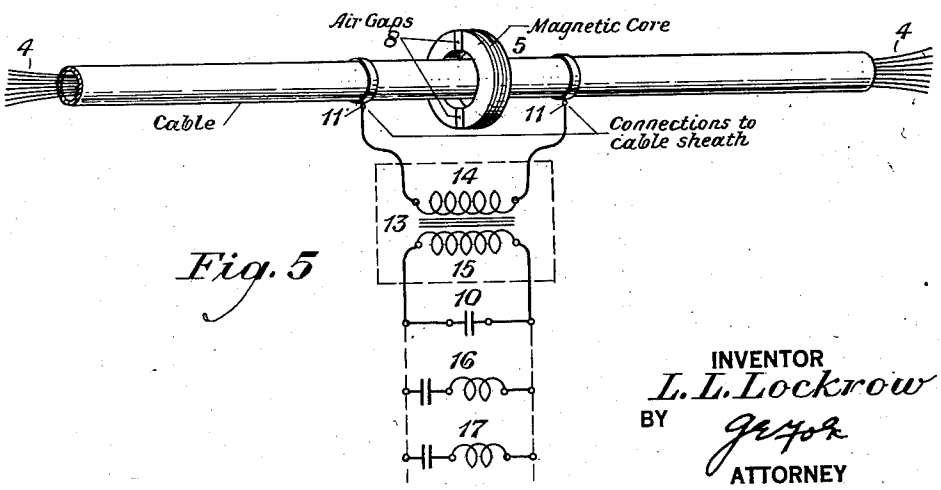


Fig. 5

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SYSTEM FOR THE NEUTRALIZATION OF INDUCTIVE INTERFERENCE

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9 Claims. (Cl. 179—78)

This invention relates to electrical circuits and, more particularly, to circuits for the neutralization and suppression of induced voltage and its effect. Still more particularly, this invention relates to circuits employing neutralizing transformers which may be applied to groups of electrical conductors and, moreover, it relates to neutralizing transformers which may be applied to cables and cable sheaths enclosing groups of conductors.

Neutralizing transformers have heretofore been employed to reduce the interference in communication circuits which may be produced by nearby power lines or other disturbing circuits to which the communication circuits are exposed. The use of neutralizing transformers generally involves an auxiliary circuit in which are induced the same disturbances as are induced in the communication circuits. In such arrangements, the neutralizing transformers have their primary windings connected in the auxiliary circuit and their secondary windings in the communication circuits, the secondary windings being so related to the primaries that the voltages induced therein by the primary windings will tend to oppose those induced directly by the power or disturbing circuits into the communication circuits.

Various arrangements have been suggested from time to time for constructing these primary and secondary windings with a view to improving the coupling between them in order to suppress the induced effects more perfectly, but because of the complexity of the suggested arrangements they were generally impractical. These former arrangements generally involved the use of primary and secondary windings which were wound around a common magnetic iron core, the primary windings being connected in series relation with the auxiliary circuit and the secondary windings in series relation with the communication circuits to be protected.

In this connection it will be noted that the primary and secondary windings above mentioned have a considerable amount of mutual capacity and direct current resistance and certain of the designs that have been suggested in the past also add an appreciable amount of inductance to the communication circuits. In consequence, these neutralizing transformer windings cause an objectionable transmission loss in the communication circuits in which they are connected and also cause substantial impedance irregularities. These impedance irregularities would impair transmission quality due to distortion caused by reflections; they would degrade the operation of voice-frequency telephone repeaters due to impaired balance between the line and balancing network circuits. These various impairments would tend to be particularly objectionable in multi-transformer installations and in some cases their cumulative effect would become intolerable.

This invention proposes to reduce the various impairments mentioned above by designing a transformer suitable for the neutralization and suppression of induced voltage effects, said transformer consisting of a magnetic iron core which surrounds the group of electrical conductors to be protected, or, more particularly, a communication cable consisting of a cable sheath enclosing groups of conductors.

Another object of this invention is to provide a simple and comparatively inexpensive means of obtaining the equivalent of a primary winding in cable circuits or in other groups of conductors which will give a maximum of magnetic coupling between the element forming the equivalent of said winding and another element or elements forming the equivalent of a secondary winding or windings, these elements together forming a transformer employed for the neutralization and suppression of induced voltage effects.

Still another object of my invention is to provide a simple and comparatively inexpensive means of obtaining greater reductions in induced voltage effects in communication circuits and, more particularly in cable circuits, than any other arrangements now known for the neutralization and suppression of induced voltage effects in such circuits.

A further object of my invention is to provide a neutralizing transformer for neutralizing and suppressing the induced voltage effects in communication circuits and, more particularly, in groups of conductors enclosed in cable sheaths, said transformer being so constructed that the mechanical and electrical disturbance to the communication circuits or groups of electrical conductors to be protected is practically nil.

My invention is illustrated in the accompanying drawing in which Figure 1 shows the application of a special type of neutralizing transformer to a communication cable and its enclosed group of conductors for the neutralization and suppression of induced voltage effects in said group of conductors. Figs. 2 and 3 are equivalent circuit diagrams used in explaining the invention. Fig. 4 shows the manner of arranging additional shunt circuits so as to make the transformer effective at several frequencies. Fig. 5 shows an alternate means of connecting a tuning condenser across the equivalent of the primary winding of the special neutralizing transformer involved in this invention.

In Fig. 1 is indicated the communication cable 1—1 having its metal sheath 2—2 grounded at the points 3—3. This metal sheath encloses a group of separately insulated wires designated 4—4. The cable is exposed to a power line or other disturbing circuit or circuits designated

7—7, and it will be understood that the disturbing circuit or circuits may have any well-known form.

The arrangement shown in Fig. 1 consists of an iron core 5 constructed of circular laminations placed around the cable and stacked lengthwise along it. A number of turns of a winding designated 9 are wound around the core, these turns being insulated from each other and from the core 5. It will be understood that this insulation may be obtained by wrapping the winding 9 in any well-known form of insulating material, thereby reducing the necessary spacings to a minimum, or the turns of said winding may be so spaced from each other and from the core 5 as to be definitely insulated from each other. A condenser designated 10 is connected to the extremities or terminals of the winding 9 for adjusting the phase relation between the neutralizing voltage set up in the special neutralizing transformer of this invention and the disturbing voltage. The section of the cable sheath between the points designated 11—11 which are immediately adjacent to the opposite faces of the core 5 serves as the equivalent of the primary of the transformer and the conductors enclosed within the section of sheath designated 11—11 serve as the equivalent of the secondary windings of the transformer and these are designated 12—12. It will be noted that the conductors 12—12 which form the secondaries of the transformer and which are enclosed within the section of the cable sheath 11—11 are, in fact, portions of the conductors 4—4.

Since the tuning condenser 10 is connected across the winding 9 which is wound around the iron core 5, it is connected inductively to the section of cable sheath designated 11—11 which serves as the primary of the transformer. The auxiliary circuit of this neutralizing transformer consists of the cable sheath 2—2 and the grounds at points 3—3 which are connected to the cable sheath at, for example, the ends of the power exposure. Although the auxiliary circuit of this neutralizing transformer is shown as consisting of the cable sheath 2—2 and the grounds at points 3—3, it will be understood that the auxiliary circuit may, if desired, consist of ground points such as 3—3 and the metal sheath 2—2 and other conductors connected in parallel with said metal sheath such as conductors enclosed within said sheath and/or conductors not enclosed therein but parallel and adjacent thereto. In cases where any two of the conductors such as 4—4 (or any multiples of two conductors) are used in parallel with the metal sheath as the auxiliary circuit, these conductors can be connected to ground points such as 3—3 through a retardation or drainage coil, thereby allowing the use of these conductors for communication purposes.

Since the cable sheath 2—2 and the electrical conductors 4—4 which are enclosed therein go through the iron core 5 as a single unit, each of the secondaries designated 12—12 will have the same number of turns as the cable sheath 11—11 which serves as the primary of the transformer. Since, in the case of communication circuits exposed to induction, as, for example, induction from power lines or electrical railways or the like, the value of induction is not ordinarily steady but varies from time to time through wide limits due to wide variations in disturbances on said power lines or the like, one or more air gaps such as 8 are placed in the magnetic core 5 so as to make the reluctance of this special type of transformer more constant through the range of flux densities for which this transformer may operate. This also prevents saturation of the iron core, thereby rendering the induction due to transformer action practically proportional to the inducing force such as that caused by the neighboring power lines. It is not practicable to use a condenser as a phase shifting device in conjunction with a winding located on a core which does not have an air gap because a core of this type has variable reluctance and the winding therefore has variable inductance corresponding to variations in the magnitude of the induced voltages. However, because of the air gaps designated 8, the transformer of this invention has practically a constant value of inductance through a wide range of flux densities, thereby permitting the effective use of a shunt condenser such as 10 for controlling the phase relation between the voltage set up in the transformer and the disturbing voltage.

The magnetic iron core 5 of the transformer of Fig. 1 is divided into two portions by the air gaps designated 8. These two core portions may be adjustably held in proper spaced relation by suitable clamping means (not shown) in order that the length of gaps 8 may be adjusted to the proper value. An increase in the air gaps 8 produces a decrease in the inductance of the winding 9. This is compensated for by increasing the capacity of the shunt condenser 10. Thus, adjustment in the air gaps 8 assist in obtaining the value of inductance which best suits the particular conditions applying for a given transformer. By this particular transformer arrangement, the neutralization and suppression of the induced voltage effects are obtained by transformer action, said transformer action causing a substantial increase in the self-impedance of the cable sheath circuit 11—11 which serves as the primary and in the mutual impedance between this primary and the cable conductors 12—12 which serve as the secondaries.

The action of this transformer in increasing the self-impedance of the section of the cable sheath between the points 11—11 or, in other words, the primary, is best described in terms of the equivalent circuit of Fig. 2. Referring to this figure, the section of the cable sheath between the points designated 11—11 constitutes the primary of the transformer and the winding 9 which is wound around the iron core 5, the secondary. The tuning condenser 10 is connected across the terminals of the secondary winding 9. By the usual circuit analysis the self-impedance of the section of the cable sheath between the points 11—11 becomes:

$$Z = Z_1 - \frac{(Z_M)^2}{Z_2 + Z_C} \qquad (1)$$

where

Z_1=impedance of primary with the secondary open.

Z_2=impedance of the secondary with the primary open.

Z_M=mutual impedance, primary to secondary.

Z_C=impedance of condenser.

The terms Z, Z_1, Z_2, Z_M and Z_C are shown in their relative positions in the equivalent circuits of Fig. 2.

It it were possible to make $Z_2 = Z_C$, the impedance Z would become infinite. This is not possible, but it is possible to choose the constants of

the winding 9 and the tuning condenser 10 so as to give a maximum impedance of the cable sheath circuit 11—11 at the fundamental frequency of the induced voltage, this frequency being the operating frequency of the nearby power lines or electrified railways.

Due to the fact that the cable sheath surrounds the cable conductors and that the resistance of the sheath between the points designated 11—11 is very small, the mutual impedance between the cable sheath circuit 11—11 and the group of conductors enclosed therein is substantially the same as the self-impedance of the cable sheath circuit 11—11. It follows then that for any increase in the self-impedance of the sheath circuit 11—11 due to transformer action, there will also be a corresponding increase in the mutual impedance between the sheath circuit designated 11—11 and the group of conductors enclosed therein, these conductors being designated 12—12 and being a portion of the conductors designated 4—4.

The action of the entire circuit is best described in terms of the equivalent circuit of Fig. 3 in which,

E=voltage induced in the sheath and its enclosed conductors by the earth-return power of conductor current.

V=net voltage in each cable conductor as measured by high-resistance voltmeter.

R_G=resistance of each ground connection of the auxiliary circuit.

Z_S=total self-impedance of sheath circuit including grounds but exclusive of that due to transformer action.

R=effective resistance of metal sheath.

Z_M=earth-return mutual-impedance of the sheath to its enclosed conductors, exclusive of that due to transformer action.

Z=self-impedance of sheath due to transformer action which is also equal to mutual-impedance of the sheath to its enclosed conductors due to transformer action.

The current I in the sheath circuit is given by the following expression:

$$I=\frac{E}{Z+Z_S} \qquad (2)$$

The net voltage V in the cable conductor is given by the following expression:

$$V=E-I(Z+Z_M)=E\left[1-\left(\frac{Z+Z_M}{Z+Z_S}\right)\right] \qquad (3)$$

And the ratio of the net voltage to the voltage induced from the power circuit is given by the following expression:

$$\frac{V}{E}=1-\frac{Z+Z_M}{Z+Z_S}=\frac{Z_S-Z_M}{Z+Z_S} \qquad (4)$$

However, since

$$Z_S=Z_M+R+2R_G \qquad (5)$$

the latter ratio reduces to the following expression:

$$\frac{V}{E}=\frac{R+2R_G}{Z+Z_S} \qquad (6)$$

From the latter expression it appears that the larger Z can be made, the lower the ratio becomes.

It is possible by proper choice of the circuit constants Z_2 and Z_C, as shown in Fig. 3, to obtain a tuned circuit such as A, this circuit having a maximum impedance at the critical or fundamental frequency of the induced voltage as previously described in the explanation of Fig. 2. Z_2 represents the impedance of winding 9 while Z_C represents the impedance of the tuning condenser 10. Thus, by virtue of this tuned circuit and the transformer action, it can be seen that the impedance Z of the cable sheath becomes very large at the fundamental frequency of the induced voltage. The large value of Z, therefore, makes the ratio

$$\frac{V}{E}$$

very small and this in turn indicates a very large reduction in the original induced voltage, this reduction being so great that the net voltage approaches zero.

Where induced voltages of several different frequencies are present as, for example, the fundamental together with the third and fifth harmonics, it is possible to neutralize and suppress these voltages by providing additional shunt circuits consisting of elements 16, 17, etc., as shown in Fig. 4. These shunt circuits will give the proper phase relation between the neutralizing and induced voltages at these different frequencies. It will be noted that these shunt circuits are connected across winding 9, an individual shunt circuit being provided for each additional frequency.

Instead of employing a winding 9 wound around a magnetic core with a tuning condenser 10 connected across the terminals of that winding, as shown in Fig. 1, the tuning condenser 10 may be connected to the cable sheath at points 11—11 through an iron core transformer designated as 13, as shown in Fig. 5. The primary winding 14 of this transformer is connected to the cable sheath at points 11—11 and the secondary winding 15 to the tuning condenser 10. It will be understood that this transformer may have any suitable turn ratio which permits the use of condenser of convenient size. As discussed above additional shunt circuits designated as 16 and 17 may be connected across the secondary winding 15 so as to obtain proper phase relation between the neutralizing and induced voltages at other frequencies as well as at the fundamental. Although the condenser 10 is shown as being inductively connected to the metal sheath through the transformer 13, it will be understood that the condenser 10 may, if desired, be connected directly to the metal sheath at points such as 11—11. Also, it will be understood that the primary of this transformer designated here as the metal sheath circuit 11—11 may consist of a metal different from that generally used in communication cables and, more particularly, a metal sleeve or sheath of higher conductivity than that used in commercial cables. This may be desirable in cases where the resistance of the cable sheath itself may be so high as to preclude the proper phase relation of the neutralizing and induced voltages.

In cases where the induced voltage is equal to or less than the rated voltage of the transformer, only one transformer and two ground connections to the auxiliary circuit are required, the ground connections being made at the ends of the power exposure. Where the induced voltage is greater than the transformer rated voltage, several transformers are placed along the cable, the ground connections to the auxiliary circuit being provided at the ends of the power exposure and at various points within the exposure. These latter ground points are so spaced and located between the transformers as to divide the total induced voltage into parts whose magnitude is equal to or less than the rated voltage of one transformer, said transformer being placed midway, in the in-

duced voltage scale, between consecutive ground points.

The operation of this transformer is as follows: The auxiliary circuit composed of the cable sheath 2—2 and the grounds at points 3—3 has induced in it from the disturbing circuit 7—7 the same voltage as the group of conductors 4—4 enclosed within the sheath. Through transformer action at the fundamental frequency of the induced voltage as, for example, frequencies such as 25 or 60 cycles, winding 9 with its shunt condenser 10 causes a substantial increase in the self-impedance of that section of the cable sheath between points 11—11 and consequently a substantial increase in the mutual impedance between that section of cable sheath designated 11—11 and the section of cable conductors designated 12—12, this latter section of conductors being a portion of the cable conductors 4—4. Therefore, the self-impedance of the cable sheath between points 11—11 at the fundamental frequency of the induced voltage will be large when compared to the self-impedance of the auxiliary circuit consisting of the remainder of the cable sheath 2—2 and the grounds at points 3—3, in which case practically all of the voltage induced in the auxiliary circuit 3—3 and 2—2 will appear across the section of the cable sheath between 11—11. By virtue of the high mutual impedance between the section of sheath designated 11—11 and the section of conductors designated 12—12, this voltage will appear in the cable conductors between points 12—12. By virtue of proper phase relation between this neutralizing voltage, and the induced voltage obtained by using the shunt condenser 10, the polarity of this neutralizing voltage is such as to oppose that voltage induced directly in the cable conductors 4—4 by the disturbing circuit or circuits 7—7. Thus the net longitudinal voltage appearing in the cable conductors 4—4 will be relatively small and will approach zero.

While the circuits 16 and 17 of Figs. 4 and 5 may be employed in conjunction with the condenser 10 in an arrangement for the suppression of a 25 or 60 cycle voltage or any other voltage and certain of its harmonics, for example, the 3rd and 5th harmonics, as described hereinabove, it will be understood, however, that the circuits 16 and 17 need not function for the suppression of harmonics of a fundamental frequency but that these may be employed to suppress any frequencies that may interfere with transmission over the conductors 4—4 and that the frequencies suppressed by the circuits 16 and 17 need not be related in any manner to the frequency suppressed by the coil 9 and condenser 10.

While the arrangement shown in Figs. 1, 4 and 5 are specifically directed to an aerial cable sheath and its enclosed conductors, it will be understood that the principles of this invention may readily be applied to any other form of cable sheath and its enclosed conductors. If the cable sheath were located under ground, it would be desirable either to insulate the cable sheath from ground throughout the length of its exposure except at the grounding points which occur approximately at the ends of the exposure, or, if preferred, the sheath may be continuously grounded and a plurality of similar devices each including a core such as 5 and a winding such as 9 may be located along the sheath at spaced intervals. In the latter case, each winding 9 and its corresponding condenser 10 may be considered as a tuned circuit which is resonant at the frequency of the current which it is intended to suppress or neutralize.

While I have shown and described certain forms of my invention merely for the purpose of illustration, it will be understood that various modifications may be made without departing from the spirit and scope of the appended claims.

What is claimed is:

1. A transformer arrangement for neutralizing the effect of induction from exposure to power circuits comprising a cable sheath, a plurality of conductors insulated from each other and enclosed within the cable sheath, the cable sheath being grounded at the ends of the section exposed to the power circuits, a core positioned coaxially about the cable sheath substantially at the midpoint of the voltage effect due to the exposure, a winding wound about said core, and a condenser connected to the winding, the condenser and the winding forming a circuit which is resonant at the frequency of the voltage effect induced from the power circuits.

2. An arrangement for protecting the conductors enclosed within a cable sheath from the influence of induction from a power circuit to which the sheath and its enclosed conductors are exposed, comprising means for grounding the cable sheath at the ends of the exposed section, a core of iron composed of two semi-circular parts which may be mounted about the exposed sheath substantially at the center of the exposure, gaps existing between the two semi-circular parts, a coil of wire wound about said iron core, and a condenser connected to terminals of said coil, said coil and condenser being tuned to the frequency of the current induced from the power circuits.

3. Apparatus for suppressing the inductive interference induced into the conductors enclosed within a cable sheath exposed to a power circuit or the like comprising a plurality of sections each composed of a magnetic core of iron formed by two semi-circular sections spaced from each other by air gaps and coaxial with the cable sheath, the cable sheath being grounded at both ends of each section of the exposed area, a core of wire wound about the iron core, and a condenser connected to the terminals of the coil, said coil and condenser being resonant to the frequency of the voltage effect introduced into the conductors due to the exposure.

4. An arrangement for suppressing the voltage effect of a power circuit induced into the conductors enclosed within a cable sheath which is exposed to the power circuit, comprising a core of iron located about the cable sheath, a coil of wire the ends of which are connected to two points along the cable sheath which are on opposite sides of the iron core, and a condenser coupled to said coil of wire, the condenser and the circuit to which it is coupled being anti-resonant at the frequency of the voltage induced from the power circuit.

5. Means for suppressing the voltage induced from a power circuit into the conductors enclosed within a cable sheath which is exposed to the power circuit, comprising a core of iron which is positioned about the cable sheath, said core of iron having an air gap, a transformer the primary winding of which is connected to two points along the cable sheath which are located on opposite sides of the iron core, and a condenser connected to the secondary winding of the transformer, said condenser and the circuit to which it is coupled being anti-resonant at the

frequency of the voltage induced from the power circuit into the various conductors.

6. An arrangement for suppressing the voltage of a predetermined frequency inductively introduced into the conductors enclosed within a cable sheath which is exposed to a power circuit or the like, comprising a core of iron composed of two semi-circular parts which are positioned about the cable sheath although spaced from each other by an air gap, a coil of wire coupled to that portion of the cable sheath which is enclosed by the iron core, and a condenser coupled to said coil of wire, the condenser and the circuits to which it is coupled being antiresonant at the frequency of the induced voltage.

7. A cable sheath enclosing a plurality of conductors exposed to a circuit which induces a voltage of a predetermined frequency in said conductors, a core of iron composed of two semicircular sections, the two sections of said core being positioned about the cable sheath which houses said conductors although spaced from each other by air gaps, the various conductors being insulated from each other and from the cable sheath, a coil of wire wound about said core of iron, and a condenser connected to the terminals of the coil of wire, whereby the voltage induced into the various conductors enclosed within the cable sheath will be neutralized by the voltage set up by the coil of wire and the condenser to which it is connected.

8. Means for eliminating the voltage effect of induction produced by a power circuit in the conductors enclosed within a cable sheath, consisting of means for grounding the cable sheath at the ends of the exposed section, a core of iron composed of two semi-circular parts which may be mounted about the exposed sheath substantially at the center of the exposure, gaps existing between the two semi-circular parts, and a condenser the two terminals of which are connected respectively to the cable sheath at two points on the opposite sides of the iron core, said condenser and the cable sheath circuit between said two points having a natural frequency substantially equal to the frequency of the interfering induction.

9. Means for eliminating the voltage effect of induction produced in the conductors enclosed within a cable sheath which is exposed to a power circuit, a section of the exposed cable sheath being grounded at both ends, an iron core surrounding a part of the grounded section of the cable sheath, and a condenser coupled to the grounded section of the cable sheath, the condenser and the grounded section of the cable sheath together forming a circuit which is antiresonant at the frequency of the induced voltage effect.

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