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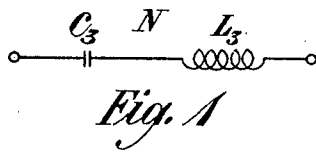
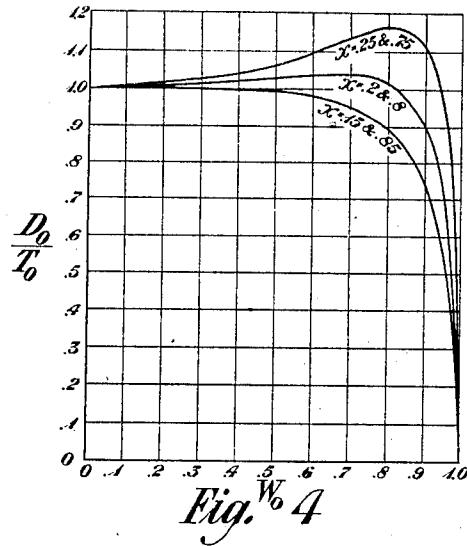
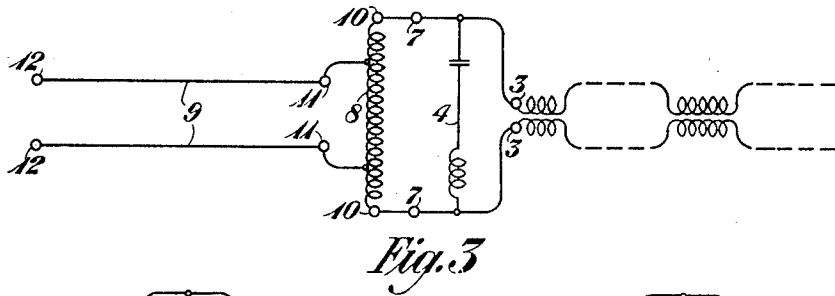
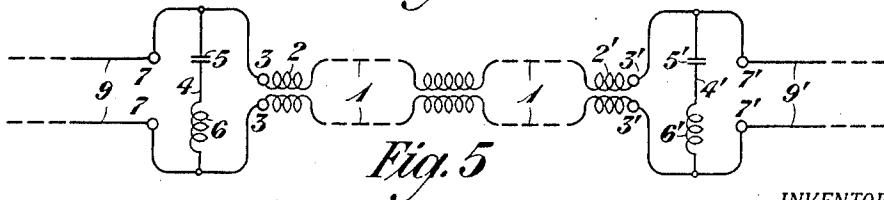
R. S. HOYT

1,475,997

NETWORK FOR NEUTRALIZING THE SUSCEPTANCE OF A LOADED LINE

Filed July 9, 1919

2 Sheets-Sheet 1



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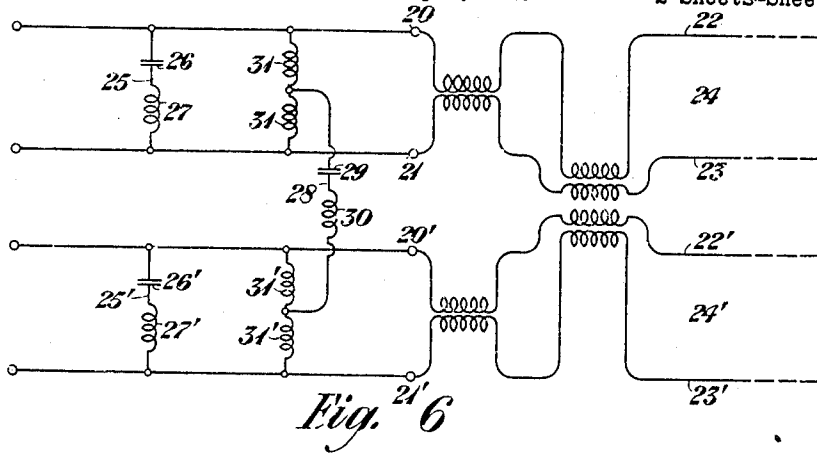
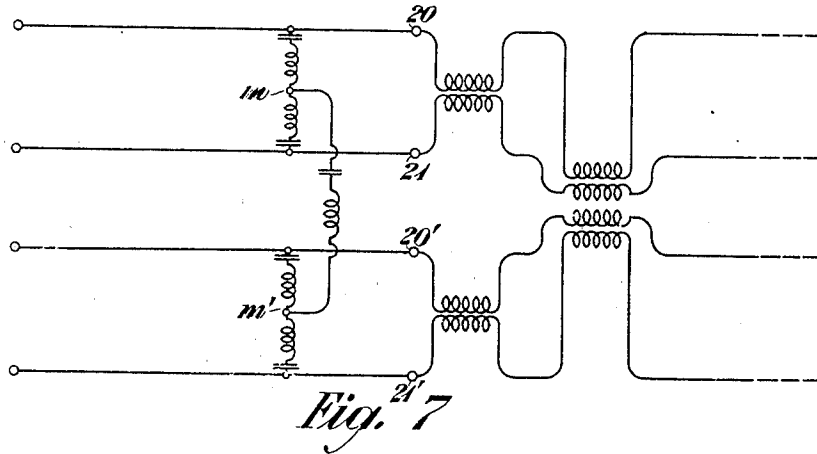
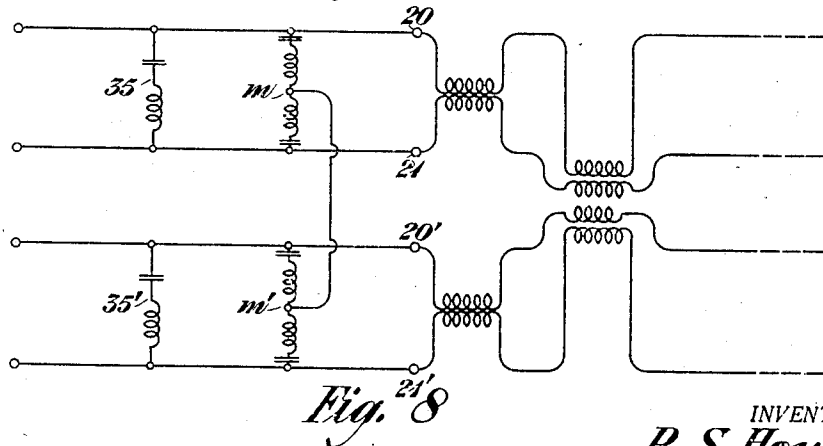
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NETWORK FOR NEUTRALIZING THE SUSCEPTANCE OF A LOADED LINE

Filed July 9, 1919

2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE.

RAY S. HOYT, OF BROOKLYN, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

NETWORK FOR NEUTRALIZING THE SUSCEPTANCE OF A LOADED LINE.

Application filed July 9, 1919. Serial No. 309,634.

To all whom it may concern:

Be it known that I, RAY S. HOYT, residing at Brooklyn, in the county of Kings and State of New York, have invented certain
5 Improvements in Networks for Neutralizing the Susceptance of a Loaded Line, of which the following is a specification.

My invention relates to a circuit arrangement associated with a periodically loaded
10 transmission line, which arrangement is hereinafter termed, in accordance with common usage, a network. The object of the invention is to provide a network having a purely susceptible admittance substantially
15 equal and opposite to the susceptance component of the characteristic admittance of a periodically loaded line over a wide range of frequencies, such for instance as the range of frequencies necessary for the telephonic
20 transmission of speech. A further object of my invention is, by the co-operative combination of said network and said loaded line, to provide a transmission system whose admittance is substantially that of a constant conductance over said range of frequencies; so that the impedance of such
25 transmission system shall be substantially that of a constant resistance over said range of frequencies.

It is a well-known fact that the non-loaded transmission line has a characteristic impedance which is substantially that of a pure resistance over the range of telephonic frequencies. It is further known that the
35 characteristic impedance of the ordinary periodically loaded line varies greatly over the range of telephonic frequencies; besides depending greatly on the fractional length of the initial section or on the fractional
40 value of the initial coil, as the case may be. The impedance characteristics of the non-loaded line and the periodically loaded line are, therefore, quite dissimilar.

In telephony it is often desirable and
45 necessary to connect a periodically loaded line in series with a non-loaded line. Owing to the above mentioned dissimilar impedance characteristics of said lines, a reflection of telephonic waves, with consequent energy
50 loss and inferior transmission, results when the said lines are connected directly in series for the telephonic transmission of speech. My invention contemplates providing and prefixing to the loaded line a network and
55 choosing a particular fractional value for

the initial load coil of the loaded line whereby the impedance of the combination is substantially that of a pure resistance over a pre-assigned range of frequencies, for example, the range of frequencies necessary
60 for the efficient transmission of speech signals. When this combination is connected in series with a non-loaded line, preferably through an autotransformer, the impedance characteristic of the arrangement,
65 as seen from the sending end of either the non-loaded line or of the loaded line, is substantially that of a single continuous transmission line.

The network of my present invention, 70 though possessing properties closely analogous to those of the network disclosed in my previous Patent No. 1,243,066, dated October 16, 1917, is nevertheless entirely distinct therefrom and independent thereof. Not
75 only is it entirely different in form, but it is also different in function, in that it neutralizes the susceptance of the loaded line at a point in a loading coil instead of neutralizing the reactance at a point in a loading
80 section. The analogy between the network of my present invention and the network of my aforesaid previous invention consists in the fact that the mathematical expression for the susceptance of my present network
85 is of the same form (when regarded as a function of the frequency) as the mathematical expression for the reactance of my aforesaid previous network; while, with reference to the loaded lines themselves, there
90 is a similar correspondence between the mathematical expressions for the susceptance and the reactance neutralized by the respective networks. Stated more specifically, my
95 present network neutralizes the susceptance of a loaded line that terminates with a certain fractional loading-coil, with the same precision as my aforesaid previous network
100 neutralizes the reactance of a loaded line that terminates with the corresponding fractional loading section. In consequence of this analogy between the two types of networks it follows that for every possible application of either type there exists a corresponding possible application of the other
105 type. On the whole the two networks possess about equal utility except for the fact that the network of my present invention is of shunt type and therefore does not require subdivision in order to maintain the bilater- 110

al symmetry of the transmission line, while the network of my aforesaid invention is of series type and therefore usually requires accurate subdivision in order to maintain the symmetry (as indicated by Figs. 2, 3, and 5 of the aforesaid Patent No. 1,243,066); in practice, this difference would usually constitute a very substantial advantage in favor of the shunt type.

My invention is best understood by reference to the accompanying drawings in which Fig. 1 is a diagram illustrating the network; Fig. 2 is a diagram illustrating the network connected to a periodically loaded line; Fig. 3 is a diagram illustrating a non-loaded line connected through an auto-transformer and the network of my invention to a periodically loaded line; Fig. 4 is a set of curves illustrating the conductance component of the characteristic admittance of the periodically loaded line as a function of the frequency; Fig. 5 is a diagram illustrating a loaded line connected between two non-loaded lines, with a network at each of the two junctions, and Figs. 6, 7 and 8 are diagrams of the arrangements of my invention embodied in a 4-wire transmission system comprising two side circuits and a phantom circuit.

The general theory underlying this invention will now be presented. Such theory can be based more simply and more conveniently on a general formula for the characteristic x -load admittance of a periodically loaded line than on the corresponding formula for its reciprocal, the characteristic x -load impedance. For any fixed frequency and initial termination, said admittance, as is well known, depends mainly on the line capacity and on the load coil inductance; but also, to a slight extent, on the distributed line inductance. This small effect produced by the distributed line inductance will not be neglected, but will be taken into account in the same manner as has already been described in my copending application No. 309,633 filed of even date herewith, and more fully set forth in my previous Patent No. 1,167,693; wherein it is shown that, as regards characteristic mid-load impedance (and hence as regards characteristic mid-load admittance), a periodically loaded line having distributed line inductance in addition to its lumped load inductance is simulated to a high degree of precision by a certain periodically loaded line having no distributed line inductance but having an inductance L_0 per load coil and a capacity sC_0 per loading section; where s is the spacing of the load coils, that is, the distance between adjacent coils, and L_0 and C_0 are approximately equal to the corresponding constants of the actual loaded line, that is, to its inductance L per load coil and to its capacity C per unit length, respectively, said

constants being related in accordance with equations (15) and (16) of my aforesaid Patent No. 1,167,693.

With the effect produced by the distributed inductance thus taken account of, the general theory underlying this invention may be based on the relatively simple formula for the characteristic x -load admittance of the aforesaid L_0C_0 equivalent loaded line having no distributed inductance, already developed as formula (6) of my above cited copending application, viz:

$$Z = \frac{T_0 \sqrt{1 - w_0^2} + iT_0 w_0 (1 - 2x)}{1 - 4x(1 - x)w_0^2} \quad (1) \quad 80$$

where i denotes the imaginary operator $\sqrt{-1}$; and T_0 and W_0 have the same significance as in my aforesaid copending application viz:

$$T_0 = \sqrt{sC_0/L_0} \quad (2) \quad 85$$

$$w_0 = p \sqrt{sC_0 L_0 / 4} \quad (3)$$

in which p is 2π times the frequency in cycles per unit time.

Writing D and Q for the conductance and susceptance components of the characteristic admittance Z so that $Z = D + iQ$, it follows that

$$D = \frac{T_0 \sqrt{1 - w_0^2}}{1 - 4x(1 - x)w_0^2} \quad (4) \quad 95$$

$$Q = \frac{T_0 w_0 (1 - 2x)}{1 - 4x(1 - x)w_0^2} \quad (5) \quad 100$$

Expressing W_0 in terms of p , as given by equation (3), and also substituting the value of T_0 as given by equation (2), the above expression for Q reduces to

$$Q = \frac{(1/2 - x)sC_0 p}{1 - x(1 - x)sC_0 L_0 p^2} \quad (6) \quad 105$$

Now consider the susceptance of a capacity element C_3 in series with an inductance element L_3 . The susceptance of this arrangement is well known to be expressible as:

$$Q_3 = \frac{C_3 p}{1 - C_3 L_3 p^2} \quad (7) \quad 115$$

Comparison of equations (6) and (7) shows that they are similar in form as regards the variable p , and further that Q_3 may be made equal and opposite to Q by proportioning C_3 and L_3 so that

$$C_3 = (x - 1/2)sC_0 \quad (8) \quad 120$$

$$C_3 L_3 = x(1 - x)sC_0 L_0$$

$$L_3 = \frac{x(1 - x)L_0}{x - 1/2} \quad (9) \quad 125$$

Of course physical limitations restrict the choice of x to those values for which C_3 and L_3 are positive; but that means only that x cannot be less than $1/2$ and cannot exceed 1, while it can have any value between those

two extremes. Thus if the value of x , which is the ratio of the inductance of the initial coil to the inductance of each of the following coils, lies between $\frac{1}{2}$ and 1, the combination of a capacity element C_3 and an inductance element L_3 in series, the values of said elements being proportioned in accordance with equations (8) and (9), has a susceptance equal and opposite to the characteristic susceptance of the periodically loaded line characterized by the parameters sC_0 and L_0 .

If now the admittance element having susceptance Q_3 is prefixed in shunt to the periodically loaded line of characteristic admittance Z the admittance of the combination is obviously $Z + iQ_3$. If, further, the component elements of Q_3 are proportioned in accordance with equations (8) and (9), then $Q_3 = -Q$, so that the admittance of the combination reduces to D as given by equation (4). Thus it is seen that the admittance of the combination has no susceptance component. D , as given by equation (4), is a function of w_0 and, therefore, of the frequency, since w_0 is directly proportional to the frequency. The value of D/T_0 is proportional to the conductance component, since T_0 is a constant for any particular line. By reference to equation (4):

$$\frac{D}{T_0} = \frac{\sqrt{1-w_0^2}}{1-4x(1-x)w_0^2} \quad (10)$$

The range of frequencies necessary for the telephonic transmission of speech usually corresponds roughly to the range from $w_0 = 0$ to $w_0 = 1$; or more accurately stated, to a little less than this range.

If now x be taken as 0.8, equation (10) reduces to

$$\frac{D}{T_0} = \frac{\sqrt{1-w_0^2}}{1-0.64w_0^2} \quad (11)$$

and if from this equation we calculate the values of D/T_0 for different values of w_0 from 0 to 1 and plot these values of D/T_0 against the corresponding values of w_0 we get the middle curve shown in Fig. 4 of the drawings. It will be noticed by reference to said Fig. 4 that the value of D/T_0 is approximately constant and closely equal to unity from $w_0 = 0$ to $w_0 = 0.9$. The corresponding range of values of frequency is substantially the range usually necessary for the telephonic transmission of speech. It should be noticed, however, that this constant conductance component characteristic is conditioned by the choice of a particular value of x , namely about 0.8, and that for values of x differing materially from 0.8 this desired characteristic does not hold. An actual loaded line does not, of course, begin in general with an 0.8 coil, the actual termination of the line being governed generally

by geographic factors and certain considerations of convenience entirely foreign to the present invention, but it can always be built out artificially to an 0.8 initial coil or to any other initial termination, as fully explained in my Patents Nos. 1,124,904 and 1,167,693 and in my above mentioned copending application.

If x is taken as 0.8 the values of C_3 and L_3 of the network of my invention become, by aid of equations (8) and (9),

$$C_3 = 3sC_0/10 \quad (12)$$

$$L_3 = 8L_0/15 \quad (13)$$

To summarize the foregoing, the combination of a network proportioned in accordance with equations (12) and (13), and illustrated in Fig. 1, prefixed in shunt to a periodically loaded line whose initial coil has an inductance equal to approximately 0.8 of the inductance of each of the following coils, has an admittance whose susceptance component is substantially zero and whose conductance component is substantially constant and equal to T_0 over approximately the entire frequency range below the critical frequency (the critical frequency being that frequency for which w_0 is equal to unity); and has, therefore, an impedance whose reactance component is substantially zero and whose resistance component is substantially constant over that frequency range. The value of T_0 is given by equation (2) above.

I do not desire to limit the proportioning of the network of my invention rigidly to formulas (8) and (9) or to values of x exactly equal to 0.8. If very high precision is not necessary, I may, for instance, with small loss in precision, proportion C_3 and L_3 in accordance with the following formulas which are obtained by neglecting the distributed inductance of the loaded line.

$$C_3 = 3sC/10 \quad (14)$$

$$L_3 = 8L/15 \quad (15)$$

On the other hand, if extremely high precision is desired, I may choose for x a value slightly different from 0.8; or I may compute rigorously the admittance of the particular loaded line and then assign to C_3 and to L_3 values slightly different from those indicated by formulas (8) and (9), whereby the neutralization of susceptance may be slightly more precise.

Referring to Fig. 1 of the accompanying drawings, N is the network of my invention comprising a capacity C_3 in series with an inductance L_3 , the values of C_3 and L_3 being those given by equations (8) and (9) of this specification, with x equal to about 0.8. The actual numerical values of C_3 and L_3 depend on the values of sC_0 and L_0 , that is, on the constants of the particular loaded line with which it is desired to associate said network,

and also on the particular value chosen for α .

Referring to Fig. 2, 1 is a periodically loaded line having load-coils 2, 2^a, 2^b, etc., inserted at regular intervals along the line. The inductance of the initial load coil 2 is approximately 0.8 of the inductance of each of the following coils 2^a, 2^b, etc. If the actual line does not have an initial 0.8 coil, it may be artificially built out to an equivalent 0.8 initial coil as hereinbefore mentioned and fully explained in my above mentioned patents and copending application. Prefixed in shunt to terminals 3, 3 is an admittance 4 comprising a capacity element 5 in series with an inductance element 6. If the line 1 is characterized by the parameters sC_0 and L_0 and α , the capacity element 5 is so proportioned that its capacity is equal to C_0 , and the inductance element 6 is so proportioned that its inductance is equal to L_0 , where C_0 and L_0 are given by equations (8) and (9), with α equal to about 0.8. From the theory developed in this specification it follows that the admittance of the combination as seen from terminals 7, 7 will be substantially that of a constant conductance equal in value to

$$\sqrt{sC_0/L_0};$$

and hence its impedance will be substantially that of a constant resistance having a value equal to

$$\sqrt{L_0/sC_0}.$$

Referring to Fig. 3, the arrangement of Fig. 2 is connected through an autotransformer 8 to a uniform non-loaded line 9. It will be understood that an equivalent transformer may replace the autotransformer, except when conductive connection is desired. Terminals 7, 7 of the loaded line system are connected to terminals 10, 10 of autotransformer 8, while line 9 is connected to terminals 11, 11 of said autotransformer. If the nonloaded line has a distributed inductance J' per unit length and a distributed capacity C' per unit length, its characteristic impedance is well known to be approximately equal, except at very low frequencies, to

$$\sqrt{J'/C'}.$$

Further if the transformer impedance ratio, as seen from terminals 11, 11, is r , then the apparent impedance of the loaded line as seen from terminals 11, 11 is substantially

$$r\sqrt{L_0/sC_0}.$$

Hence if the transformer be so designed that

$$r = \sqrt{J'/C'}$$

the impedance of the entire system as seen

from any point in the non-loaded line will be merely

$$\sqrt{J'/C'}$$

that is, the same as the impedance of an infinitely long uniform non-loaded line. Inversely, when the non-loaded line is effectively infinitely long, the impedance of the entire system as seen from any point in the loaded line is the same as the impedance of an infinitely long loaded line. As hereinbefore stated this is the condition for propagation without reflection losses.

Figs. 2 and 3 have been given for the purpose of illustrating the use of a single neutralizing network; Fig. 2 showing such a network prefixed in shunt to a periodically loaded line, and Fig. 3 showing the so modified periodically loaded line connected to a non-loaded line (through a suitable transformer). Fig. 5 is given to illustrate the simultaneous use of two such networks 4, 4' one at each end of a piece of loaded cable 1 occurring between two non-loaded lines 9, 9'. (In case either of the non-loaded lines differs in impedance from the loaded line, it is to be understood that a transformer of suitable ratio would be inserted at the corresponding junction, as in Fig. 3). In consequence of the networks 4, 4' the impedance of the system as seen from any point in either non-loaded line is substantially the same as the impedance of an infinitely long non-loaded line; while, as seen from any point in the loaded line, the impedance of the system in each direction is substantially the same as the impedance of an infinitely long loaded line.

In loaded line systems it is customary and desirable to employ two parallel and preferably similar circuits as the two sides of a third circuit called the phantom circuit. If neutralizing networks of my invention are to be employed in such a system to neutralize the susceptance of the two side circuits and of the phantom circuit, means must be provided whereby the neutralizing arrangement associated with any one circuit shall not affect the transmission of current in the other circuits. Fig. 6 is a diagram of a susceptance neutralizing arrangement designed to be prefixed to such a system and to satisfy the requirement just mentioned. Referring to Fig. 6, conductors 22 and 23 constitute one side circuit 24, and in parallel they serve as one side of the phantom circuit; similarly, conductors 22' and 23' constitute the second side circuit 24', and in parallel they serve as the other side of the phantom circuit. The two side circuits and the phantom circuit are represented as being periodically loaded and as terminating with fractional load coils connected to terminals 20, 21, 20', 21' of the neutraliz-

ing arrangement. Considering the side circuit 24, the network of my invention associated therewith is represented by an arrangement 25, comprising a condenser 26 having a capacity equal to C_3 , and an inductance coil 27 having an inductance equal to L_3 , C_3 and L_3 being computed from the constants of line 24 as hereinbefore explained. It will be evident, therefore, that the network 25 offers to the voltage impressed on line 24 an admittance equal to that of the network N of Fig. 1, provided, of course, that C_3 and L_3 are proportioned in accordance with the constants of line 24. It will be further evident that network 25 produces no effect on the phantom current flowing in conductors 22 and 23, since said two conductors are then at the same potential.

Network 25' is similar in its component parts to network 25 and is the neutralizing network of line 24'. The condenser 26' and the inductance coil 27' are, of course, proportioned in accordance with the constants of line 24'. In ordinary practice, lines 24 and 24' would be alike, in which case networks 25 and 25' would be alike.

The circuit arrangement 28 comprising a condenser 29 and an inductance coil 30, together with the four auxiliary inductance coils 31, 31, 31', 31', constitutes the neutralizing network of the phantom circuit. The two auxiliary coils 31, 31 are wound on a common magnetic circuit and are so related thereto that said coils 31, 31 are non-inductive with respect to the phantom circuit current in line 24, while at the same time they can be made of sufficiently high impedance to produce but a negligible effect (except at very low frequencies) on the side circuit current in line 24. The auxiliary coils 31', 31', are similarly related to line 24' and to the phantom circuit. The capacity of the element 29 is made equal to C_3 , and the inductance of the element 30 is made equal to L_3 , where C_3 and L_3 are computed from the phantom circuit constants in the manner hereinbefore explained. It will be evident then, that as regards the phantom circuit, the circuit arrangement 28 is equivalent to the network of Fig. 1, and that further its insertion in the circuit will not appreciably affect the transmission of the side circuit currents.

It will be understood that it is not always necessary to employ the entire neutralizing arrangement of Fig. 6; for example, if the phantom circuit is non-loaded while the side circuits are loaded, the network 28 is omitted together with the auxiliary coils 31, 31, 31', 31'. It should be further observed that, while I have shown the network of my invention as proportioned in accordance with an actual loaded line, it may likewise be proportioned to neutralize the susceptance of

an artificial loaded line. A well known form of artificial loaded line consists of a number of coils of substantially equal impedance connected in series with the line and a number of condensers of substantially equal capacity connected in shunt thereto, alternately with the said coils. The coils correspond to the loading coils of the geographical loaded line and the condensers correspond to the distributed capacity per section between loads of the geographical loaded line. The term "loaded line" as used throughout this specification designates both the geographical and the "artificial" form of line, unless the context restricts the meaning otherwise.

The arrangement shown in Fig. 7 accomplishes the susceptance neutralization for the two side circuits and for the phantom circuit without the employment of the auxiliary coils 31, 31 and 31', 31'. In this arrangement the side circuit neutralizers are constructed symmetrically so as to afford a pair of neutral midpoints m, m' to which the phantom circuit neutralizer is connected. Strictly, the neutralizer connected to these neutral points accomplishes only a part of the neutralization for the phantom circuit, the remainder of such neutralization being accomplished by the side circuit neutralizers in consequence of their effective connection with the phantom circuit through the neutral points m, m' . Thus, while the proportioning of the side circuit neutralizers depends only on the constants of the side circuits, and is, therefore, independent of the presence or absence of a phantom circuit neutralizer, the proportioning of the phantom circuit neutralizer depends not only on the phantom circuit constants, but also on the side circuit constants. Consequently in practice the side circuit neutralizers are first proportioned in accordance with the formulæ (8) and (9) already given, due allowance being made for the necessary subdivision of each condenser element into two serially connected parts to meet the requirements for symmetry. Next the phantom circuit neutralizer is proportioned by means of the same design formulæ by substituting therein the constants of the phantom circuit and then correcting for the effective capacity and the effective inductance contributed to the phantom circuit neutralizer by the two side circuit neutralizers.

In certain cases it is more convenient to determine, first, the susceptance required to neutralize the phantom circuit and connect the same into the system as shown in Fig. 8. If it is then found that the side circuits require additional susceptance for their complete neutralization, the same may be introduced therein by additional networks, 35 and 35' shunted across the side circuits.

The uses of my invention are not limited to the cooperative arrangements illustrated herewith, but my invention is applicable to any arrangement wherein it is desirable that a periodically loaded line shall have substantially no susceptible admittance and hence no reactive impedance. As examples of further uses, my invention may be employed: (1) to connect a loaded line type of filter to a repeater element whose impedance is nearly constant resistance; (2) to connect a loaded line to a repeater system whose impedance is nearly constant resistance; (3) to connect a loaded line to terminal apparatus whose impedance is nearly constant resistance.

Finally, I desire to emphasize the fact that to secure for the loaded line equally good impedance properties without employing either the network of my present invention or the network of my previous invention (Fig. 1, Patent No. 1,243,066) would necessitate spacing the loading coils at much closer intervals. For if the networks were omitted the critical frequency of the loaded line would have to be very much increased to maintain substantially the pre-existing impedance properties over the contemplated frequency-range; and, with the impedance approximately fixed, an increase in the critical frequency can be attained only by a correspondingly closer spacing of the loading coils.

Although only a few forms and arrangements of apparatus embodying the invention are shown and described herein, it is readily understood that various changes and modifications may be made therein within the spirit and scope of the following claims without departing from the scope of the invention.

What is claimed is:

1. A network for neutralizing the characteristic susceptance of a periodically loaded signaling line beginning at a point in a loading coil, said network comprising pre-computed admittance elements so proportioned in accordance with the constants of said line that the susceptance of said network is substantially equal and opposite to the characteristic susceptance of said line beginning at a point in a loading coil.

2. A network for neutralizing the characteristic susceptance of a periodically loaded signaling line beginning at a point in a loading coil, said network comprising inductance and capacity elements so proportioned in accordance with the constants of said line that the susceptance of said network is substantially equal and opposite to the characteristic susceptance of said line beginning at a point in a loading coil.

3. A network having a susceptance equal and opposite to that of an actual loaded signaling transmission line beginning at a point in a loading coil, said network comprising

inductance and capacity elements having precomputed values dependent on the loading coil inductance, the distance between consecutive loading coils, and the distributed capacity and inductance of said line.

4. A network having a susceptance substantially equal and opposite to the characteristic susceptance of a periodically loaded signaling line, said network comprising an inductance coil in series with a condenser, the values of the inductance of said coil and the capacity of said condenser being pre-computed in accordance with the loading coil inductance, the distance between consecutive loading coils and the distributed capacity and inductance of said loaded line.

5. In a signaling system, the combination of a periodically loaded transmission line and a network connected in shunt therewith, said network consisting of inductance and capacity elements so proportioned in accordance with the constants of said loaded line that the admittance of said combination is a practically pure, constant conductance over a pre-assigned range of frequencies.

6. In a signaling system, the combination of two parallel transmission lines constituting two side circuits and a phantom circuit, said circuits being periodically loaded, and a plurality of networks connected in shunt therewith, said networks including admittance elements so proportioned that the susceptance of each of said circuits is substantially neutralized.

7. In a signaling system, the combination of two parallel transmission lines constituting two side circuits and a phantom circuit, said lines being periodically loaded as regards each side circuit and also as regards said phantom circuit, with two similar and equal networks one in shunt with each of said side circuits and a connection between said networks for associating the same with the phantom circuit, each of said networks including precomputed inductance coils and condensers so proportioned in accordance with the constants of said side circuits and said phantom circuit that the impedance of the combination, as seen from each of said side circuits, and from said phantom circuit, is approximately a pure non-inductive resistance over a pre-assigned range of frequencies.

8. In a signalling system, four parallel conductors constituting two separate transmission lines, and providing two side circuits and one phantom circuit, said conductors being periodically loaded as regards each side circuit, and also as regards the phantom circuit, each of said circuits including impedance elements connected in shunt thereto, said impedance elements being so related that the characteristic impedance of each side circuit and of the phantom circuit is

substantially a pure constant resistance over a pre-assigned range of frequencies.

9. The combination of a loaded line comprising lump series inductances and shunt capacities, with a network comprising an inductance coil in series with a condenser, said network being connected in shunt to said line and having a susceptance substantially equal and opposite to that of said loaded line beginning at a point in a loading coil, and the values of the inductance of said inductance coil and the capacity of said condenser being proportioned in accordance with the inductance and capacity of said loaded line.

10. A device for neutralizing the susceptance of a phantom periodically loaded line, comprising a network for neutralizing the susceptance of each side circuit, and arranged to provide a point neutral to each side circuit, and a network for neutralizing the susceptance of the phantom circuit connected between said neutral points.

11. In a device for neutralizing the susceptance of a loaded transmission line, having side circuits and phantom circuits, a pair of networks connected in series with each other across each side circuit, a common connection uniting the pairs at their middle points, said networks being of a value to fully neutralize the line as to one of the two kinds of circuits, and a network located exclusively in the other kind of circuit to neutralize the remaining susceptance of the circuit without affecting the first named neutralizing devices.

12. In a signaling system, the combination of a non-loaded line comprising two sections, with a loaded line interposed between said sections, and a plurality of networks shunted across the terminals of said loaded line to neutralize the susceptance thereof over a pre-assigned range of frequencies.

13. In combination, a circuit comprising

shunt capacity and lumped series inductances placed at substantially equal capacity intervals, and a network for changing the impedance of said circuit to a substantially constant resistance over a wide range of frequencies, said network comprising inductive and capacity reactance elements connected in series with each other and in shunt to the said circuit, said elements having their magnitudes determined to make the impedance of the entire combination substantially a constant resistance over a wide range of frequencies.

14. A circuit comprising shunt capacity and lumped series inductances placed at substantially equal capacity intervals and an impedance device connected in shunt to said circuit, said device having a reactance substantially equal and opposite to that of the remaining part of the circuit throughout a wide range of frequencies.

15. In a combination, a plurality of transmission lines associated with each other in tandem, said lines having different ratios of reactance to impedance, and means shunted across said lines at their junction, for substantially equalizing said ratios.

16. In combination, a conductor pair comprising equal inductances in series, equal shunt capacities alternating therewith, said conductor pair having at its initial end a series inductance substantially 0.8 of the other inductances, and a shunt across the initial end comprising inductance and capacity in series.

17. In combination, a loaded line and at 0.8 load therein an inductance and capacity in series with each other and across the line and of proper value to reduce the impedance of the line substantially to a pure resistance.

In testimony whereof, I have signed my name to this specification this 8th day of July, 1919.

RAY S. HOYT.