

R. S. HOYT,
 NETWORK FOR NEUTRALIZING THE CHARACTERISTIC REACTANCE OF A LOADED LINE.
 APPLICATION FILED JAN. 24, 1916.

1,243,066.

Patented Oct. 16, 1917.
 3 SHEETS—SHEET 1.

Fig. 1

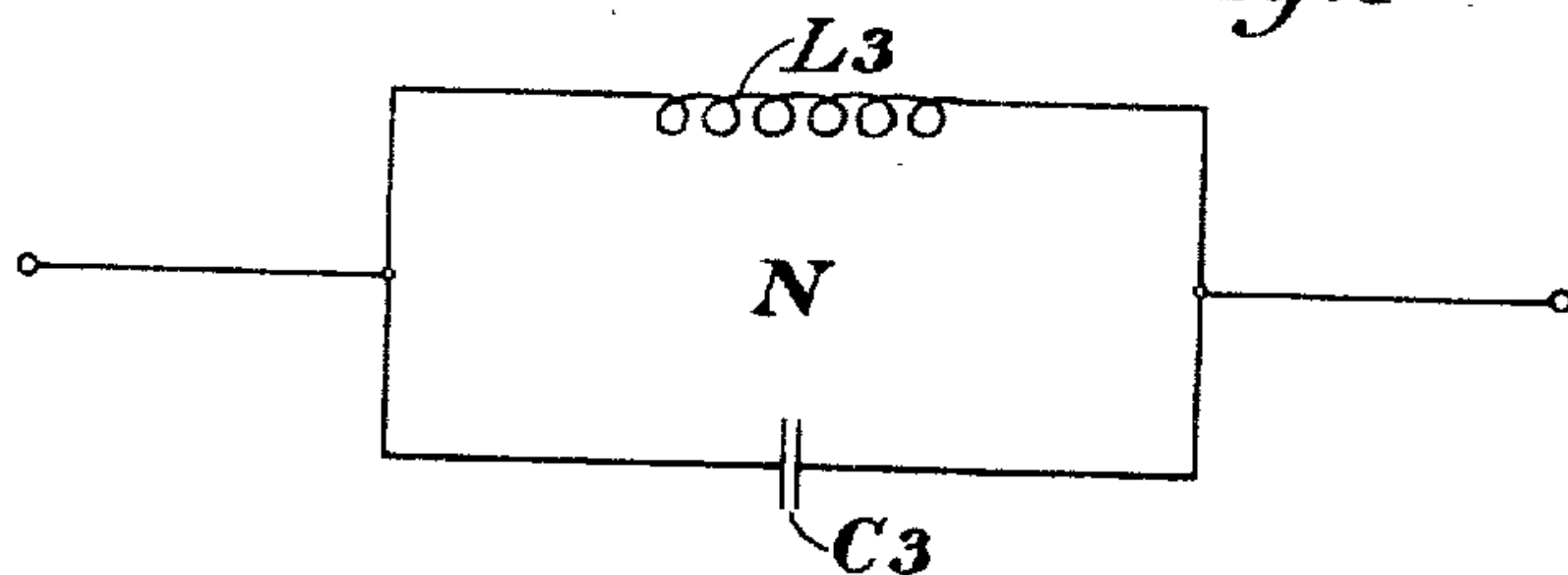


Fig. 2

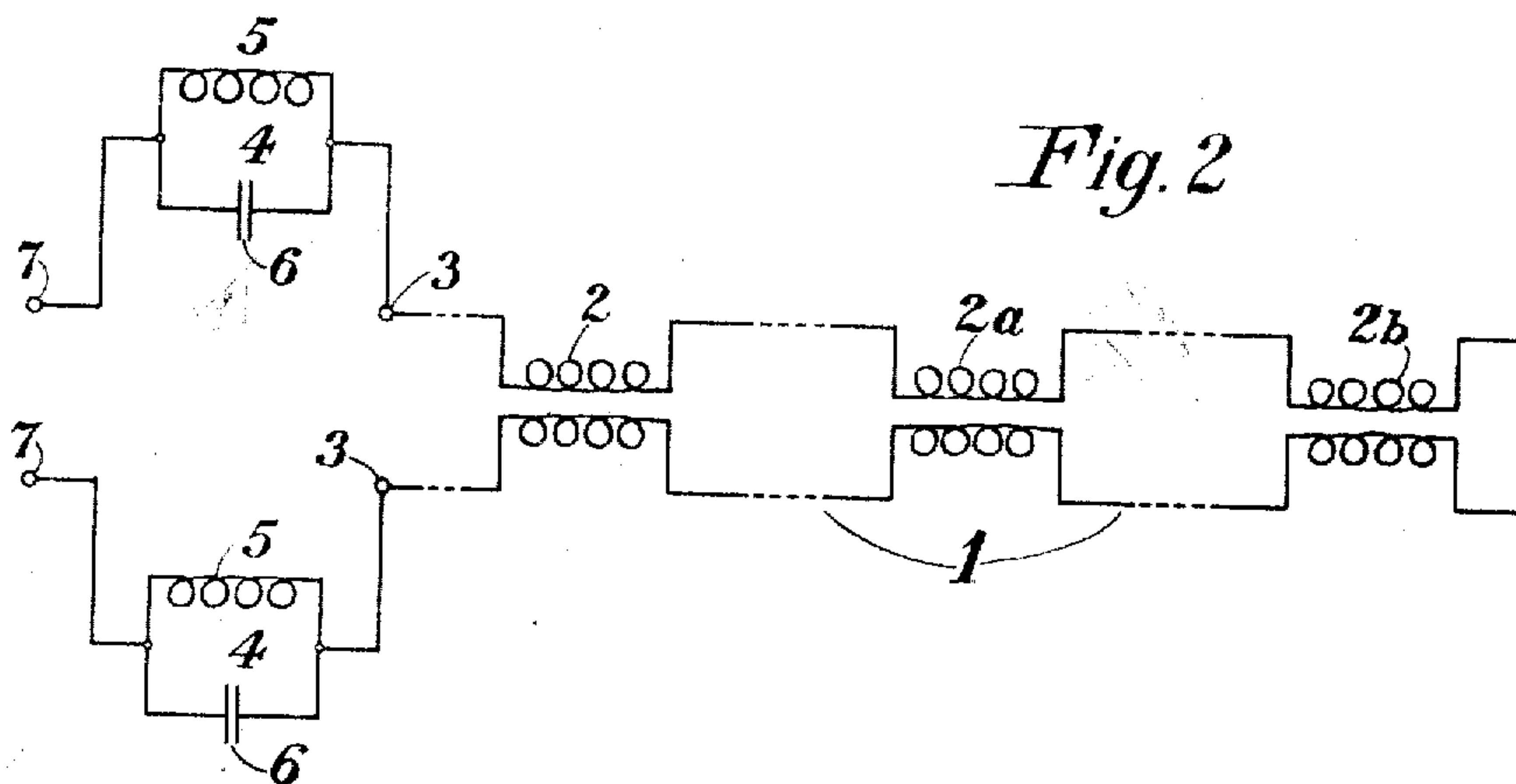
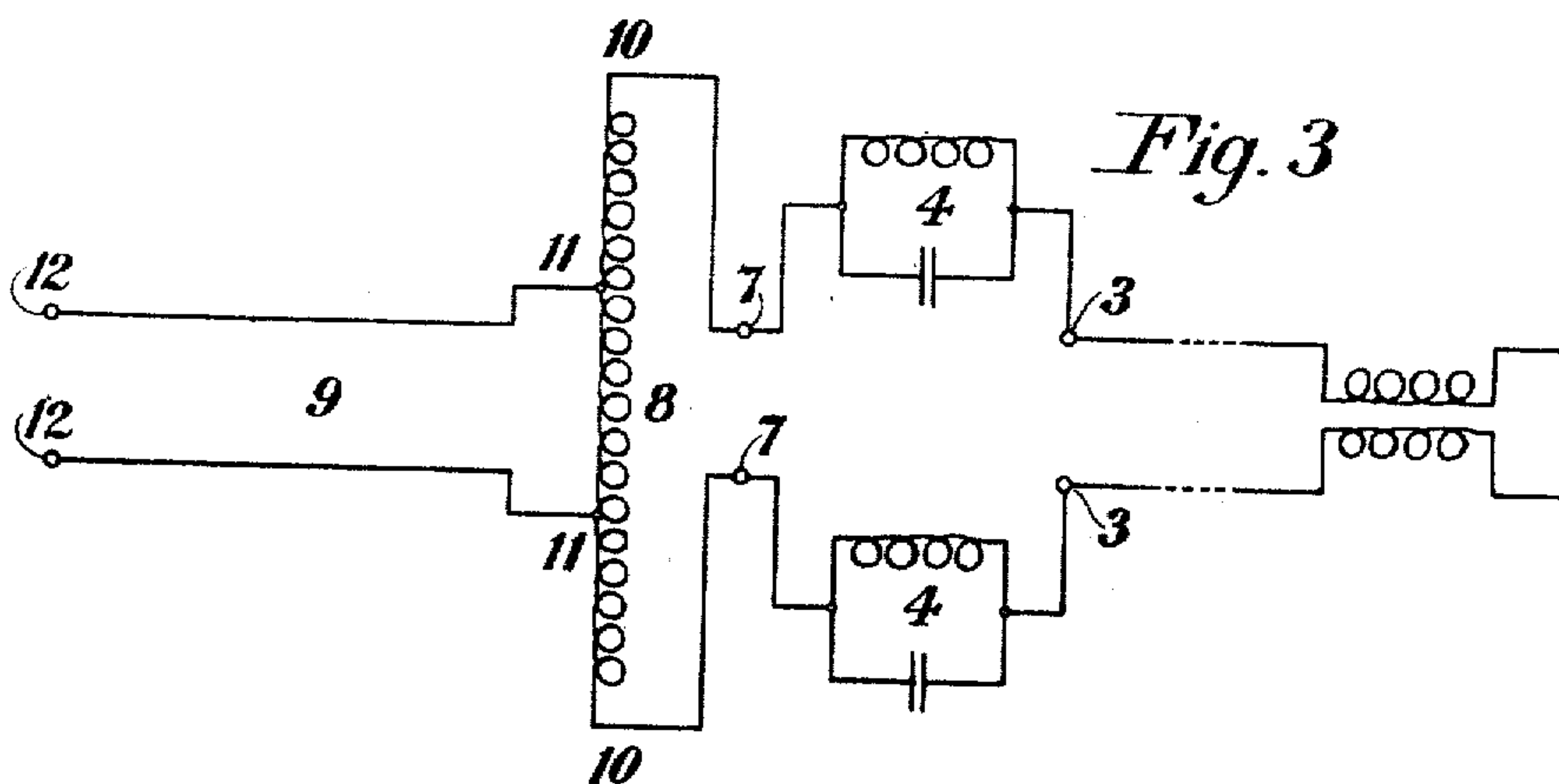


Fig. 3

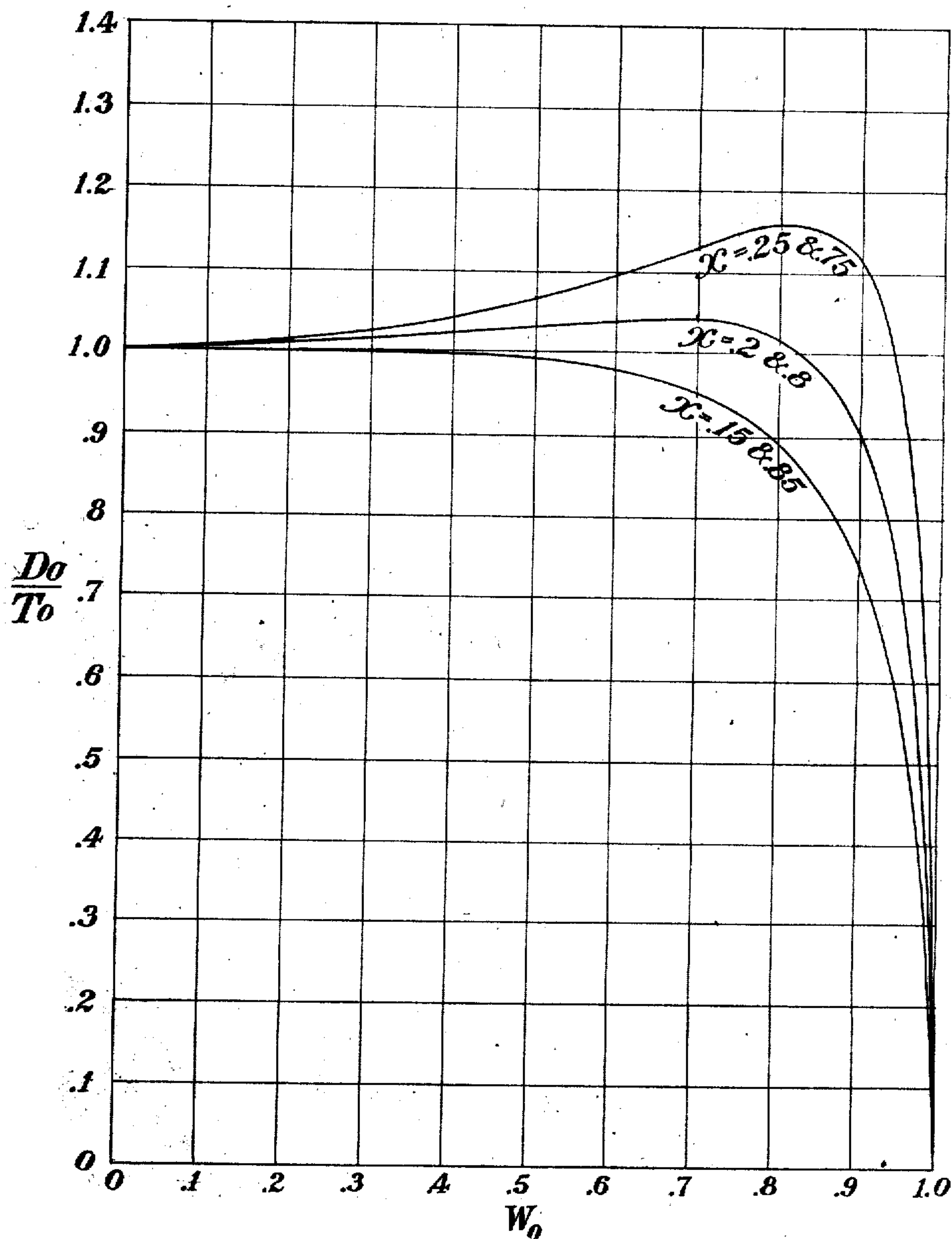


Inventor:
 Ray S. Hoyt
 per Thomas D. Lockwood
 Attorney.

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 3 SHEETS—SHEET 2.

Fig. 4



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 per Thomas D. Lockwood
 Attorney.

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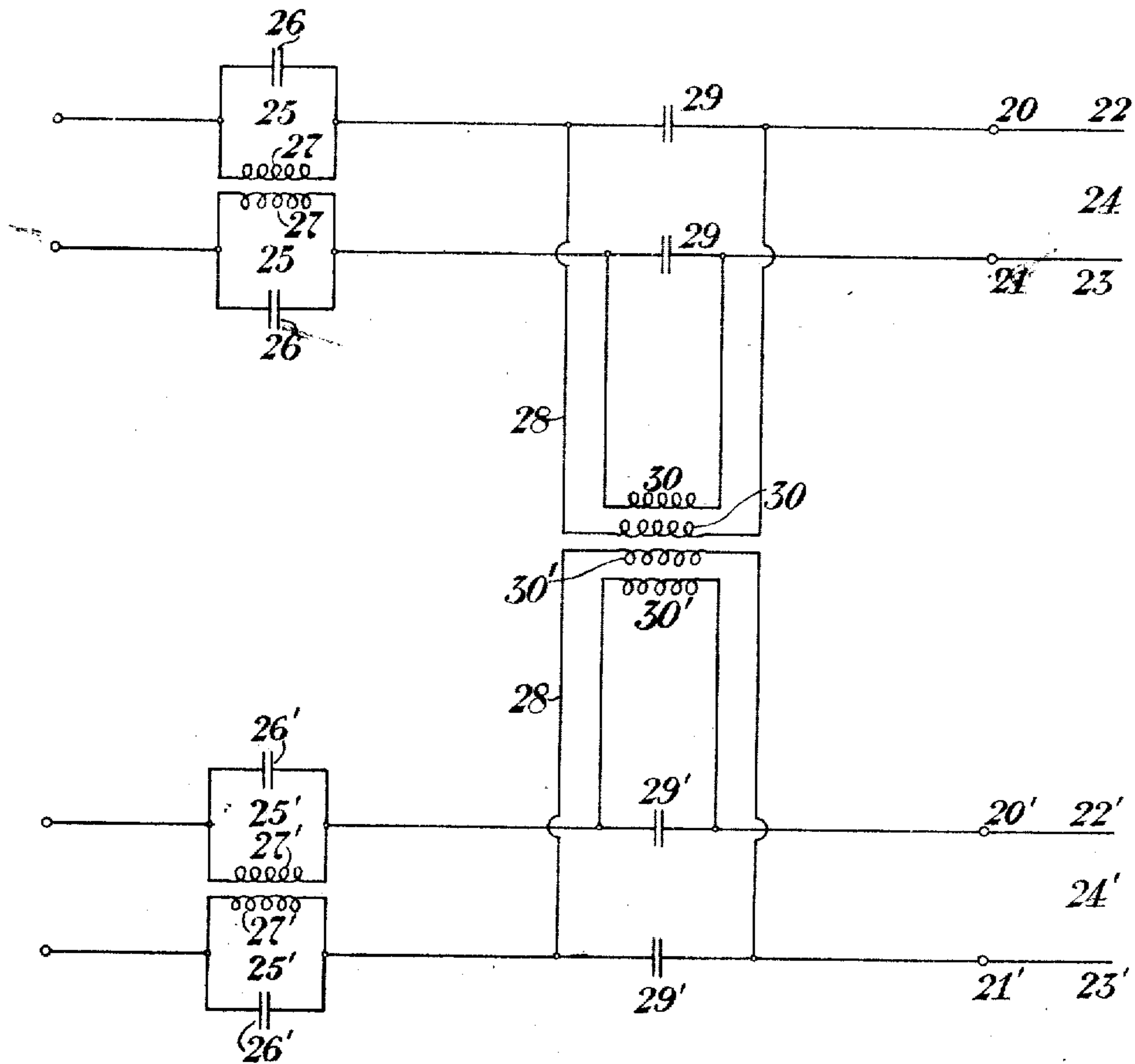
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3 SHEETS—SHEET 3.

Fig. 5



Inventor:
Ray S. Hoyt
per Thomas D. Lockwood
Attorney.

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 CHARACTERISTIC REACTANCE OF A LOADED LINE.

1,243,066.

Specification of Letters Patent.

Patented Oct. 16, 1917.

Application filed January 24, 1916. Serial No. 73,950.

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 Improvements in Network for Neutralizing the Characteristic Reactance of a Loaded Line, of which the following is a specification.

My invention relates to a circuit arrangement associated with a periodically loaded transmission line. Said circuit arrangement is hereinafter termed in accordance with common usage, a network. Its object is to provide a network having a purely reactive impedance substantially equal and opposite to the reactance component of the characteristic impedance of a periodically loaded line over the range of frequencies necessary for the telephonic transmission of speech. A further object of my invention is by the coöperative combination of said network and said loaded line to provide a transmission system whose impedance is substantially that of a constant non-inductive resistance over said range of frequencies.

It is a well known fact that the uniform non-loaded transmission line has a characteristic impedance which is substantially that of a pure non-inductive resistance over the range of telephonic frequencies. It is further known that the characteristic impedance of a periodically loaded line has a resistance component which is a function of the length of the initial section, that is, the distance from the beginning of the line to the first load coil, and which in general varies greatly over the range of telephonic frequencies. Said characteristic impedance has also a reactance component which likewise varies with the length of initial section and also with the frequency. The impedance characteristics of the non-loaded line and the periodically loaded line are, therefore, quite dissimilar.

In telephony it is often desirable and 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 loss and inferior transmission, results when 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 choosing a particular length of initial section of the loaded line whereby the characteristic impedance of the combination is substantially that of a pure resistance over a preassigned range of frequencies, preferably the range of frequencies necessary 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, as seen from the sending end, is substantially that of a single continuous transmission line.

My invention is best understood by reference to the accompanying drawings in which Figure 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 autotransformer and the network of my invention to a periodically loaded line; Fig. 4 is a curve illustrating the resistance component of the characteristic impedance of a periodically loaded line as a function of the frequency; and Fig. 5 is a diagram of the arrangements of my invention embodied in a four wire transmission system comprising two side circuits and a phantom circuit.

In my co-pending application Serial #44173 filed November 30, 1913 and issued June 11, 1916 as Patent 1,167,693 I have shown that the actual resistance of the line and of the load coils of a periodically loaded line have in practice a negligible effect on the characteristic impedance and that, over the range of frequencies necessary for the efficient transmission of speech, said characteristic impedance may be represented with a very high degree of precision by the following formula:

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

This formula is identical with equation (19) of my above-mentioned co-pending application, and the symbols have the same significance as follows: Z is the characteristic impedance of the periodically loaded line, x is the ratio of the initial length of line up

to the first load coil to the distance between load coils, and i denotes the imaginary operator

$$\sqrt{-1}.$$

T_0 and w_0 are parameters having the same significance as that assigned to them in my copending application, viz:

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

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

In equations (2) and (3), s is the length of loading section, that is, the distance between adjacent load coils and p is 2π times the frequency in cycles per second. L_0 and C_0 are parameters approximately equal to L , the load coil inductance, and C , the distributed line capacity per unit length respectively, and related to said constants L and C by the following equations:—

$$L_0 = L \frac{\sqrt{1+v^2}}{w_0} \quad (4)$$

$$C_0 = C \frac{1}{w_0 \sqrt{1+v^2}} \quad (5)$$

In equations (4) and (5)

$$v^2 = \frac{sJ}{L},$$

where J is the distributed line inductance per unit length. v^2 is then the ratio of the line inductance per section to the inductance of one load coil. w_0 is a numeric, closely equal to unity, whose exact value is determined by the value of v^2 as shown in the following table:

v^2	w_0
0	1.0000
.0529	.9913
.0900	.9852
.1369	.9778
.1936	.9689

The above table includes the range of values of v^2 found in practice, and for any particular value of v^2 the corresponding value of w_0 may be readily obtained by interpolation therein. All of the foregoing equations are derived and explained in my above-mentioned co-pending application.

Returning to equation (1) and writing D and Q for the resistance and reactance components of the characteristic impedance Z so that $Z = D + iQ$, it follows at once that

$$D = \frac{T_0 \sqrt{1-w_0^2}}{1-4x(1-x)w_0^2} \quad (7)$$

$$Q = \frac{T_0(1-2x)w_0}{1-4x(1-x)w_0^2} \quad (8)$$

Writing 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

$$Q = \frac{pL_0(1-2x)/2}{1-x(1-x)sC_0L_0p^2} \quad (9)$$

Now consider the reactance Q_3 of an inductance element L_3 in parallel with a capacity element C_3 . The reactance of this arrangement is well known to be expressible as:

$$Q_3 = \frac{L_3 p}{1-L_3 C_3 p^2} \quad (10)$$

Comparison of equations (9) and (10) 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 L_3 and C_3 so that

$$L_3 = (x-1/2)L_0 \quad (11)$$

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

$$C_3 = \frac{x(1-x)sC_0}{x-1/2} \quad (12)$$

Inspection of equation (11) shows that, since all quantities therein are by their nature necessarily positive, the relation expressed by said equation can only be satisfied values of x equal to or greater than $1/2$. If, however x , the ratio of the length of the initial section to the length of each following section, is equal to or greater than $1/2$ the combination of an inductance element L_3 and a capacity element C_3 in parallel, the values of said elements being proportioned in accordance with equations (11) and (12), has a reactance equal and opposite to the characteristic reactance of a periodically loaded line characterized by the parameters L_0 and C_0 . As may be shown from the analysis appearing in my aforementioned co-pending application, this equality is of very high precision over substantially the entire range of frequencies corresponding to $w_0=0$ to $w_0=1$, that is, over the range of frequencies necessary for the telephonic transmission of speech.

If now the impedance element having reactance Q_3 is prefixed to the periodically loaded line of characteristic impedance Z , the impedance of the combination is obviously $Z + iQ_3$. If, further, the component elements of Q_3 are proportioned in accordance with equations (11) and (12), then $Q_3 = -Q$, so that the impedance of the combination reduced to D as given by equation (7). Thus it is seen that the impedance of the combination has no reactance component. D as given by equation (7) is a function of w_0 and, therefore, of the frequency, since w_0 is directly proportional to the frequency. The value of $\frac{D}{T_0}$ is proportional to the resistance component,

since T_0 is a constant for any particular line. By reference to equation (7):

$$\frac{D}{T_0} = \frac{\sqrt{1-w_0^2}}{1-4x(1-x)w_0^2} \quad (13)$$

The range of frequencies necessary for the telephonic transmission of speech 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 (13) reduces to

$$\frac{D}{T_0} = \frac{\sqrt{1-w_0^2}}{1-.64w_0^2} \quad (14)$$

and if from this equation we calculate the values of $\frac{D}{T_0}$ for different values of w_0 from 0 to 1, and plot these values of $\frac{D}{T_0}$ against the corresponding values of w_0 , we get the curve shown in Fig. 4 of the drawings. It will be noticed by reference to said Fig. 4 that the value of $\frac{D}{T_0}$ is approximately constant and closely equal to unity from $w_0=0$ to $w_0=.9$. The corresponding range of values of frequency are substantially those which are necessary for the telephonic transmission of speech. It should be noticed, however, that this constant resistance 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 section; but it can always be built out artificially to a 0.8 initial section, as fully explained in my Patent #1,124,904, dated January 12, 1915 and in my co-pending application, hereinbefore referred to.

If x is taken as 0.8 the values of L_3 and C_3 of the network of my invention become by aid of equations (11) and (12)

$$L_3 = 3L_0/10 \quad (15)$$

$$C_3 = 8sC_0/15 \quad (16)$$

To summarize the foregoing, the combination of a network proportioned in accordance with equations (11) and (12), and illustrated in Fig. 1, prefixed to a periodically loaded line having an initial sectional length equal to approximately 0.8 of a loading section, has an impedance whose reactance component is substantially zero and whose resistance component is substantially constant and equal to T_0 over the range of telephonic frequencies. The value of T_0 is given by equation (2) above.

Referring to Fig. 1 of the accompanying drawings, N is the network of my invention comprising an inductance L_3 in parallel with

a condenser C_3 , the values of L_3 and C_3 being those given by equations (15) and (16) of this specification. The actual numerical values of L_3 and C_3 depend on the values of L_0 and sC_0 , that is on the constants of the particular loaded line with which it is desired to associate said network.

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 distance between the line terminals 3, 3 and the initial load coil 2 is approximately 0.8 of the distance between any two adjacent coils such as 2 and 2_a or 2_a and 2_b, for example. If the actual line does not have an initial 0.8 section it may be artificially built out to an equivalent 0.8 initial section as hereinbefore mentioned and fully explained in my above-mentioned patent. Prefixed to terminals 3, 3 are similar and equal impedances 4, 4, each of said impedances comprising an inductance element 5, in parallel with a condenser 6. If the line 1 is characterized by the parameters L_0 and sC_0 , then inductances 5, 5, and condensers 6, 6, are so proportioned that the inductance of inductance element 5 is $1/2L_3$ and the capacity of condenser 6 is $2C_3$, where L_3 and C_3 are given by equations (15) and (16). The impedance of the two impedances 4, 4, in series is, therefore, the same as the impedance of the network N of Fig. 1. The reason for dividing the network into two equal parts, each having one-half the impedance of the required network is to maintain the symmetry of the two sides of the transmission line and thereby to maintain its balance. From the theory developed in the specification it follows that the impedance of the combination as seen from terminals 7, 7, will be substantially that of a constant non-inductive resistance of magnitude

$$\sqrt{L_0/sC_0}$$

over the range of telephonic frequencies.

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 transformer 8, while line 9 is connected to terminals 11, 11 of said transformer. If the non-loaded 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 closely equal, except for very low frequencies, to

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

Further, if the transformer impedance-ratio as seen from terminals 11, 11 is r the appar-

ent impedance of the loaded line system, as seen from terminals 11, 11, is substantially

$$r \sqrt{\frac{L_0}{sC_0}}$$

Hence if the transformer be so designed that

$$r = \sqrt{\frac{J/C'}{L_0/sC_0}}$$

the impedance of the entire system, as seen from terminals 12, 12, will be simply

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

that is, the same as the impedance of an infinitely long uniform non-loaded line. As hereinbefore stated this is the condition for propagation without reflective losses.

The uses of my invention are not limited to the cooperative arrangement illustrated in Fig. 3, but my invention is applicable to any arrangement wherein it is desirable that a periodically loaded line shall have substantially 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 a nearly constant resistance; (2) to connect a loaded line to a repeater system whose impedance is nearly constant resistance; and (3) to connect a loaded line to terminal apparatus whose impedance is a nearly constant resistance.

I do not desire to limit the proportioning of the network of my invention rigidly to formulæ (11) and (12) or to values of α exactly equal to 0.8. If very high precision is not necessary, I may, for instance, with small precision loss, proportion L_3 and C_3 in accordance with the following formulæ, obtained by neglecting the distributed inductance of the loaded line,

$$L_3 = 3L/10 \quad (17)$$

$$C_3 = 8sC/15 \quad (18)$$

on the other hand, if extremely high precision is desired I may choose for α a value slightly different from 0.8; or I may compute rigorously the impedance of any particular loaded line and then assign L_3 and C_3 values slightly different from those indicated by formulæ (11) and (12) whereby the neutralization of reactance may be slightly more precise.

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. Three circuits are thus provided by means of four conductors, these circuits consisting of two "side" circuits and a "phantom" circuit. The current in each side circuit flows in opposite directions in the two conductors of one line, while the current in the phantom circuit flows in the same direction in the

two conductors of a line. If the neutralizing network of my invention is to be employed in such a system to neutralize the reactive impedance of the two side circuits and of the phantom circuit, means must be provided whereby the neutralizing arrangements associated with one circuit shall not affect the transmission of current in the other circuits. Fig. 5 is a diagram of a reactance neutralizing arrangement designed to be prefixed to such a system and which shall satisfy the above-mentioned condition. Referring to Fig. 5, the terminals 20, 21 are connected to the two sides 22, 23 of a loaded line 24; similarly terminals 20', 21' are connected to the two sides 22', 23' of a parallel loaded line 24'. Conductors 22 and 23 in parallel serve as one side of the phantom circuit, of which the other side is composed of conductors 22' and 23' in parallel, said phantom circuit being also periodically loaded. Lines 24 and 24' are separately the side circuits of the system. Considering the side circuit 24, the network of my invention associated therewith is represented by an arrangement 25, comprising two similar and equal condensers 26, 26, and two similar and equal coils 27, 27 wound on a common magnetic core and preferably as closely coupled as possible. The two coils 27, 27 are so wound as to be practically non-inductive to equal currents flowing in the same direction in conductors 22 and 23 while to current flowing in the opposite directions in conductors 22 and 23 their resultant inductance is L_3 , when L_3 is computed from the constants of line 24 as hereinbefore explained. The capacity of each condenser 26, 26 is $2C_3$. It will be evident therefore that the network 25 offers to the side circuit current flowing in line 24 an impedance equal to that of the network N of Fig. 1, provided, of course, that L_3 and C_3 are proportioned in accordance with the constants of line 24. It will be further evident that network 25 offers practically no impedance to the phantom current flowing in conductors 22 and 23, since coils 27, 27 are non-inductive with respect to the phantom current and their resistance may be made as small as desired.

Network 25' is similar in its component parts to network 25, and is the neutralizing network of line 24'. The values of condensers 26', 26' and inductance coils 27', 27' are of course, proportioned in accordance with the constants of line 24'. In practice lines 24 and 24' are similar and equal in which case networks 25 and 25' are similar and equal.

The circuit arrangement 28 comprising four similar and equal condensers 29, 29, 29', 29' and four similar and equal inductance coils 30, 30, 30', 30', constitutes the neutralizing network of the phantom circuit.

The four inductance coils 30, 30, 30', 30' are wound on a common magnetic circuit and are so related thereto that coils 30 and 30 are non-inductive with respect to the side circuit current in line 24 and coils 30' and 30' are non-inductive with respect to the side circuit current in line 24'. Said four coils are so proportioned as to offer a resultant inductance to the phantom circuit current of L_2 when L_3 is computed in accordance with the phantom circuit constants. The capacity of each of the condensers 29, 29, 29', 29' is C_3 , when C_2 is computed in accordance with the phantom circuit constants. It will be evident then, that as regards the phantom circuit, the circuit arrangement 28 is equivalent to the network N 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 also observed that the inductance coils of Fig. 5 are wound and related in substantially the same manner as are the load coils in a four wire transmission system comprising two loaded side circuits and a loaded phantom circuit.

It will be understood that it is not necessary to combine the entire arrangement of Fig. 5 in a single organization; for example if the phantom circuit is non-loaded while the side circuits are loaded, the network 28 is omitted. 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 be more simply and exactly proportioned to neutralize the reactance of an artificial loaded line, since the two lines differ only in that the effect of distributed inductance is absent in the latter.

Claims:

1. A network for neutralizing the characteristic reactance of a periodically loaded signaling line, said network comprising pre-computed impedance elements so proportioned in accordance with the constants of said line that the reactance of said network is substantially equal and opposite to the characteristic reactance of said line.

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

3. A network having a reactance equal and opposite to that of an actual loaded signal transmission line, said network comprising inductance and capacity elements having precomputed values depending on the load coil inductance, the distance between consecutive load coils and the distributed capacity and inductance of said line.

4. A network having a reactance substantially equal and opposite to the characteristic reactance of a periodically loaded signaling line, said network comprising an inductance coil in parallel with a condenser, the values of the inductance of said coil and the capacity of said condenser being precomputed in accordance with the load coil inductance, the distance between consecutive load coils and the distributed capacity and inductance of said loaded line.

5. In a telephone system, the combination of a periodically loaded transmission line and a network in series therewith, said network consisting of inductance and capacity elements so proportioned in accordance with the constants of said loaded line that the impedance of said combination is a practically pure constant resistance over the range of frequencies necessary for the transmission of speech.

6. In a telephone 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 therewith, said networks including impedance elements so proportioned that the reactance of each of said circuits is substantially neutralized.

7. In a telephone 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 in series with each of said side circuits respectively, 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.

8. In a telephone 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 conductors including two condensers in series, and an inductance coil shunting each of said condensers, the said inductance coils being so related as regards their mutual inductances and said inductance coils and said condensers being so proportioned in accordance with the constants of the periodically loaded side circuits and the periodically loaded phantom circuit that the characteristic impedance of each side circuit and of the phantom circuit is substantially a pure resistance.

9. The combination of a loaded line comprising lumped series inductance and shunt

- capacity in series with a network comprising an inductance coil in parallel with a condenser, said network having a reactance substantially equal and opposite to that of said loaded line, 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 10. A telephone circuit comprising a plurality of conductors through which current flows in series and in parallel, and a conductive network included in each of the conductors, said networks being adapted to neutralize the reactance of the circuit to current flow in one direction and cooperating with one another to prevent such neutralization for current flow in the other direction.
- 20 11. A telephone circuit comprising a plurality of conductors, and a conductive network associated with each of the conductors, each network including branches containing impedances of different character, impedances of the same character in different networks being arranged in mutually inductive relation. 25
12. A telephone circuit comprising a plurality of conductors, and a network consisting of a plurality of branches included in each conductor, with the branches of the networks of different conductors having inductance elements in mutually inductive relation. 30
13. A telephone circuit comprising a plurality of conductors, and a network included in each of the conductors and consisting of a branch containing an inductance element and a branch containing a capacity element, the inductance elements of the networks being in mutually inductive relation. 35 40
- In testimony whereof, I have signed my name to this specification in the presence of two subscribing witnesses, this 20th day of January, 1916.
- RAY S. HOYT.
- Witnesses:
FRED'K S. ROBINSON,
RALPH W. WOLF.