

May 23, 1939.

W. D. CANNON

2,159,927

NEUTRALIZATION OF INDUCTIVE INTERFERENCE

Filed June 25, 1935

2 Sheets-Sheet 1

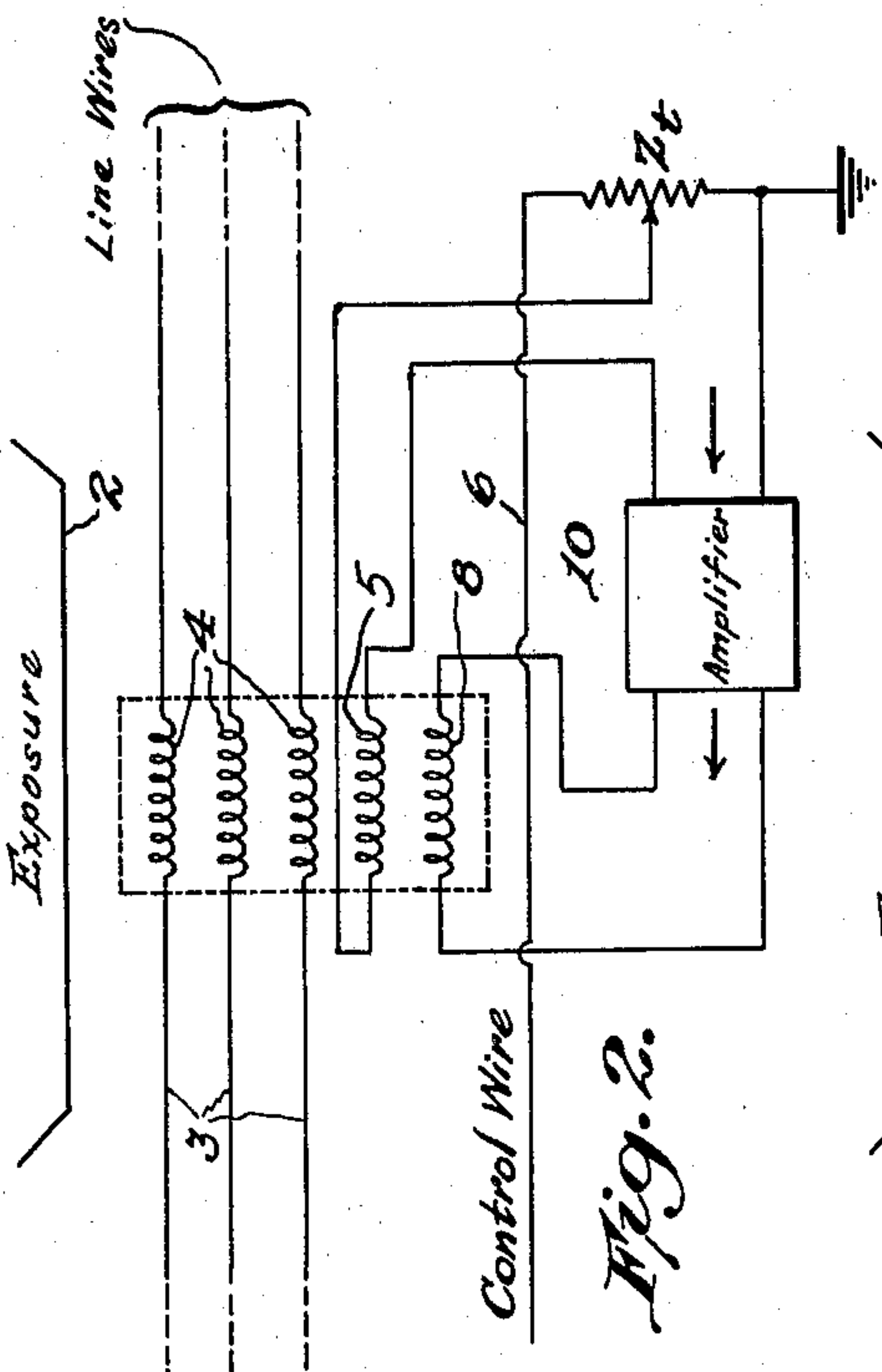


Fig. 1.

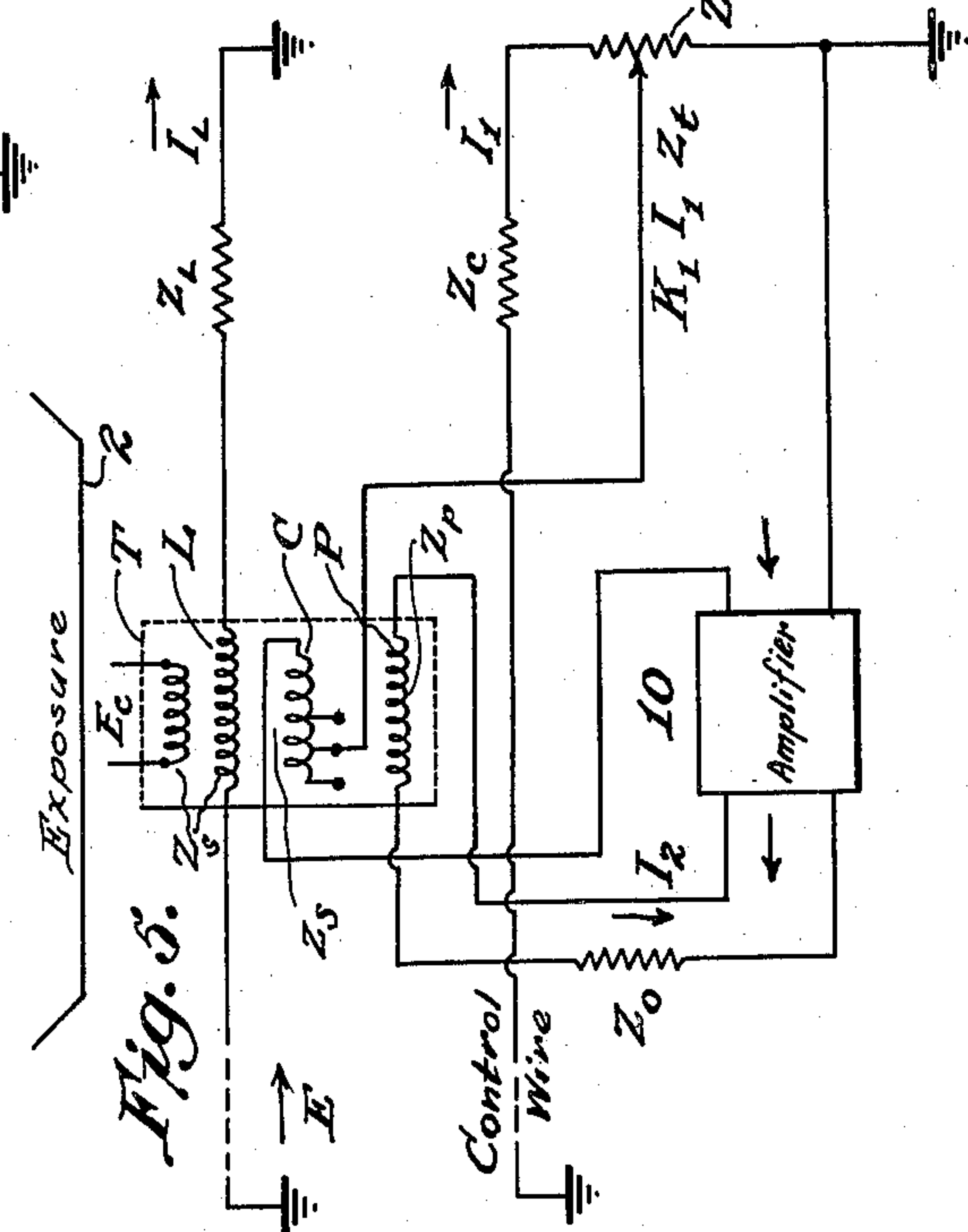


Fig. 2.

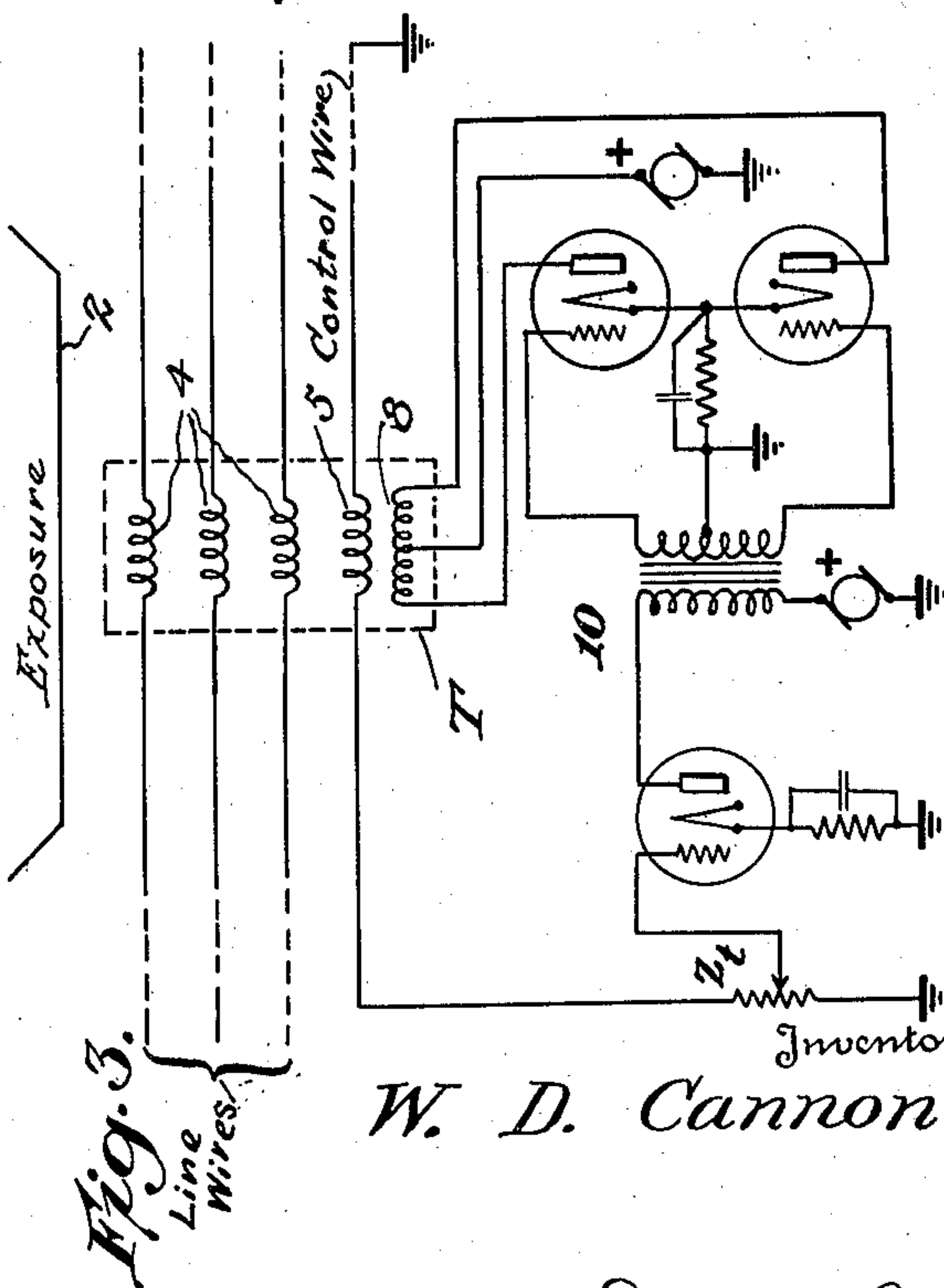


Fig. 3.

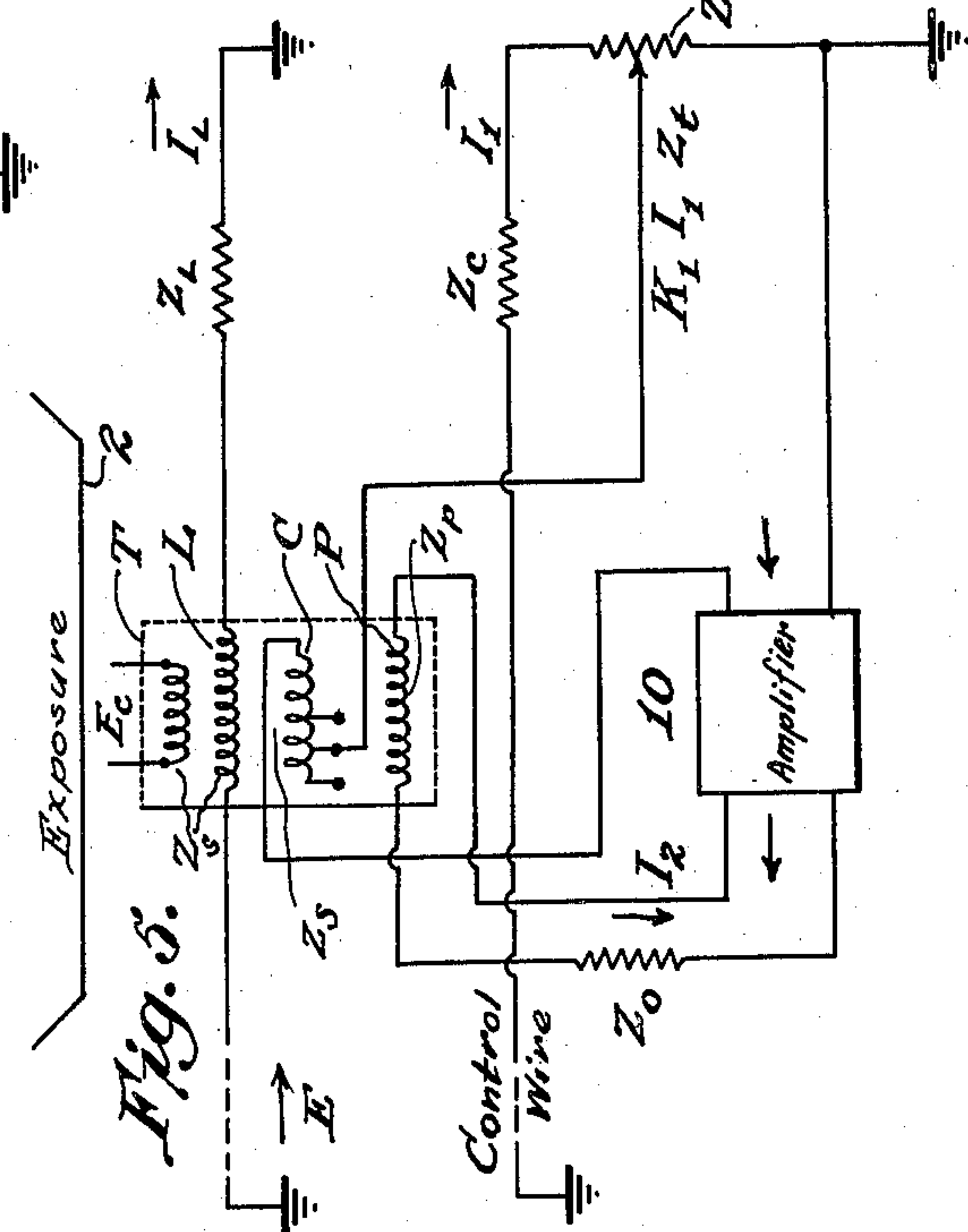


Fig. 4.

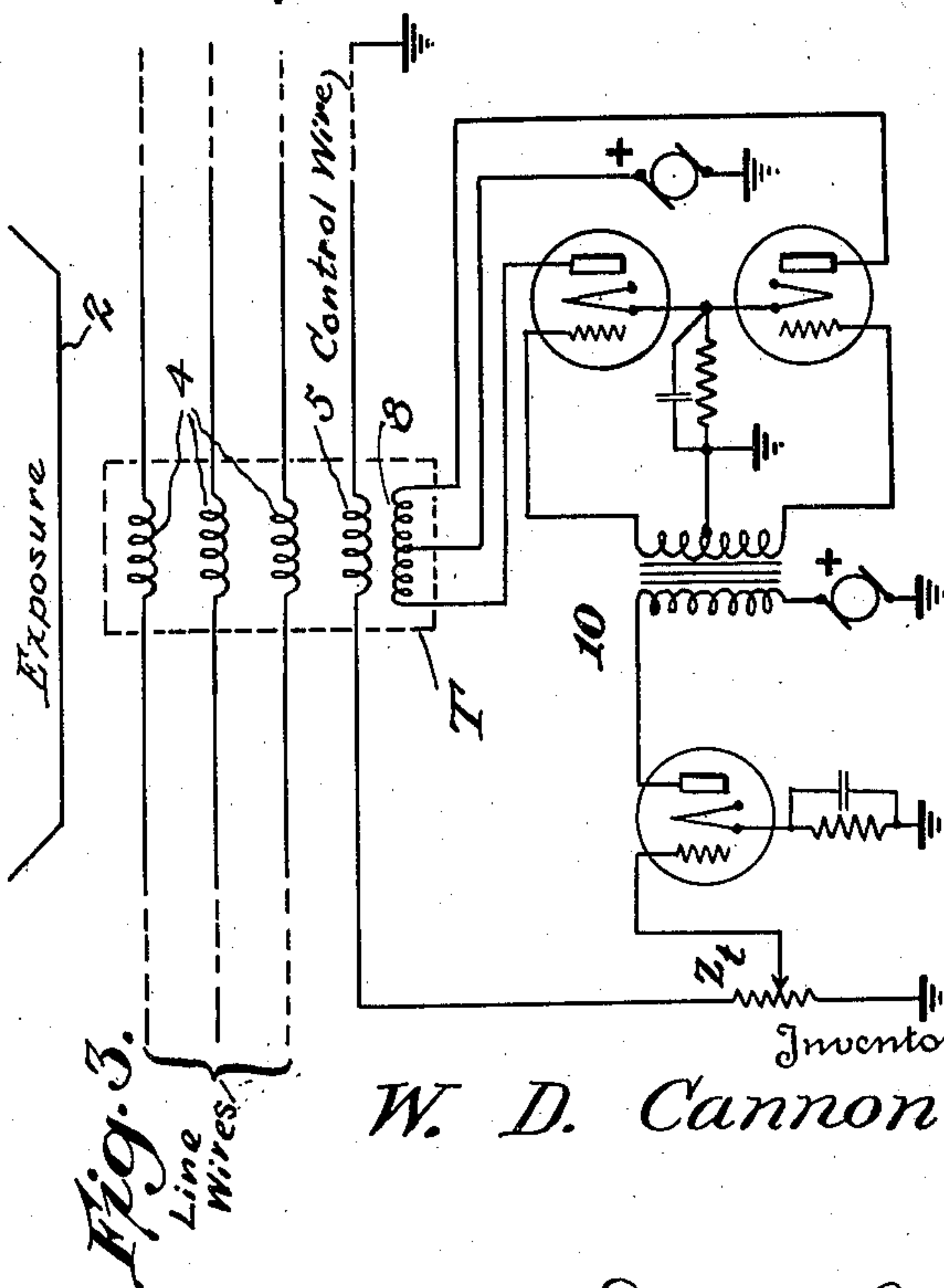


Fig. 5.

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2 Sheets-Sheet 2

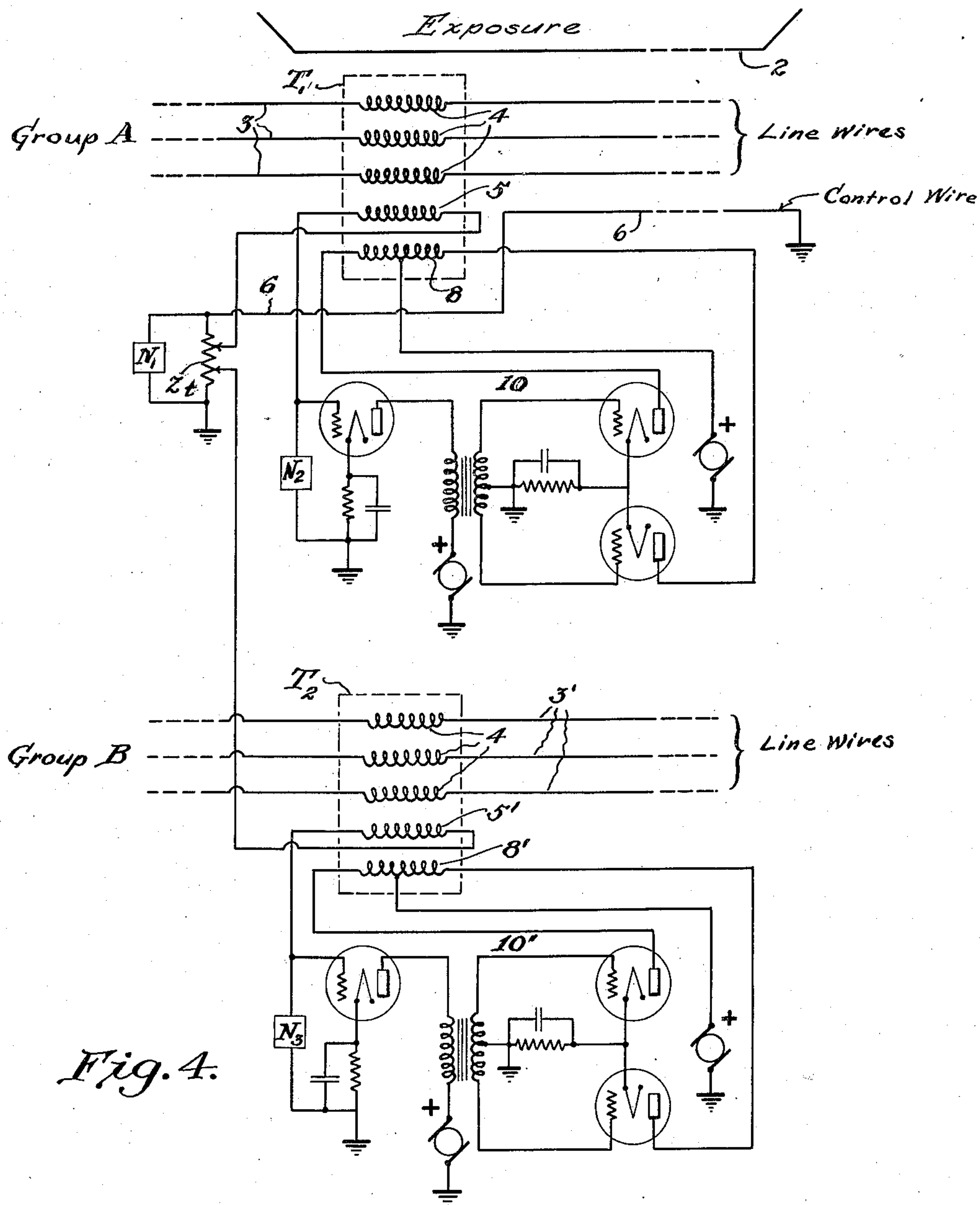


Fig. 4.

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UNITED STATES PATENT OFFICE

2,159,927

NEUTRALIZATION OF INDUCTIVE
INTERFERENCE

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Application June 25, 1935, Serial No. 28,359

13 Claims. (Cl. 178—69)

This invention relates to the neutralization of interfering potentials that may be set up in signaling or communication circuits by adjacent power, railway or lighting circuits or by any cause extraneous to the circuits themselves. Its purpose is to provide a simple and efficient arrangement for the reduction or elimination of interference, especially where a number of lines are subject to the same disturbing influences.

A neutralizing system common to a plurality of communication circuits, inherently causes "crossfire" between the various circuits, since the neutralizing system and the communication wires are inter-connected through a transformer.

The ordinary neutralizing transformer is suitable for neutralizing induction from various sources for short distances only, since the control wire resistance must be kept below a certain maximum value in order that it may act as a substantial short-circuit for the energy induced in the windings of the transformer. Otherwise the crossfire introduced by the transformer may be prohibitive. Neutralizing systems employing neutralizing generators having automatic controls for adjusting the amplitude, frequency and phase of the neutralizing voltage with respect to the disturbing voltage may be used in cases where the control wire resistance must unavoidably be high. However, this system is somewhat unsatisfactory and has a very poor transient response. The neutralizing transformer will respond to a sudden change in induction in about one-half cycle while the neutralizing generator system usually requires several cycles.

Accordingly, the more specific objects of my invention are to provide:

- (a) A neutralizing means for long exposures or cases where the control wire resistance must be high.
- (b) A means useful for neutralizing induction over an exclusive band of frequencies.
- (c) A system substantially aperiodic in order to give efficient transient response.
- (d) A system substantially free from inherent crossfire.

In the following description of my invention I shall refer to the accompanying drawings, in which—

Figure 1 represents diagrammatically the neutralizing transformer and associated amplifier applied to a plurality of disturbed lines which are subject to a plurality of disturbing frequencies.

Figure 2 is a modification of the circuit arrangement shown in Figure 1, the control coil

being placed in series with the input of the amplifier instead of being in series with the control wire.

Figure 3 is a more detailed illustration of the system substantially as shown in Figure 1, the amplifier being of the conventional two-stage type with a push-pull output stage. While this figure shows the system applied to only one end of the exposure, the system may be applied to any part of the circuit and a plurality of systems may be applied at different points, using the same control wire.

Figure 4 is an arrangement embodying the principle of Figure 2 applied to separate groups of line wires.

Figure 5 is a further modification of the circuit embodying my invention and is particularly referred to in the following description in the discussion of the mathematical relations which serve as guides in the design of the system.

Referring to Figure 1, the disturbing power line or other extraneous cause of induction is indicated at 2 and the communication or line wires are indicated at 3. A control wire 6 parallels the line wires and may be carried upon the same pole line throughout that portion of the system which is subject to the disturbing induction. The control wire is grounded at each end either directly or through an impedance or network Z_t . The line wires include coils 4 of a neutralizing transformer T and a coil 5 in the control wire 6. A thermionic tube amplifier 10 is associated with the transformer and control wire, having its input adjustably connected across the impedance Z_t and its output connected to a coil 8 which constitutes the primary of transformer T.

The operation is as follows: The exposure 2 induces substantially equal voltages in the line wires 3 and in the control wire 6 which are partially neutralized by transformer action in coils 4 and 5, and leave a residual voltage in both the line wires and in the control wire. The control wire current due to this residual voltage produces a voltage drop across the network Z_t . This voltage is adjustably amplified and applied to a coil 8 of the transformer in such a direction as to further reduce said residual voltages in both the line wires and in the control wire. The final residual voltage can thus be reduced to a negligible value if sufficient amplification is used.

"Crossfire" introduced among the line wires by the transformer itself when the system is properly adjusted, is negligible in amount, even with a very large control wire resistance. The reason for this will be evident. Suppose a cur-

rent is flowing in one of the line wires which produces a voltage across the network Z_t . This voltage is amplified by the amplifier 10 and causes a current to flow in coil 8 substantially opposite in phase relation and equal to the current in the line wire, thus neutralizing the effect of the original current. Consequently, practically no voltage is induced in the other line wires.

A more complete diagram of the system is shown in Fig. 3, the thermionic tube amplifier being of the conventional two-stage type with a push-pull output stage. The voltage impressed upon the input of the amplifier from Z_t is amplified and is then applied to a coil 8 of the transformer T. While Fig. 3 shows the system applied to only one end of the exposure, the system may be applied to any part of the circuit, or a plurality of systems may be applied at different points using the same control wire.

A modification of the circuit of Fig. 1 may be made as shown in Fig. 2. Instead of placing the control coil 5 in series with the control wire 6, it is placed in series with the input to the amplifier. The operation is quite similar to that of Figure 1.

In said Figure 2 a substantially equal voltage from the exposure 2 is induced both in the line wires 3 and in the control wire 6. A current will then flow in the control wire producing a voltage drop across Z_t which may be applied in series with the control coil 5 to the input of the amplifier. The output from the amplifier is then applied to the primary coil 8 in such a direction as to neutralize the induction in the line wires 3, and at the same time by means of coil 5, it opposes the voltage drop across the high resistance of impedance Z_t . When properly adjusted, the residual voltage in the line wires will be small and the voltage applied to the amplifier, which is the difference between the voltage drop across Z_t included in the input to the amplifier and the voltage in coil 5, will also be small as compared to the voltage induced from the exposure.

The circuit shown in Fig. 2, has an advantage over the circuit of Fig. 1, in that the line wires may be arranged in small groups, each group having its own transformer and amplifier, but all controlled from the same control wire. A failure in one of the groups will not affect operation of the other groups, although a failure of the control wire will affect all of the wires unless separate control wires are used for each group.

A practical arrangement embodying the principle of Fig. 2 applied to separate groups of wires is shown in Fig. 4. For the purpose of illustration only two groups of wires are shown. Transformers T_1 and T_2 with their associated amplifiers are used to neutralize induction respectively in groups A and B. Coil 5 is the control coil for group A and coil 5', for group B. A single control wire 6 supplies the voltage drop in Z_t which is applied separately through the coils 5 and 5' to the associated amplifiers 10 and 10'. The output from the amplifiers is supplied to coils 8 and 8' to neutralize induction in groups A and B respectively.

It is possible to serve a number of neutralizing transformers spaced at suitable intervals along a disturbed section of line by means of a single control wire. To accomplish this, the control wire is connected to ground through impedances Z_t at the location of each transformer, and the necessary neutralizing voltage is secured from this impedance, as illustrated for the case of transformers located at the terminus of the control wire. A single control wire may serve a neutral-

izing transformer at each end of the circuit, and the impedance Z_t , which is large as compared with the impedance of the control wire, then serves to localize a disturbing voltage introduced near one end of the system so that it would practically all appear across the impedance Z_t . The transformer at that end nearest the disturbance thus provides the neutralizing voltage.

A network N_1 may be connected across Z_t to bypass any undesired currents and to limit the working frequency range to a selected band. Networks N_2 and N_3 may be further used to limit the range to a selected band and also to prevent spurious frequencies lying usually above the useful band of frequencies from being introduced into the system.

In prior arrangements employing neutralizing transformers for neutralizing inductive interference, the circuit of the neutralizing winding may have low impedance during normal operation of the transformer, but should the control wire fail, this circuit assumes the impedance of the output circuit of the vacuum tube, which is normally high. In consequence, the crossfire between conductors becomes so high as to render the circuits practically unworkable even in the absence of power induction. In the system of Figure 2, however, the input circuit of the amplifier is separately included in the transformer, and should the control wire fail, the crossfire voltages arising from the different line wires will be amplified and impressed on the transformer in such a direction as to neutralize the crossfire currents. The wires may therefore continue to work at a somewhat reduced efficiency. This feature is of considerable importance when it is considered that all of the wires of a route may be included in the neutralizing system, and all may be rendered practically inoperative by the failure of a single control wire. Furthermore, in order to assure satisfactory operation of the system, it is common practice to make daily tests of the control wire. By making these tests at periods of low induction the working circuits are entirely undisturbed, an advantage which is entirely absent in the systems of the prior art.

While in the illustrations the signal circuits have been shown as single conductors, it is to be understood that these circuits may be in pairs or other groups as is common in neutralizing transformers. Further, the amplifiers have been shown of a particular type which has been found to operate very satisfactorily. They are not to be construed as limited to this type, however, as numerous other arrangements may be employed as will be evident to engineers.

Certain mathematical relations which serve as guides in the design of such a system will now be developed. While developed with particular attention to the system of Fig. 2, the final resulting approximate equations are applicable to Fig. 1 as well.

Referring to Fig. 5, let

Z_L =Impedance of a single line wire.

Z_c =Impedance of the control wire.

Z_t =Impedance of control wire termination.

Z_o =Output impedance of amplifier.

Z_p =Self impedance of primary coil of transformer T.

Z_s =Self impedance of each secondary coil; also mutual impedance between secondary coils.

Z_m =Mutual impedance between primary coil and any secondary coil $=\sqrt{Z_p Z_s}$.

E =Voltage induced in line wires from exposure.

E_r = Residual voltage = difference between E and voltage in secondary coils.

I_1 = Current in control wire.

I_L = Current in a line wire.

5 I_2 = Current output from amplifier.

K_1 = Percentage of Z_t .

K_2 = Percentage of turns of control coil C.

μ = Amplification constant of amplifier.

10 If the input impedance of the amplifier is very large, then:

$$I_1 = \frac{E}{Z_c + Z_t} \quad (1)$$

15 The input voltage to the amplifier =

$$I_1 K_1 Z_t - K_2 (I_2 Z_m + I_L Z_s)$$

The output voltage from amplifier =

$$\mu [I_1 K_1 Z_t - K_2 (I_2 Z_m + I_L Z_s)]$$

20 and from Kirchhoff's Law—

$$\mu [K_1 I_1 Z_t - K_2 (I_2 Z_m + I_L Z_s)] = I_2 (Z_p + Z_o) + I_L Z_m \quad (2)$$

Further:

$$25 \quad E = I_L (Z_s + Z_L) + I_2 Z_m \quad (3)$$

Substituting (1) and (3) in (2) we have

$$30 \quad \mu \left\{ \frac{K_1 E Z_t}{Z_c + Z_t} - K_2 I_L Z_s - K_2 [E - I_L (Z_s + Z_L)] \right\} \\ = \frac{(Z_p + Z_o) [E - I_L (Z_s + Z_L)]}{Z_m} + I_L Z_m$$

Whence

$$35 \quad \frac{I_L}{E} = \frac{\frac{\mu K_1 Z_t}{Z_c + Z_t} - \mu K_2 - \frac{Z_p + Z_o}{Z_m}}{\mu K_2 Z_s - \mu K_2 (Z_s + Z_L) - \frac{(Z_p + Z_o)(Z_s + Z_L)}{Z_m}} + Z_m$$

If we let

$$40 \quad K_2 = \frac{K_1 Z_t}{Z_c + Z_t}$$

then

$$\frac{I_L}{E} = \frac{Z_p + Z_o}{\mu K_2 Z_L Z_m + Z_L (Z_p + Z_o) + Z_o Z_s}$$

45 But $E_r = I_L Z_L$, then

$$\frac{E_r}{E} = \frac{Z_p + Z_o}{\mu K_2 Z_m + Z_p + Z_o + \frac{Z_o Z_s}{Z_L}} \quad (4)$$

50 For a high percentage of neutralization of the induction E , the ratio

$$\frac{E_r}{E}$$

55 should be small. This can be accomplished by making the amplification factor μ of the amplifier sufficiently large, in which case the ratio

$$60 \quad \frac{E_r}{E}$$

i. e., the residual voltage, approaches zero, and becomes

$$65 \quad \frac{E_r}{E} = \frac{Z_p + Z_o}{\mu K_2 Z_m} \text{ approx.} \quad (5)$$

70 Equation (5) reveals that the output impedance Z_o of the amplifier should be as small as practicable.

In order to show that the system is substantially free from inherent crossfire, assume a current I_L in one of the line wires and let E_o be the voltage developed across the secondary coils as a result of this current as shown in Fig. 5.

Also let the current in the primary coil be I_2 .

Then

$$E_c = I_L Z_s - I_2 Z_m \quad (6)$$

and

$$\text{Voltage input to amplifier} = K_2 (I_L Z_s - I_2 Z_m)$$

$$\text{Voltage output from amplifier} = \mu K_2 (I_L Z_s - I_2 Z_m)$$

and

$$\mu K_2 (I_L Z_s - I_2 Z_m) + I_L Z_m = I_2 (Z_p + Z_o) \quad (7)$$

Substituting (6) in (7) we have

$$K_2 \mu [I_L Z_s - (I_L Z_s - E_c)] + I_L Z_m = \frac{(I_L Z_s - E_c)(Z_p + Z_o)}{Z_m}$$

Solving for

$$\frac{E_c}{I_L} \quad 15$$

$$\frac{E_c}{I_L} = \frac{Z_o Z_s}{\mu K_2 Z_m + Z_p + Z_o} \quad (8)$$

To be substantially free from inherent crossfire, the ratio

$$\frac{E_c}{I_L}$$

should be small. This can be accomplished by making the amplification factor μ sufficiently large, in which case the ratio

$$\frac{E_c}{I_L}$$

approaches zero, and becomes

$$30 \quad \frac{E_c}{I_L} = \frac{Z_o Z_s}{\mu K_2 Z_m} \text{ approx.} \quad (9)$$

Equation (9) reveals, as in the case of Equation (5), that the output impedance of the amplifier should be as small as practicable. By specifically observing this requirement in design, the transformer can be given a very high efficiency for neutralizing disturbing currents and at the same time be kept substantially free of inherent crossfire.

Inasmuch as this neutralizing system contains no tuned circuits, as in the case of the usual neutralizing transformer, the system is aperiodic and will thus be effective in neutralizing transients of very short duration.

I have thus shown that the neutralizing system disclosed herein is substantially aperiodic in operation, capable of responding quickly to a sudden change in induction and substantially free from inherent crossfire. Although this invention has been disclosed in particular forms for the purpose of illustration, it is evident to engineers that it is capable of embodiment in other forms within the scope of the appended claims.

I claim:

1. In a system for neutralizing current induction in line wires, a compensating transformer having coils connected in said line wires, a control wire external to said transformer and exposed to the same induction with said line wires, an amplifier having its input adjustably connected to receive a portion of the voltage induced in said control wire, the output of said amplifier being connected to a coil of the transformer, and a coil of said transformer connected in the input of said amplifier to thereby cause the neutralizing action of the transformer to respond under all varying conditions to which the line wires are subjected.

2. In a system for neutralizing current induction in line wires, a compensating transformer having coils connected in said line wires, a control wire external to said transformer and exposed to the same induction with said line

wires, an amplifier having its input adjustably connected to receive a portion of the voltage induced in said control wire, said transformer having a coil included in the input circuit of said amplifier and a coil in the output of said transformer so connected as to provide a neutralizing flux to nullify the current induction in the lines.

3. In a system for neutralizing disturbing current due to extraneous induction in line wires, a compensating transformer having coils connected in said line wires, a control wire external to said transformer and provided with a lumped high impedance, said control wire being likewise exposed to said extraneous induction, an amplifier having its input adjustably connected to receive a portion of the voltage drop across said impedance, a control coil of said transformer also connected in said input and a primary coil of said transformer connected to the output of the amplifier, whereby the voltage applied to the input of the amplifier is the differential of that induced in said control coil and said selected portion of the drop across said impedance.

4. In a system for neutralizing disturbing current due to extraneous induction in line wires, a compensating transformer having coils connected in said line wires, a control wire external to said transformer and exposed to the same induction with said line wires and having a high impedance in a portion thereof, an amplifier having its input connected to receive a portion of the voltage induced across said high impedance, said transformer having a coil connected in the input of said amplifier, and a coil connected in the output of the amplifier to provide a neutralizing flux to nullify the current induction in the lines, the efficiency of said neutralization thereby being independent of the resistance of the control wire.

5. In a system for neutralizing disturbing current due to extraneous induction in line wires, a compensating transformer having coils connected in said line wires and productive of cross-fire between the wires, a control wire external to said transformer and having high impedance in a portion thereof, said control wire being likewise exposed to said extraneous induction, an auxiliary circuit connected to receive a portion of the voltage induced in said control wire and means connected to said transformer to apply said voltage to nullify the current induced in the line wires, and said means also operating independent of the condition of the control wire to prevent the occurrence of cross-fire between the line wires.

6. In a system for nullifying disturbing currents due to induction, a group of communication wires and a control wire provided with an impedance element, all of said wires being subject to interference from a common external source, a transformer having windings included in each of said wires except said control wire and tending to produce mutual interference therebetween, and an amplifier having an input circuit and a low impedance output circuit, each including a winding of said transformer, said input circuit including also a portion of said control wire impedance, whereby said amplifier neutralizes both the external interference and the mutual interference in said conductors.

7. In a system for nullifying disturbing currents in line wires due to induction, a neutralizing transformer having a winding connected in each line, and tending to produce mutual interference therebetween, a control wire for said

transformer external thereto and terminating in an impedance, a thermionic device having an input circuit so connected as to receive a potential proportional to that developed across said control wire impedance, and having its output connected to a winding of the transformer, and an additional winding of said transformer included in said input circuit whereby the thermionic device operates to neutralize the induction in the line wires and also to neutralize the mutual interference between said conductors connected to said transformer.

8. In a system for nullifying disturbing currents in communication conductors, a transformer having windings connected in each conductor, a control wire external to said transformer and subject to the same induction with said conductors, and a coupling circuit between said control wire and said transformer, comprising an amplifier, the input and output circuits of said amplifier being inductively coupled together within said transformer so that the amplifier may continuously respond to the varying induction within the transformer and automatically produce corresponding neutralizing currents.

9. In a system for neutralizing current induction, a plurality of groups of line wires subjected to the same external source of interference, a transformer associated with each group and having coils connected to the line wires in its group, a control wire external to the transformer but exposed to the same induction with the line wires, a thermionic tube amplifier associated with each transformer and having its input circuit adjustably connected to receive a portion of the voltage induced in said control wire, each transformer having a coil connected in the input circuit of its associated amplifier and a low impedance coil connected to the output of the amplifier, said coil in the output circuit being connected so that the current therein is in a direction to neutralize the induction in the line wires.

10. In a system for neutralizing current induction, a plurality of groups of line wires subjected to the same external source of interference, a transformer associated with each group and having coils connected to the line wires in its group, a control wire external to the transformer and exposed to the same induction with the line wires, a thermionic tube amplifier associated with each transformer and having its input circuit connected to a coil of said transformer and adjustably connected to receive a portion of the voltage induced in said control wire, a coil of said transformer being connected in the output circuit of said amplifier so that the current therein is in a direction to neutralize the induction in the line wires.

11. In a neutralizing system as set forth in claim 9, a network connected in shunt to an impedance in the control wire to bypass undesired currents and limit the working frequency range to a selected band of frequencies.

12. In a neutralizing system as set forth in claim 9, a network connected to the input of each amplifier to limit the range to a selected band of frequencies and to prevent spurious frequencies from being introduced into the system.

13. In a neutralizing system as set forth in claim 3, a network connected in shunt to an impedance in the control wire to bypass undesired currents and limit the working frequency range to a selected band of frequencies.

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