Dec. 15, 1931. W. D. CANNON 1,836,575

METHOD OF NEUTRALIZING DISTURBING FREQUENCIES IN COMMUNICATION CIRCUITS

Filed Jan. 31, 1930 2 Sheets-Sheet 1

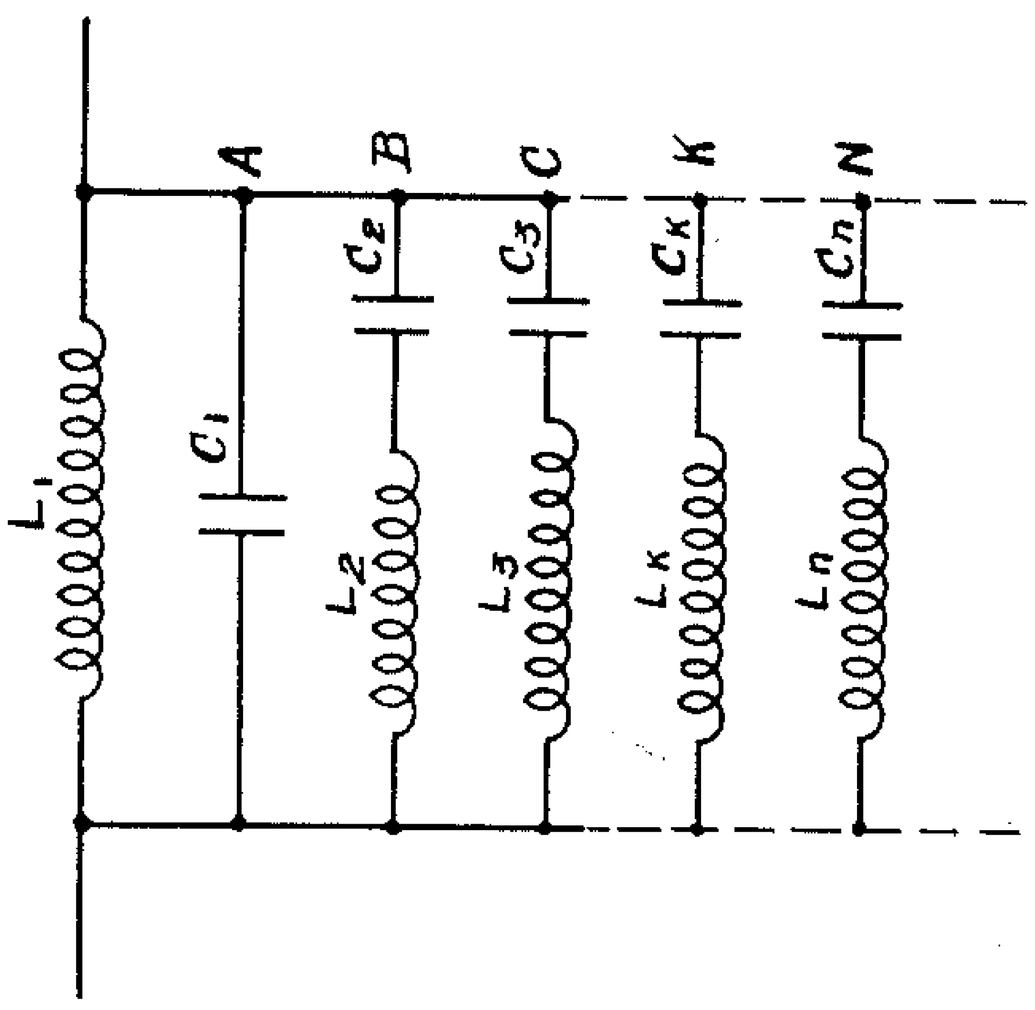

Fig. 2

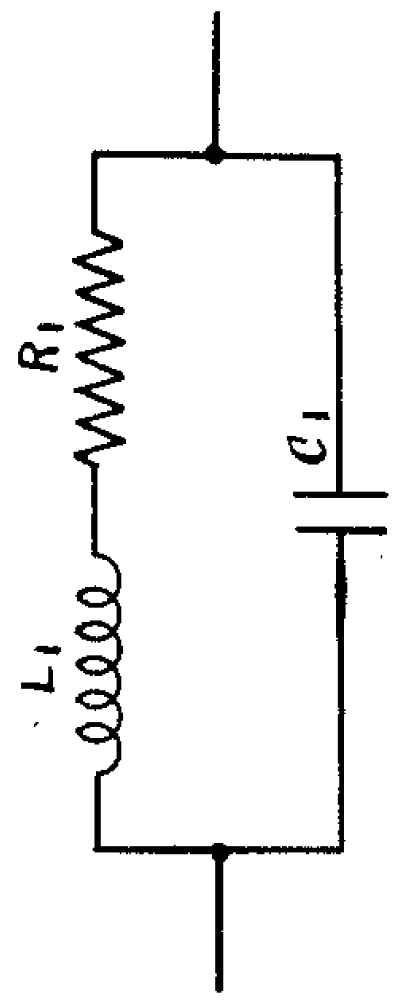

Fig. 3

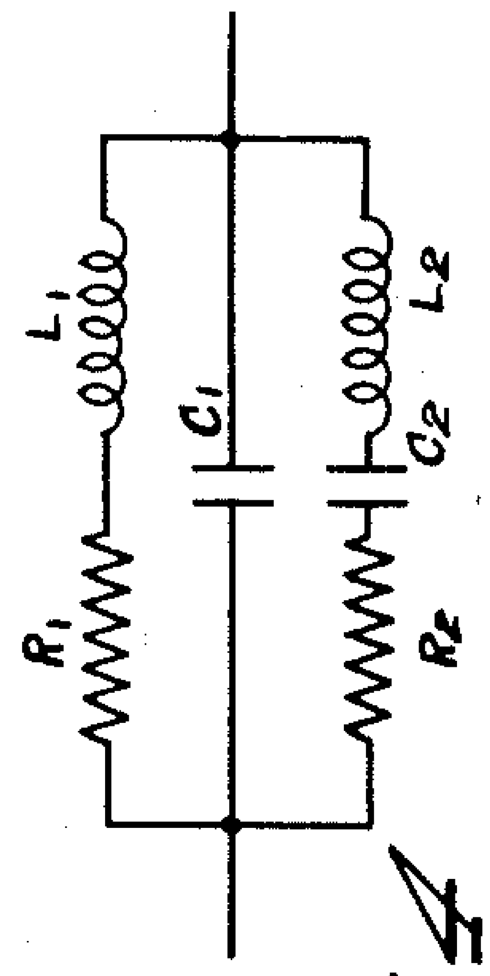

Fig. 4

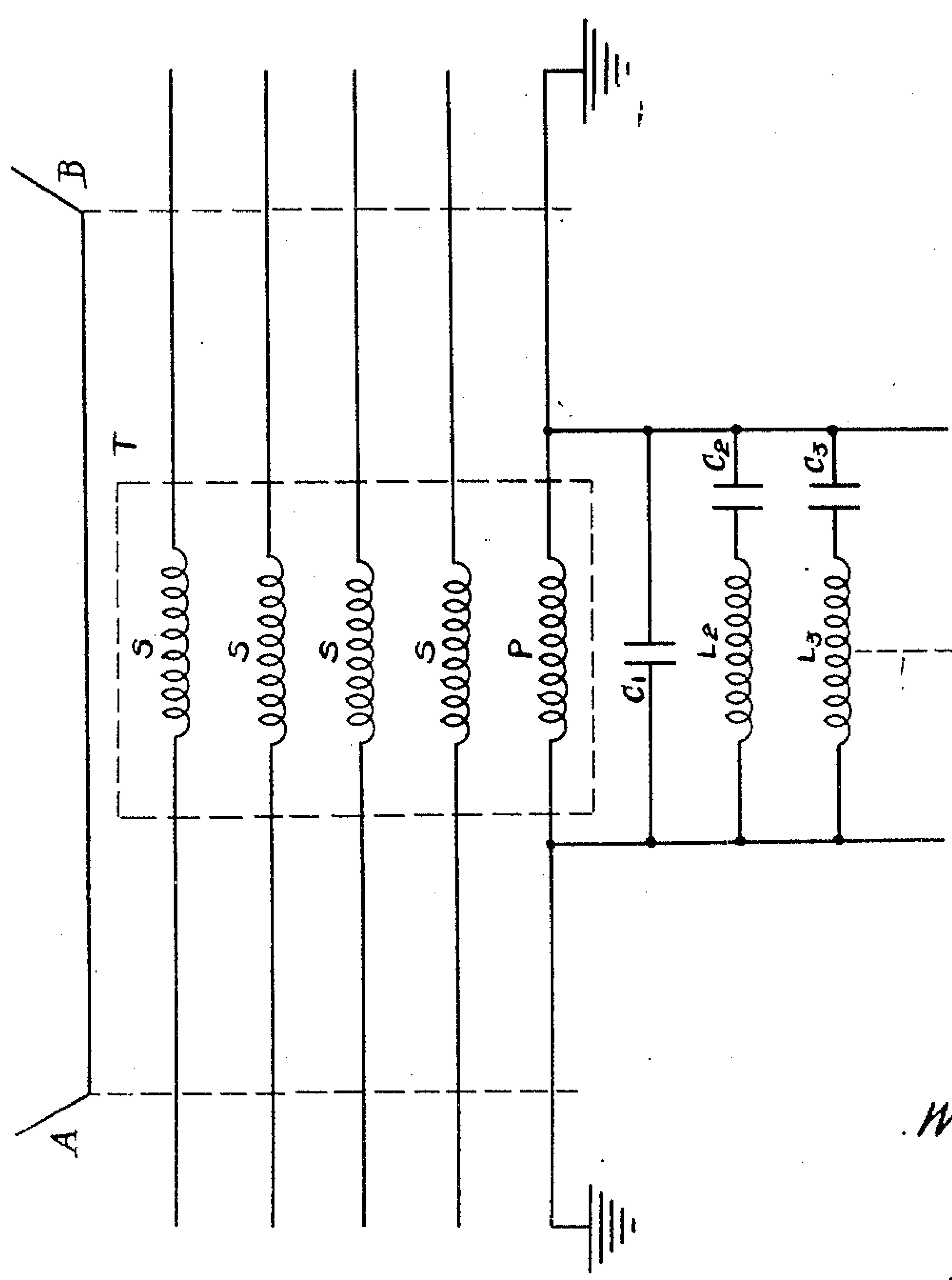

Fig. 1

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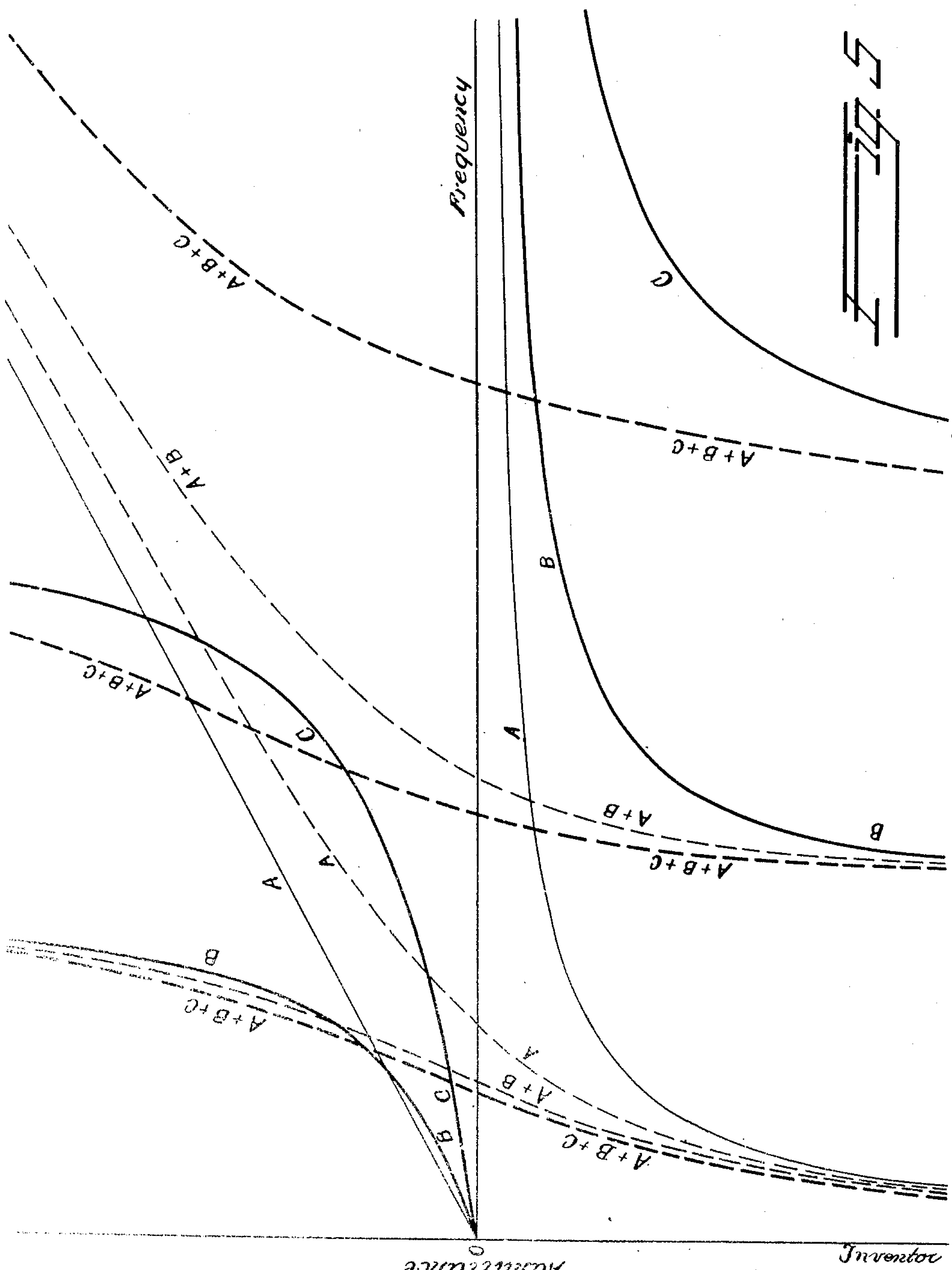

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UNITED STATES PATENT OFFICE

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METHOD OF NEUTRALIZING DISTURBING FREQUENCIES IN COMMUNICATION CIRCUITS

Application filed January 31, 1930. Serial No. 425,044.

My invention relates to an improved method of and means for protecting communication circuits from interfering currents which may be induced in them by paralleling power circuits or from other sources. The method is particularly adapted to the neutralization of a plurality of frequencies.

More specifically, my invention relates to a multiple frequency neutralizing transformer; it comprises a neutralizing transformer in combination with a shunting network designed to make the transformer function effectively at a plurality of frequencies.

One of the objects of the invention is to neutralize in a communication circuit, or group of circuits, disturbing currents induced from a plurality of sources.

Another object is to neutralize in such communication circuits a fundamental power frequency and its harmonics.

It is a further object to accomplish effective neutralization of a plurality of disturbing frequencies while keeping disturbances occasioned by crossfire between the communication circuits at a minimum.

My invention also comprises a convenient method of applying a shunting network to a neutralizing transformer of the type disclosed, so as to provide for the effective neutralization of disturbing frequencies commonly encountered in communication circuits.

My invention is illustrated in the accompanying drawings in which:—

Fig. 1 represents diagrammatically the neutralizing transformer and its shunting network applied to a plurality of disturbed lines which are subject to a plurality of disturbing frequencies.

Fig. 2 is a further diagrammatic representation of the neutralizing transformer and its shunting network, which will be used to explain the method of determining mathematically the electrical values of the elements of the shunting network.

Fig. 3 is a diagrammatic representation of the transformer primary and one of the branches of the shunting network, intended to represent its electrical make up when account is taken of the copper and iron losses.

Fig. 4 is a similar representation of a transformer designed to provide neutralization of two frequencies.

Fig. 5 is a graphical representation of the electrical characteristics of the various branches of the shunting network, which will be used in explaining a convenient method of applying a shunting network to the primary of a neutralizing transformer.

It has long been the practice to neutralize disturbing currents of a single frequency in a communication circuit by means of neutralizing transformers. An improved transformer of this type is described in Patent No. 1,714,476 to J. W. Milnor, and is again illustrated in its essentials in the Fig. 1 accompanying this description.

Referring to Fig. 1, the distance A—B constitutes an exposure of a group of communication circuits to a disturbing power line. T represents the neutralizing transformer containing a secondary coil S for each conductor of the communication circuits to be protected, and a primary coil, or coils, P which is in series with a primary wire. This primary wire, of very low resistance, and grounded at each end of the exposure, serves to pick up a disturbing voltage similar to that induced in the signal conductors and applies it to these conductors in opposing direction by means of the primary coil, thereby neutralizing the voltages induced in the other wires. A condenser C_1 is usually placed in parallel with the primary coil and adjusted to such a value that the neutralizing voltage is exactly 180° out of phase with the disturbing voltage. It follows then that the circuit comprising the coil P and the condenser C_1 will be antiresonant at the power frequency, and will thus have at that frequency a resistive impedance of maximum value. A fortunate result of this high impedance is that at this frequency a maximum proportion of the voltage present in the primary wire is applied across the transformer primary and is thus made effective for neutralizing purposes.

A neutralizing transformer functions at any frequency for which its primary has a high impedance, as compared with the impedance of the primary wire, and zero reactance. The transformer just described is effective at only one frequency.

Communication circuits are frequently subjected to disturbances of more than one frequency. They may be exposed to power systems using different frequencies, or if there are harmonics of the power frequencies present in considerable strength, these may also be induced in the communication circuits.

In the present invention, the transformer is made effective at a number of different frequencies. This is accomplished by connecting a network in parallel with the primary coil, which when considered in conjunction with the inductance of the primary has a high impedance and substantially zero reactance at each disturbing frequency.

As illustrated in Fig. 1, this network is made up of a first branch comprising a condenser C_1, a second branch comprising a series arrangement of inductance L_2 and condenser C_2, and a third branch comprising inductance L_3 and condenser c_3. If the transformer is to function at a large number of disturbing frequencies, additional branches will be connected in parallel to the branches illustrated and to the primary P, as indicated diagrammatically in Fig. 1 by the extended terminals in full lines and the dotted line extending vertically downward therebetween.

Fig. 2 shows a primary coil L_1 of a neutralizing transformer shunted by a network comprising a number of branches. If the network contained only branch A, comprising the condenser C_1 alone, the primary circuit would have high impedance at but one frequency, and the neutralizing transformer would be effective at that frequency only. It is possible however to devise a network containing one branch for each frequency that is to be neutralized, which when connected in parallel with the transformer primary will possess a high impedance at each of the prescribed frequencies. The network of Fig. 2 containing branches A to N has been found to fulfill this condition. It will now be shown that this network containing n branches can be made to have a high impedance and substantially zero reactance at n frequencies.

Under operating conditions practically no load is placed on the transformer secondaries, and since the primary coil resistance is small, it may be represented for simplicity as an inductance L_1. It is convenient to represent the condition of high impedance and zero resistance across the transformer primary by the condition of zero susceptance. The susceptance of branch A taken alone in conjunction with L_1 is:

$$B_a = j\frac{L_1C_1\omega^2-1}{L_1\omega} \quad (1)$$

in which

$$j=\sqrt{-1}$$

and $\omega=2\pi$ times the frequency to be neutralized.

The susceptance of any element K of the remaining elements is

$$B_k = j\frac{C_k\omega}{1-L_kC_k\omega^2} \quad (2)$$

The susceptance of the entire network is the sum of the component susceptances; if this sum is set equal to zero and the resulting equation divided by j, then

$$Y_{a-n} = \frac{L_1C_1\omega^2-1}{L_1\omega} + \frac{C_2\omega}{1-L_2C_2\omega^2} + \frac{C_k\omega}{\ldots 1-L_kC_k\omega^2} + \frac{C_n\omega}{\ldots 1-L_nC_n\omega^2} = 0 \quad (3)$$

Clearing of fractions.

$$(L_1C_1\omega^2-1)\ (1-L_2C_2\omega^2)\ (1-L_3C_3\omega^2)\ \ldots (1-L_nC_n\omega^2) + L_1C_2\omega^2(1-L_3C_3\omega^2)(1-L_4C_4\omega^2) \ldots (1-L_nC_n\omega^2 + L_1C_3\omega^2(1-L_2C_2\omega^2)(1-L_4C_4\omega^2) \ldots (1-L_nC_n\omega^2)$$

$$L_1C_n\omega^2(1-L_2C_2\omega^2)\ (1-L_3C_3\omega^2) \ldots (1-L_{n-1}C_{n-1}\omega^2) = 0 \quad (4)$$

This is an equation of degree n in ω^2 and from which, consequently, n values of frequency may be found at which the susceptance is zero. If the primary of a neutralizing transformer is shunted by a network, containing n branches, which meets the above condition, neutralization will be effective at n frequencies.

In practice a small amount of resistance will always be present in the transformer primary and in the inductance coils. This resistance however will not affect the validity of the method, and when it is within limits easily realizable commercially, will have but negligible effect on the value of the elements for the given n frequencies to be neutralized. That this is true may be shown by considering Fig. 3 which contains the reactance elements L_1 and C_1 of Fig. 2 but has a resistance R_1 (simulating both the copper and iron losses at the frequency considered) associated with the inductance. When the resistance is considered the circuit will have a finite impedance which must be resistive if the voltage in the secondary circuit or circuits is to be 180 degrees out of phase with the voltage of the primary or control circuit. If the impedance is to be made resistive the imaginary part of the admittance equation which is,

$$Y_a=\frac{\frac{R_1}{\omega^2L_1^2}}{1+\left(\frac{R_1}{\omega L_1}\right)^2}+j\omega\left[\frac{\frac{R_1^2C_1}{\omega^2L_1^2}+C_1-\frac{1}{\omega^2L_1}}{1+\left(\frac{R_1}{\omega L_1}\right)^2}\right]\quad(5)$$

must be zero, that is, the numerator,

$$\frac{R_1^2C_1}{\omega^2L_1^2}+C_1-\frac{1}{\omega^2L_1}=0\quad(6)$$

For given values of L_1, C_1 and R_1 this may be accomplished at one frequency only; i. e., only one frequency may be effectively neutralized. Equation (6) may therefore be written

$$\omega_1=\frac{1}{\sqrt{L_1C_1\left(1+\left(\frac{R_1}{\omega_1L_1}\right)^2\right)}}\quad(7)$$

where ω_1 is the frequency to be neutralized. Since it is practicable commercially to make

$$\frac{R_1}{\omega_1L_1}$$

small at commercial frequencies, the square of

$$\frac{R_1}{L_1\omega_1}$$

may be neglected and ω_1 approximates the value of

$$\frac{1}{\sqrt{L_1C_1}},$$

which it should have if R_1 is zero. The real part of (5) then becomes

$$Y_a=\frac{\frac{R_1}{\omega_1^2L_1^2}}{1+\left(\frac{R_1}{\omega_1L_1}\right)^2}\quad(8)$$

that is

$$Z_a=\frac{\omega_1^2L_1^2}{R_1}\left[1+\left(\frac{R_1}{\omega_1L_1}\right)^2\right]\quad(9)$$

Since

$$\left(\frac{R_1}{\omega_1L_1}\right)^2$$

is small, the impedance of Z_a approximates

$$\frac{\omega_1^2L_1^2}{R_1},$$

which can be made sufficiently high for satisfactory compensation.

Applying the same theory to a network like that illustrated in Fig. 4, which is designed to provide neutralization at two frequencies, the admittance is found to be;

$$Y_{ab}=jC_1\omega+\frac{1}{R_1+jL_1\omega}+\frac{1}{R_2+j\left[L_2\omega-\frac{1}{C_2\omega}\right]}$$

$$=\frac{\frac{R_1}{L_1^2\omega^2}}{1+\frac{R_1^2}{L_1^2\omega^2}}+\frac{\frac{R_2}{\left(L_2\omega-\frac{1}{C_2\omega}\right)^2}}{1+\frac{R_2^2}{\left(L_2\omega-\frac{1}{C_2\omega}\right)^2}}+$$

$$j\left[C_1\omega-\frac{\frac{1}{L_1\omega}}{1+\frac{R_1^2}{L_1^2\omega^2}}+\frac{\frac{1}{\frac{1}{C_2\omega}-L_2\omega}}{1+\frac{R_2^2}{\left(L_2\omega-\frac{1}{C_2\omega}\right)^2}}\right]\quad(10)$$

When the susceptance is zero—

$$C_1\omega-\frac{\frac{1}{L_1\omega}}{1+\left(\frac{R_1}{L_1\omega}\right)^2}+\frac{\frac{1}{\frac{1}{C_2\omega}-L_2\omega}}{1+\left(\frac{R_2}{L_2\omega-\frac{1}{C_2\omega}}\right)^2}=0\quad(11)$$

When the values of the elements are fixed in accordance with this equation, there will be two frequencies at which this equation will hold. These frequencies are approximately

$$\omega_2^2=\frac{L_1+L_2+\frac{C_1L_1}{C_2}+\sqrt{\left(L_1+L_2+\frac{C_1L_1}{C_2}\right)^2-\frac{4C_1L_1L_2}{C_2}}}{2C_1L_1L_2}\quad(12)$$

and

$$\omega_3^2=\frac{L_1+L_2+\frac{C_1L_1}{C_2}-\sqrt{\left(L_1+L_2+\frac{C_1L_1}{C_2}\right)^2-\frac{4C_1L_1L_2}{C_2}}}{2C_1L_1L_2}\quad(13)$$

As before,

$$\frac{R_1}{L_1\omega}$$

in an efficient design should be small, and so

$$\left(\frac{R_1}{L_1\omega}\right)^2$$

may be neglected. R_2, L_2, and C_2 form a series resonant circuit which may have a low admittance at the frequencies ω_2 and ω_3 at which compensation is sought; i. e.,

$$\frac{R_2}{L_2\omega-\frac{1}{C_2\omega}}$$

will be small and its square may be neglected. The relation among circuit constants and frequency of equation (11) with these three approximations then becomes

$$C_1\omega-\frac{1}{L_1\omega}+\frac{1}{\frac{1}{C_2\omega}-L_2\omega}=0 \quad (14)$$

which is identical with that obtained from the general equation previously deduced when the resistances are assumed as zero.

Using the same approximations referred to above, the admittance of the system at frequencies ω_2 and ω_3 becomes

$$Y_{ab}=\frac{R_1}{L_1^2\omega_2^2}+\frac{R_2}{\left(L_2\,\omega_2-\frac{1}{C_2\omega_2}\right)^2}$$

and

$$Y_{ab}=\frac{R_1}{L_1^2\omega_3^2}+\frac{R_2}{\left(L_2\omega_3-\frac{1}{C_2\omega_3}\right)^2} \quad (15)$$

Since both terms of each of these equations are small, the impedance

$$Z_{ab}=\frac{1}{Y_{ab}}$$

will be sufficiently large at the chosen frequencies ω_2 and ω_3 at which neutralization is desired. However, at the frequency that the series resonant circuit R_2, L_2 and C_2 become resonant, the impedance Z_{ab} becomes small. Since the impedance of the primary circuit must be small, as shown in the patent to Milnor referred to above, in order that the crossfire may be low, this low value of Z_{ab} is of importance in reducing the crossfire in the neighborhood of the resonant frequency of the circuit including R_2, L_2, and C_2; particularly if this resonant frequency can be made to fall at the point where crossfire is most severe.

It follows then that in a properly designed network such as shown in Fig. 4, the resistance will have but slight effect on the value of L_1, L_2, C_1 and C_2 to be chosen for neutralizing two frequencies, the impedance will be sufficiently high for neutralizing each of the two frequencies, and the reactance will be substantially zero.

By a continuation of the theory just detailed, it is possible to prove that a network such as Fig. 2, containing n branches will have a high impedance at n different frequencies and when used in conjunction with the primary coil of a neutralizing transformer will be effective in neutralizing disturbing currents of n different frequencies.

The values of the inductances and capacities comprising the network to be used with a given transformer for neutralizing a plurality of frequencies can be obtained by the solution of a set of simultaneous equations. A more convenient method, however, is the graphical method which will be explained in connection with Fig. 5.

In Fig. 5, admittance was plotted against frequency as successive branches were added to the initial branch A of the network. First, the light lines, A, A, represent the admittance of the coil L_1 and the condenser C_1 while their sum is indicated by the dotted line A. A zero admittance is obtained at the point where the dotted line crosses the frequency axis and as a consequence the most effective neutralization will occur at substantially this one frequency. If now the branch B is added to the network, the admittance of the added branch will be represented by the medium heavy lines B, B while the total admittance follows the two medium heavy dotted lines A+B. There are now two frequencies at which zero admittance occurs.

It will be noted that the original frequency calculated for the network A has been displaced somewhat to the left, that is, the first frequency for which neutralization was indicated has been reduced to a slightly lower value. When the third branch C is added to the network and the admittance curves C, C shown in the very heavy lines are added to the two medium heavy dotted lines A+B, three points of zero admittance will result where the three heavy dotted lines cross the frequency axis, and the two points previously found will be shifted to a slightly lower frequency.

It is apparent that as each additional branch is placed in the network, neutralization will be accomplished for an additional frequency and that the frequencies at which the previously existing branches accomplished neutralization will be slightly altered. This alteration however can be corrected as successive networks are added by slight readjustment of the capacity values so that the frequencies at which zero admittance occurs can be made to agree with the disturbing frequencies.

As illustrative of practicable values of inductance and capacitance in combination to produce satisfactory compensation at a number of frequencies, the following numerical examples are given:

Neutralizing transformer	Primary L_1	Shunt C_1	First added tranch		Second added branch		Frequencies compensated
			L_2	C_2	L_3	C_3	
Single frequency	.6	68.	0	0	0	0	25 cycles
Double frequency	.6	35.	.34	25.5	0	0	25 cycles 75 cycles
Triple frequency	.6	46.2	.4	15.4	.2	2.66	25 cycles 75 cycles 225 cycles

Disturbing power frequencies usually have known constant values such as the fundamental from one or more sources, the fundamental and certain of its harmonics or certain of the harmonics alone. It is preferable to design a network so that the disturbing voltages of certain fixed frequencies which are known to exist will be effectively suppressed while leaving the primary impedance low for all other frequencies, instead of designing the system so that a band or all frequencies are suppressed. This is a condition which is conducive to the reduction of crossfire between the communication circuits inasmuch as the severity of the crossfire is a direct function of the resistance of the primary system. At the points of high impedance the primary system presents to crossfire currents the impedance of the primary wire and its ground return circuit, which in any case is kept small and thus crossfire should not be a serious factor.

From the foregoing it is apparent that when the network described herein is applied to the primary of a neutralizing transformer any of the disturbing frequencies commonly encountered in communication circuits can be effectively neutralized. At the same time the coupling between the various secondary conductors which is inherent in the transformer will have a minimum effect in transferring energy between the various conductors.

Instead of connecting the entire network in shunt to a single one of the transformer windings, the various elements may be distributed among several windings without regard to their function as primaries or secondaries. However if the turn ratio between primary and secondary windings differs from unity this fact must be taken into consideration in computing the values of the branches.

I claim:

1. In a system for neutralizing disturbing voltages, a disturbed circuit, a neutralizing circuit, said circuits being exposed to the same disturbing magnetic field, a transformer coupling said disturbed and neutralizing circuits, and a frequency selective network in shunt to the neutralizing circuit winding comprising a plurality of branches having impedance values such that the combination of transformer and network offers maximum impedances at a plurality of separated frequencies.

2. In a system for neutralizing disturbing voltages, a disturbed circuit, a neutralizing circuit, said circuits being exposed to the same disturbing magnetic field, a transformer coupling said disturbing and neutralizing circuits having its primary in the neutralizing circuit, and a network in shunt to said primary comprising n branches having constants such that the transformer has high impedance and substantially zero reactance at n frequencies.

3. In a system for neutralizing disturbing voltages, a disturbed circuit, a neutralizing circuit, said circuits being exposed to the same disturbing magnetic field, a transformer coupling said disturbed and neutralizing circuits having its primary in the neutralizing circuit, and a network associated with said transformer comprising a plurality of frequency selective branches whose elements have precomputed values such that the transformer functions at a plurality of non-adjacent frequencies.

4. In a system for neutralizing disturbing voltages, a disturbed circuit, a neutralizing circuit, said circuits being exposed to the same disturbing magnetic field, a transformer coupling said disturbed and neutralizing circuits having its primary in the neutralizing circuit, and a network in shunt to said primary comprising n branches having constants such that the transformer has high impedance and substantially zero reactance at n frequencies, and low impedance at frequencies intermediate said n frequencies.

5. In a system for neutralizing disturbing voltages of a plurality of frequencies, a disturbed conductor, a neutralizing conductor, and means for applying to the disturbed conductor at a plurality of non-adjacent frequencies substantially all of the voltages of said frequencies present in the neutralizing conductor, said means including a transformer having a primary in said neutralizing conductor and a secondary in said disturbed conductor, and means for reducing the voltages induced between the secondary conductors at frequencies intermediate said non-adjacent frequencies.

6. In a system for neutralizing disturbing voltages of a plurality of frequencies, a disturbed conductor, a neutralizing conductor and means for applying to the disturbed conductor at each of a plurality of frequencies a major portion of the voltages of said frequencies present in the neutralizing conductor at each of said plurality of frequencies, said means including a transformer having a primary in said neutralizing conductor, a secondary in said disturbed conductor, and a network in shunt to said primary comprising a capacity in one branch and an inductance and capacity in series in another branch.

7. In a system for neutralizing disturbing voltages of a plurality of frequencies, a disturbed conductor, a neutralizing conductor and means for applying to the disturbed conductor at each of a plurality of frequencies a major portion of the voltages of said frequencies present in the neutralizing conductor, said means including a transformer having a primary in said neutralizing conductor, a secondary in said disturbed conductor and a plurality of shunts across said

primary one of which comprises a capacity and the others inductance and capacity in series.

8. In a system for neutralizing disturbing voltages, a disturbing circuit which is the source of disturbing voltages of a plurality of frequencies, a communication circuit and a neutralizing circuit, a neutralizing transformer coupling said communication and neutralizing circuits and means associated with the windings of said transformer for producing in said communication circuit neutralizing voltages of said plurality of frequencies and for limiting to negligible values voltages of intermediate frequencies induced by one communication circuit into another communication circuit.

9. In a system for neutralizing disturbing voltages, a disturbing circuit which is the source of disturbing voltages of fundamental and harmonic frequencies, a communication circuit, a neutralizing circuit, a neutralizing transformer coupling said communication and neutralizing circuits, and means associated with the windings of said transformer for producing in said communication circuit neutralizing voltages of said fundamental and harmonic frequencies and for limiting to negligible values voltages of intermediate frequencies induced by one communication circuit into another communication circuit.

10. In a system for neutralizing disturbing voltages, a disturbing circuit which is the source of disturbing voltages of a plurality of frequencies, a plurality of communication circuits, a neutralizing circuit, a neutralizing transformer comprising a primary in said neutralizing circuit and secondaries in each of said communication circuits, means including said neutralizing transformer and a frequency selective network for introducing into each of said communication circuits neutralizing voltages of said plurality of frequencies, and means comprising said frequency selective network for reducing crossfire between said communication circuits to a minimum.

11. In combination, a plurality of communication circuits located in a disturbing magnetic field, an auxiliary conductor adjacent to the communication circuits, and a transformer coupling said auxiliary conductor to the communication circuits, said auxiliary conductor having an abnormally low resistance as compared with the communication circuits whereby the creation of crossfire among the communication circuits is substantially avoided, and means associated with the auxiliary conductor winding of the transformer for producing a high impedance therein at each of a plurality of frequencies.

12. In combination, a plurality of communication conductors subject to electrical disturbances, an auxiliary conductor adjacent to the communication conductors, a transformer coupling the auxiliary conductor to the communication conductors, said auxiliary conductor having an abnormally low resistance as compared with that of the communication conductors whereby the creation of crossfire among the communication circuits is substantially avoided, and means associated with the auxiliary conductor winding of the transformer for producing in said winding a high impedance at each of a plurality of disturbing frequencies and a low impedance at intermediate frequencies.

13. The method of neutralizing disturbances in communication circuits subjected to crossfire and to disturbing magnetic fields of a plurality of power frequencies, which comprises selectively inducing in said communication circuits neutralizing voltages of maximum values at said plurality of disturbing frequencies while limiting the magnitudes of currents induced between the secondary conductors at frequencies intermediate said disturbing frequencies at frequencies intermediate said disturbing frequencies.

14. The method of applying a selective network to the primary of a neutralizing transformer to adapt the transformer for neutralizing operation at a plurality of disturbing frequencies which comprises adjusting the impedance of the transformer primary to a high value at a given disturbing frequency, by the addition of shunt capacity, adjusting the impedance of the transformer anew to a high value at a second disturbing frequency by the addition of inductance and capacity in series, thereby altering the impedance of the transformer for said first frequency, and readjusting the value of said shunt capacity to restore the high impedance at said first frequency.

15. The method of applying a selective network to the primary of a neutralizing transformer to adapt the transformer for neutralizing operation at a plurality of disturbing frequencies which comprises securing a high impedance in the transformer primary, at one frequency by the addition of shunt capacity, and successively securing a high impedance at other disturbing frequencies by adding elements to the network thereby altering the impedance of the transformer for the preceding frequencies in the series, and compensating for said impedance changes between successive adjustments.

16. In a system for neutralizing disturbing voltages of a plurality of non-adjacent frequencies, a disturbed circuit, a neutralizing circuit, said circuits being exposed to the same disturbing magnetic field, transformers coupling said disturbed and neutralizing circuits, and networks comprising a plurality of frequency selective branches in shunt to the windings of said transformers,

the frequency selective branches of said networks having values such that the system offers maximum impedances at said non-adjacent frequencies and low impedances at all other frequencies.

In testimony whereof I affix my signature.

WILLIAM D. CANNON.