Dec. 15, 1931. W. P. MASON 1,836,810

DISTORTION CORRECTION IN TRANSMISSION SYSTEMS

Filed Oct. 3, 1928 2 Sheets-Sheet 1

FIG. 1

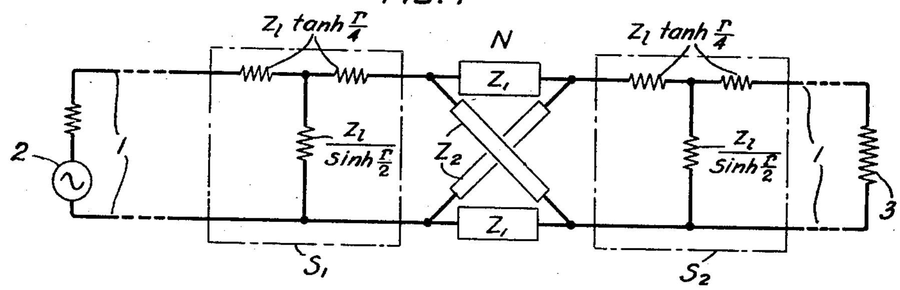


FIG. 2

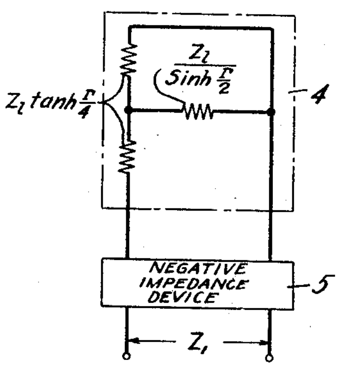


FIG. 3

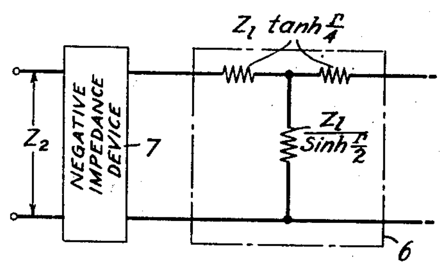
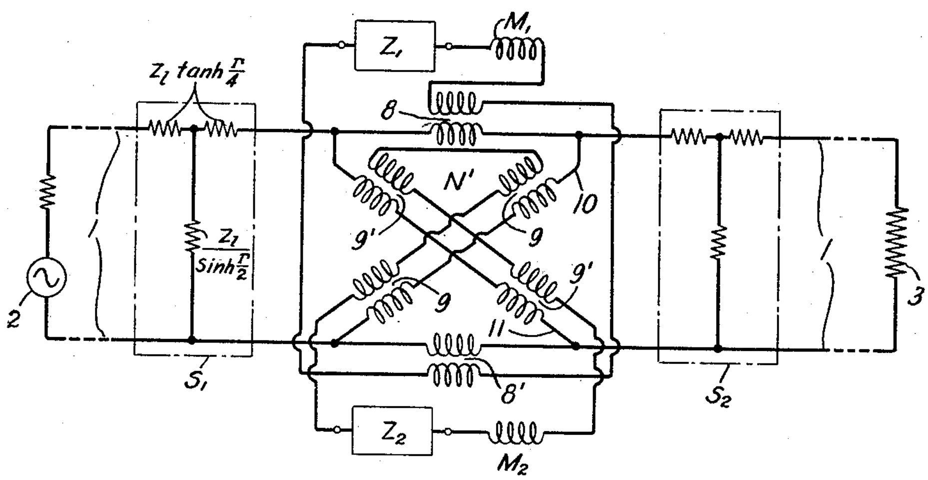


FIG. 4

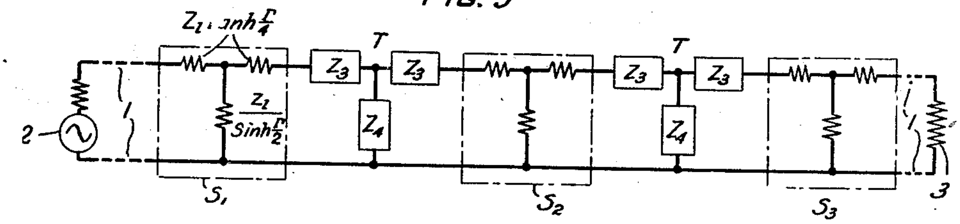


INVENTOR
W. P. MASON
BY H. A. Burgess
ATTORNEY

DISTORTION CORRECTION IN TRANSMISSION SYSTEMS

Filed Oct. 3, 1928 2 Sheets-Sheet 2

FIG. 5



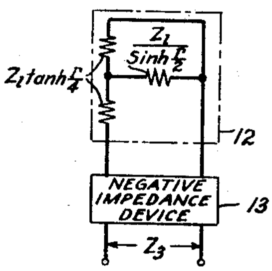


FIG. 6

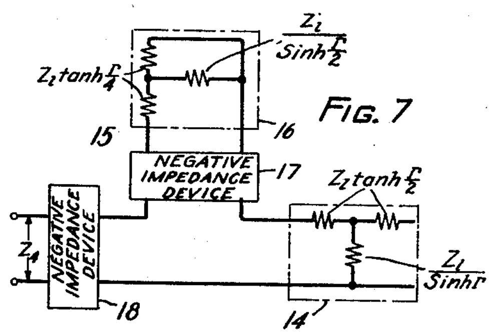
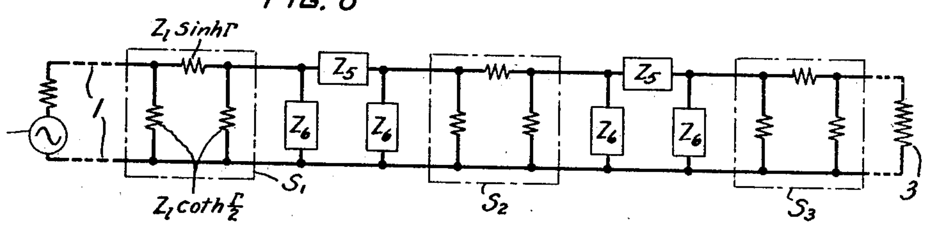


FIG. 7

FIG. 8



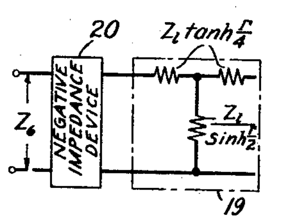


FIG. 9

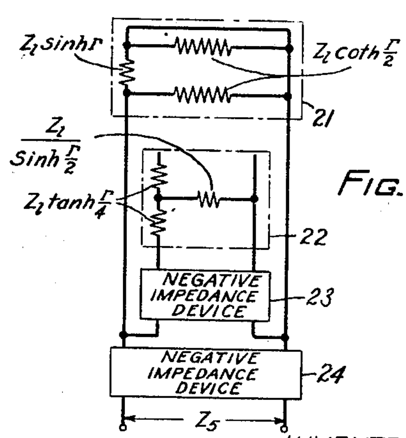
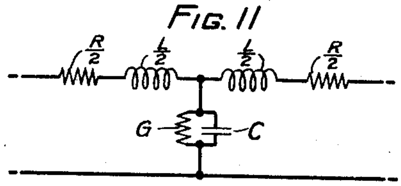


FIG. 10

FIG. 11



INVENTOR
W. P. MASON
BY H. A. Burgess
ATTORNEY

Patented Dec. 15, 1931 1,836,810

UNITED STATES PATENT OFFICE

WARREN PERRY MASON, OF EAST ORANGE, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

DISTORTION CORRECTION IN TRANSMISSION SYSTEMS

Application filed October 3, 1928. Serial No. 310,166.

This invention relates to systems for transmitting electrical wave energy, such as telephone transmission systems and the like, and particularly to correction of distortion in such systems.

From an ideal quality standpoint a transmission system should be designed so that the currents received thereover are exact copies of the corresponding currents entering the system at the transmitting end; in other words, the transmission system should be distortionless. When electrical waves, such as telephonic currents, are transmitted over conductors of relatively great length, the distortion produced in the waves due to the inherent properties of the conductors becomes of increasing importance. In long high quality systems, such as are now being used for telephone transmission, program broadcasting, television, etc. the distortion produced by lines is often of such magnitude as to impair appreciably the quality of the received waves, and thus reduces the commercial efficiency of such systems.

Distortion in transmission lines is, in general of three different kinds—first, attenuation of the transmitted waves by the line; second, variation in the degree of attenuation of waves of different frequencies by the line; and third, a relative phase change in the transmitted waves of different frequencies. The cause of such distortion is the improper proportioning of the resistance, the leakance, the capacity and the inductance of the line.

The Pupin-Campbell and other methods of loading transmission systems have been devised with the object of reducing attenuation in the useful frequency range in such systems. The use of such loading methods in transmission systems has been supplemented in practice by the use of amplifiers, such as the telephone repeater, to compensate for reduction in the amplitude of the transmitted waves. The second type of distortion inherent in transmission systems, an unequal degree of attenuation in the transmitted waves of different frequencies, may be overcome by the use of attenuation equalizing networks at different points in the system, this expedient having been brought to a high state of development in practice. Phase corrective networks or phase compensators to supplement other types of distortion correction, such as loading, have been used in connection with lines to correct phase distortion in the transmitted waves over a desired range of frequencies. Other networks have been devised and utilized in connection with transmission lines to combine the functions of phase distortion correction and attenuation equalization in transmitted waves of a desired range of frequencies. The latter networks have been either designed, in part at least, by empirical methods, or else, in their design all factors contributing to distortion have not been taken into account. Their use, therefore, enables only an approximation of the ideal distortionless line to be obtained.

An object of the invention is to correct distortion in electric wave transmission.

Another and more specific object is to reduce the attenuation in, and to minimize variations in the velocity of propagation of electric waves over transmission systems.

A feature of the invention is a unitary network which, when combined with a transmission line, without altering the characteristic impedance of the line, will simultaneously compensate for amplitude and phase distortion in waves of all frequencies transmitted thereover, and at the same time will restore the waves to their original amplitudes.

In accordance with the invention, exact design formulæ have been developed for the impedance relations which a structure must satisfy when combined with a transmission line in a given manner in order to completely compensate for distortion produced by the line in waves of all frequencies transmitted thereover. Networks of different types have been designed in accordance with these formulæ, which, when combined with a transmission system or line in a given manner will, without altering the characteristic impedance of the line, reduce or substantially compensate for the amplitude and phase distortion in waves of all frequencies transmitted thereover.

More specifically stated the above mentioned objects and features have been obtained in accordance with the invention by inserting in a transmission system or line in the path of waves transmitted thereover an impedance structure having one or more series arms and one or more lattice or shunt arms, the structure as a whole having a characteristic impedance equal to that of said line, and a propagation constant, the negative of that of said line.

In a preferred embodiment of the invention, the compensating structure is of the lattice type. Each of the two series arms of this lattice structure comprises a short circuited section of smooth line half as long as, and with the same characteristic impedance as the line to be compensated before the compensating structure was inserted therein, in tandem with a device, which will effectively change the positive impedance of the short circuited line to a negative impedance of equal value. Each of the two lattice arms of the lattice network comprises an open-circuited section of smooth line half as long as, and with the same characteristic impedance as the line to be conpensated before the insertion of the compensating structure therein, in tandem with a device which will effectively change the positive impedance of the open circuited line to a negative impedance of equal value.

In another embodiment of the invention the compensating structure comprises a T type structure. Each of the two series arms of this T structure comprises a short circuited section of smooth line half as long as the line to be compensated, and having the same characteristic impedance as the line to be compensated before insertion therein of the compensating structure, and in tandem therewith a device which will effectively change its positive impedance to a negative impedance of equal value. The shunt arm of the T network comprises an open-circuited section of smooth line, the same length as, and having the same characteristic impedance as the line to be compensated in series with an impedance which is the equivalent of that of the series arm above described, and in tandem therewith a device which will change the net impedance of the whole combination to a negative impedance of equal value. An extension of this embodiment is the π network which is equivalent to the T structure described.

The objects and advantages of the invention will be better understood from the following detailed description, when read in connection with the accompanying drawings in which

Fig. 1 is the diagram of a transmission system employing distortion correcting networks of the lattice type embodying the invention;

Figs. 2 and 3 show diagrammatically the construction of the lattice networks used in the system of Fig. 1;

Fig. 4 shows diagrammatically a modification of the invention requiring fewer impedances in the distortion correcting networks than employed in the system of Fig. 1;

Fig. 5 shows diagrammatically a modification of the invention employing T type networks for the distortion correcting structures;

Figs. 6 and 7 show diagrammatically the construction of the impedance arms of the T type networks of Fig. 5;

Fig. 8 shows diagrammatically a modification of the invention employing π type networks for the distortion correcting structures;

Figs. 9 and 10 show diagrammatically the construction of the impedance arms in the π type networks of Fig. 6; and

Fig. 11 shows a type of simulating network which may be used in place of each line in the structures of Figs. 2, 3, 6, 7, 9 and 10 to approximate the results obtainable with the artificial lines of said structures.

In Fig. 1 is shown a transmission line for transmitting alternating current waves of a plurality of frequencies generated by a source 2 to a load circuit represented by the resistance 3. The line 1 comprises a plurality of smooth line sections $S_1, S_2, \ldots$, which are indicated in the figure by their equivalent T networks having two series arms, each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}$$

where Z_l is the characteristic impedance of line 1 and Γ is the propagation coefficient for a section of line 1 of length l.

Inserted in line 1 between each two adjacent sections is a 4-terminal network N which is designed in accordance with the invention to correct for the attenuation distortion and phase distortion in transmitted waves of all frequencies produced by a section of line 1 of length l, for example, a section comprising the adjacent half of section S_1 and the adjacent half of section S_2. Each network N is of the lattice type comprising two series impedance arms represented by the boxes Z_1 and two lattice impedance arms represented by the boxes Z_2.

The values for the impedances of Z_1 and Z_2 are determined in the following manner.

The propagation coefficient P and the characteristic impedance Z_K of the complex line including the smooth sections $S_1, S_2, \ldots$, and the distortion correcting networks N are given by the following equations:

$$\cosh P = \cosh \Gamma \cosh \Gamma_1 + \sinh \Gamma \sinh \Gamma_1 \frac{Z_l^2 + Z_{l_1}^2}{2Z_l Z_{l_1}} \quad (1)$$

$$Z_K^2 = Z_{l_1}^2 \frac{2Z_l Z_{l_1} \coth \Gamma_1 + Z_{l_1}^2 \coth \frac{\Gamma}{2} + Z_l^2 \tanh \frac{\Gamma}{2}}{2Z_l Z_{l_1} \coth \Gamma_1 + Z_l^2 \coth \frac{\Gamma}{2} + Z_{l_1}^2 \tanh \frac{\Gamma}{2}} \quad (2)$$

where P and Z_K are the propagation coefficient and the characteristic impedance respectively of the complex line, Γ and Z_l the parameters for the smooth line without the distortion correcting networks N, and Γ_1 and Z_{l_1} the parameters for the distortion correcting networks N.

Where the inserted networks are of the lattice type, such as the network N shown in Fig. 1 comprising the two series arms Z_1 and the two lattice arms Z_2, the parameters Z_{l_1} and Γ_1 are given by the equations:

$$Z_{l_1} = \sqrt{Z_1 Z_2}\,; \quad \cosh \Gamma_1 = \frac{Z_2 + Z_1}{Z_2 - Z_1} \quad (3)$$

Let

$$Z_1 = -Z_l \tanh \frac{\Gamma}{2} \quad (4)$$

and

$$Z_2 = -Z_l \coth \frac{\Gamma}{2} \quad (5)$$

Substituting in Equation (3), it is found that

$$Z_{l_1} = Z_l\,; \quad \Gamma_1 = -\Gamma \quad (6)$$

Substituting the values for Z_{l_1} and Γ_1 in Equations (1) and (2), it is found

$$\cosh P = 1 \text{ or } P = 0 \quad (7)$$

and Z_K is indeterminate, and in fact equals the terminating impedance.

Hence, if the impedances in the arms Z_1 and Z_2 of the networks N in the system are given the values of Equations (4) and (5), the complex line will produce zero overall attenuation and a theoretically infinite or very high, constant velocity in the transmitted waves of all frequencies.

Equation (4) for the series impedance Z_1 of networks N may be physically realized by the structure of Fig. 2. The structure of Fig. 2, which in the system of Fig. 1 would be inserted in the boxes Z_1 in series with the terminals thereof comprises a short-circuited section of smooth artificial line 4 half as long as, and with the same characteristic impedance as the section of line 1 in which the distortion is to be compensated, and in tandem therewith a device 5 which will effectively change the positive impedance of artificial line 4 to a negative impedance of equal value.

The negative impedance device 5 may be of any suitable type, for example, the feed-back amplifier described and claimed in the patent to R. C. Mathes, No. 1,779,382, issued October 21, 1930, which will effectively give between two terminals thereof for a wide range of frequencies, the negative of a resistance, inductance, capacity or complex combination thereof utilized as the feed-back impedance. If the structure of Fig. 1 of the Mathes patent is used as the device 5 in the structure of Fig. 2 of this application, the terminals Z_1 of the latter structure would be connected to the terminals 16 and 17 of the former structure, and one pair of terminals of network 4 of said latter structure would be connected to the terminals of box 14 in the circuit of said former structure so that network 4 acts as the feed-back impedance Z in said circuit.

The short-circuited length of line 4 has been represented in Fig. 2 by its equivalent T network having two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}.$$

Equation (5) for the lattice impedance Z_2 of the networks N may be physically realized by the structure of Fig. 3. This structure, which in the system of Fig. 1 would be inserted in the boxes Z_2 in series with the terminals thereof, comprises an open-circuited section of smooth line 6 half as long as, and with the same characteristic impedance as the section of line 1 to be compensated, and in tandem therewith a device 7, similar to the device 5 of Fig. 2, which will effectively change the positive impedance of line 6 to a negative impedance of equal value.

The section of line 6 has been represented in Fig. 3 by its equivalent T network having two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$Z_l \sinh \frac{\Gamma}{2}.$$

In Fig. 4 is shown a modification of the system of Fig. 1 in which only one impedance Z_1 and one impedance Z_2 is required in each lattice network N′ to correct completely for phase and amplitude distortion in transmitted waves of all frequencies produced by a section of line 1. This is accomplished by using two transformers in conjunction with the correction impedance elements Z_1 and Z_2. One transformer 8, 8′ effectively connects the structure Z_1, which is equivalent to the structure Z_1 in the system of Fig. 1, in series with the line 1, and another transformer comprising two parts 9, 9′ effectively couples the impedance structure Z_2, which is equivalent to the structure Z_2 of the system of Fig. 1, respectively in series with the lattice arms 10 and 11 of the network. An inductance of value M_1, where M_1 is the mutual impedance of transformer 8, 8′, is connected in series with the impedance structure Z_1 and the secondary windings of transformer 8, 8′. An inductance of value M_2, where M_2 is the mutual impedance of the lattice transformer 9, 9′ is connected in series with the impedance structure Z_2 and the secondary windings of transformer 9, 9′.

A lattice network N′, such as shown in Fig. 4, with equal effective series impedances Z_1 and a mutual impedance M_1 between them, and two lattice arms with equal impedances Z_2 and a mutual impedance M_2 between them is equivalent to a lattice network with equal series arms of impedances Z_1-M_1, and equal lattice arms of impedances Z_2-M_2, with no mutual impedances appearing in the circuit. If the two primary windings of transformer 8, 8′ in series with line 1 have an equal number of turns and each is coupled to a secondary winding which has the same number of turns as each of the primary windings, then each series impedance Z_1 of the lattice network will be equal to the terminating impedance Z_T of transformer 8, 8′ minus the mutual impedance M_1, that is,

$$Z_1=Z_T-M_1 \quad (8)$$

Then, if the terminating impedance of the series transformer 8, 8′ is made equal to

$$-Z_l \tanh\frac{\Gamma}{2}+M_1,$$

the impedance of each series arm reduces to

$$Z_1=-Z_l \tanh\frac{\Gamma}{2}+M_1-M_1=-Z_l \tanh\frac{\Gamma}{2} \quad (9)$$

Similarly, if the primary windings of the transformer 9, 9′ in the lattice arms 10 and 11 of the lattic network N′ have an equal number of turns and each is coupled to a secondary winding having the same number of turns as the primary windings, each lattice impedance will be equal to the terminating impedance Z_{T1} of the transformer 9, 9′ minus the mutual impedance M_2, that is,

$$Z_2=Z_{T1}-M_2 \quad (10)$$

Then, if the terminating impedance of transformer 9, 9′ is made equal to

$$Z_l \coth\frac{\Gamma}{2}+M_2;$$

the impedance of each lattice arm reduces to

$$Z_2=-Z_l \coth\frac{\Gamma}{2}+M_2-M_2=-Z_l \coth\frac{\Gamma}{2} \quad (11)$$

The series impedances

$$Z_1=-Z_l \tanh\frac{\Gamma}{2}$$

and the lattice impedance

$$Z_2=-Z_l \coth\frac{\Gamma}{2},$$

may be physically realized by the structures of Figs. 2 and 3, respectively, which have been described.

In Fig. 5 is shown a transmission system equivalent to that of Fig. 1 except that a T type structure T having two series arms of impedance Z_3, represented by the boxes so labeled, and a shunt arm of impedance Z_4, represented by a box so labeled, is inserted between each two adjacent line sections S_1, S_2, . . . in place of the lattice type structure N of Fig. 1, the impedance arms of this T structure being designed to compensate completely for the phase and amplitude distortion in transmitted waves of all frequencies produced by a section of line 1 of length l.

The smooth sections S_1, S_2, S_3 . . . in line 1 may be represented, as indicated in Fig. 5, by their equivalent T networks comprising two series arms each of impedance

$$Z_l \tanh\frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh\frac{\Gamma}{2}}.$$

It is apparent, therefore, that if the impedances Z_3 in the series arms of network T each have an impedance of

$$-Z_l \tanh\frac{\Gamma}{4},$$

and the impedance Z_4 in the shunt arm of network T an impedance of

$$-\frac{Z_l}{\sinh\frac{\Gamma}{2}},$$

the effective series and shunt impedances of one section of line 1 of length l will be effectively cancelled. Therefore, each T structure will effectively compensate the distortion in both phase and amplitude produced by one section of line 1 of length l in the transmitted waves for all frequencies.

The impedance Z_3 in each series arm of the structures T in the system of Fig. 5 will have a value of

$$Z_l \tanh \frac{\Gamma}{4}$$

if the elements thereof connected in series with its terminals are as shown in Fig. 6. The structure of Fig. 6 comprises a short-circuited length of smooth line 12 half as long as, and with the same characteristic impedance as the section of line 1 in which the distortion is to be compensated, and in tandem therewith a device 13, similar to the device 5 of Fig. 2, which will effectively change the positive impedance of network 12 to a negative impedance of equal value.

The line 12 in Fig. 6 has been represented by its equivalent T network comprising two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}.$$

The network Z_4 will have an impedance of

$$\frac{-Z_l}{\sinh \frac{\Gamma}{2}}$$

if the elements connected in series with its terminals are as shown in Fig. 7. The structure of Fig. 7 comprises the combination of an open-circuited section of smooth line 14 of the same length as, and with the same characteristic impedance as the section of line 1 to be compensated, in series with a structure 15 comprising a short-circuited length of line 16 half as long as, and with the same characteristic impedance as the section of line to be compensated, in tandem with a device 17, similar to the device 5 of Fig. 2, which will effectively change the positive impedance of line 16 to a negative impedance of equal value, and in tandem with the combination a device 18, similar to the device 17, which will effectively change the positive impedance of the combination to a negative impedance of equal value.

The section of artificial line 14 in Fig. 7 has been represented by its equivalent T network comprising two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{2}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \Gamma}.$$

The section of artificial line 16 of Fig. 7 has been represented by its equivalent T network having two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm if impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}.$$

In Fig. 8 is shown a transmission system similar to that of Fig. 5, but in which the distortion correcting networks are of the π type instead of the T type. To show the manner in which the π type networks are designed to compensate for distortion in phase and amplitude in waves of all transmitted frequencies produced by the line, the sections of line to be compensated, S_1, S_2, S_3 . . ., have been represented in the figure by their equivalent π networks each having a series arm if impedance $Z_l \sinh \Gamma$ and two shunt arms each of impedance

$$Z_l \coth \frac{\Gamma}{2}.$$

It is apparent, therefore, that if the structure Z_5 in the series arm of each π correcting network has an impedance of $-Z_l \sinh \Gamma$, and the structure Z_6 in each shunt arm of the π structure has an impedance of

$$-Z_l \coth \frac{\Gamma}{2},$$

the series and shunt impedances of one section of line will be effectively canceled by each π network and the overall phase and amplitude distortion in the system may be made zero.

The shunt impedance structure Z_6 will have an impedance of

$$-Z_l \coth \frac{\Gamma}{2}$$

if the structure of Fig. 9 is connected in series with its terminals. The structure of Fig. 9 comprises an open-circuited section of smooth line 19 half as long as, and with the same characteristic impedance as, the section of line 1 to be compensated, and in tandem therewith a device 20, similar to the device 5 of Fig. 2, which will effectively change the positive impedance of line 19 to a negative impedance of equal value. The open-circuited length of line 20 in Fig. 9 has been represented by its equivalent T network having two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}.$$

The impedance Z_5 in the series arm of each π network in the system of Fig. 8 will have an impedance of $-Z_l \sinh \Gamma$ if elements such as shown in the structure of Fig. 10 are connected in series between its terminals. The structure of Fig. 10 comprises a parallel combination of a section of short-circuited line 21 of the same length as, and with the same characteristic impedance as the section of line 1 to be compensated, and a section of open-circuited line 22 half as long as, and with the same characteristic impedance as the section of line 1 to be compensated in tandem with a device 23 which will change the positive impedance of line 22 to a negative impedance of equal value, and in tandem with the parallel combination a device 24, similar to device 23, which will change the positive impedance of the combination to a negative impedance of equal value.

The short-circuited length of line 22 has been represented in Fig. 10 by its equivalent π network comprising a series arm of impedance $Z_l \sinh \Gamma$ and two shunt arms each of impedance

$$Z_l \coth \frac{\Gamma}{2},$$

and the open-circuited line 22 by its equivalent T network comprising two series arms each of impedance

$$Z_l \tanh \frac{\Gamma}{4}$$

and a shunt arm of impedance

$$\frac{Z_l}{\sinh \frac{\Gamma}{2}}.$$

A simulating network, such as shown in Fig. 11, may be used in place of one or more of the sections of smooth line in the structures of Figs. 2, 3, 6, 7, 9 and 10 to obtain an approximation of the results, as regards phase and amplitude distortion correction, obtainable with these structures when the sections of smooth line are employed therein. The simulating network of Fig. 11 is a T structure having two series arms each comprising a resistance of value

$$\frac{R}{2}$$

in series with an inductance of

$$\frac{L}{2},$$

and a shunt arm comprising a parallel combination of a resistance of value

$$\frac{1}{G}$$

and a capacity of value C, where R is the resistance, L the inductances, G the leakance, and C the capacity of the section of line 1 to be compensated.

It should be noted that each impedance element in the structures of the invention which have been illustrated and described contributes both to attenuation distortion correction and phase distortion correction this being an important distinguishing feature from the structures of the prior art in which attenuation distortion correction or phase distortion correction is the sole function of separate elements therein.

Although the invention as described has been principally directed to the obtaining of complete compensation for attenuation and phase distortion, it is apparent that it may be utilized also for obtaining any desired degree of attenuation and phase distortion correction.

Although the invention has been described in connection with a particular transmission system comprising a plurality of uniform smooth sections of line and a plurality of distortion correcting networks spaced at equal intervals along the transmission line, the invention is not so limited but is applicable also to a transmission system comprising a smooth or a loaded line in combination with a single distortion correcting network or a plurality of such networks inserted at unequal intervals along the line, or any other combination within the scope of the appended claims.

What is claimed is:

1. In combination in a wave transmission system, a transmission line, and means for substantially neutralizing phase and amplitude distortion in waves of all frequencies transmitted thereover, said means comprising a complex electrical structure comprising a plurality of impedance arms inserted in said line in the path of said waves, and having propagation and impedance characteristics substantially complemental to those of said line, each of said impedance arms comprising a section of smooth line in tandem with a device which will change its positive impedance to a negative impedance of equal value.

2. A combination in accordance with claim 1 and in which said impedance arms of said complex electrical structure comprise an impedance arm effectively in series with said transmission line and an impedance arm effectively in shunt with said transmission line.

3. In combination in a wave transmission system, a transmission line, and means for completely neutralizing amplitude and phase distortion in waves of all frequencies transmitted thereover, said means comprising an electrical structure inserted in said line in the path of said waves, and having a plurality of impedance arms, said structure having propagation characteristics which at all frequencies are effectively the negative of the propagation characteristics of said transmission line, at least one of said impedance arms

including an open circuited smooth line half the length of said transmission line and having the same characteristic impedance as said transmission line before the insertion of said structure therein.

4. In combination in a wave transmission system, a transmission line, and means for completely neutralizing amplitude and phase distortion in waves of all frequencies transmitted thereover, said means comprising an electrical structure inserted in said line in the path of said waves, and having a plurality of impedance arms, said structure having a propagation characteristic which is the negative of that of said line, and a characteristic impedance equal to that of said line, at least one of said impedance arms including an open circuited line half the length of said transmission line and having the same characteristic impedance as said transmission line before the insertion of said structure therein, and in tandem therewith a device which will change the positive impedance of said open circuited line to a negative impedance of equal value.

5. In combination in a wave transmission system, a transmission line, and means for neutralizing amplitude and phase distortion in waves of all frequencies transmitted thereover, said means comprising an electrical structure inserted in said line in the path of said waves, and having a plurality of impedance arms, said structure having propagation characteristics which are at all frequencies effectively the negative of those of said transmission line, at least one of said impedance arms including a short circuited smooth line half the length of said transmission line and having the same characteristic impedance as said transmission line before insertion of said structure therein.

6. In combination in a wave transmission system, a transmission line, and means for neutralizing amplitude and phase distortion in waves of all frequencies transmitted thereover, said means comprising an electrical structure inserted in said line in the path of said waves, and having a plurality of impedance arms, said structure having at all frequencies propagation characteristics which are effectively the negative of those of said transmission line, at least one of said impedance arms including a short circuited smooth line half the length of said transmission line and having the same characteristic impedance as said transmission line before the insertion of said structure therein, and in tandem therewith a device which will change the positive impedance of said short circuited line to a negative impedance of equal value.

7. In combination with a wave transmission system, a transmission line, and means for substantially neutralizing amplitude and phase distortion in electrical waves of all frequencies transmitted thereover, said means comprising a lattice type structure inserted in said line and having impedance characteristics complemental to those of said line.

8. In combination, a line for transmitting electrical waves of different frequencies, and means associated therewith for compensating for phase and amplitude distortion in transmitted waves of all frequencies, said means comprising a bridge network of the lattice type inserted in said line in the path of said waves, and comprising two series impedance arms and two lattice impedance arms, each of said series arms having a characteristic impedance

$$-Z_l \tanh \frac{\Gamma}{2},$$

and each of said lattice arms having a characteristic impedance

$$-Z_l \coth \frac{\Gamma}{2},$$

where Z_l is the characteristic impedance and Γ the propagation constant for said transmission line before the insertion of said compensating means therein.

9. In combination in a wave transmission system, a transmission line for transmitting electrical waves of different frequencies and a bridge network of the lattice type inserted in said line in the path of said waves and serving to completely correct phase and amplitude distortion produced by said line on waves of all frequencies transmitted thereover, said network comprising two series arms and two lattice arms, each of said series arms comprising a short circuited smooth line half the length of said transmission line and having the same characteristic impedance as said transmission line without said bridge network and in tandem therewith a device which will change the positive impedance of said short circuited line to a negative impedance of equal value, and each of said lattice arms comprising an open circuited line half the length of said transmission line and having the same characteristic impedance as said transmission line without said bridge network and in tandem therewith a device which will effectively change the positive impedance of said open circuited line to a negative impedance of equal value.

10. In combination, a line for transmitting waves of a plurality of frequencies and means for compensating for the phase and amplitude distortion produced by said line on transmitted waves of all frequencies, said means comprising a bridge network of the lattice type inserted in said line in the path of said waves, said network comprising two arms of equal impedance in series with said line and two arms of equal impedance in lattice relation thereto, a series transformer, a

lattice transformer, a circuit comprising an impedance substantially equal to

$$-Z_l \tanh \frac{\Gamma}{2}$$

and an inductance substantially equal to M_1 in series therewith, connected effectively in series with each of said series arms by said series transformer, and a second circuit comprising an impedance substantially equal to

$$-Z_l \coth \frac{\Gamma}{2}$$

and an inductance of value M_2 in series therewith, connected effectively in series with each of said lattice arms by said lattice transformer, where Z_l is the characteristic impedance and Γ the propagation constant for said line before the insertion of said compensating means therein, M_1 is the mutual impedance of said series transformer and M_2 is the mutual impedance of said lattice transformer.

11. The combination of claim 10 and in which said impedance substantially equal to

$$-Z_l \tanh \frac{\Gamma}{2}$$

comprises a short circuited section of smooth line half the length of, and with the same characteristic impedance as said transmission line to be compensated without said bridge network and in tandem therewith a device which will effectively change a positive impedance of said short circuited section of line to a negative impedance of equal value.

12. The combination of claim 10 and in which said impedance substantially equal to

$$-Z_l \coth \frac{\Gamma}{2}$$

comprises an open circuited section of smooth line half the length of, and with the same characteristic impedance as said transmission line to be compensated without said bridge network, and in tandem with a device which will effectively change the positive impedance of said open circuited section of line to a negative impedance of equal value.

13. An electrical network comprising a plurality of impedance elements, a single negative impedance device, and means for coupling said single negative impedance device simultaneously with two or more of said impedance elements so as to produce between the terminals of each of the coupled impedance elements what is effectively a negative impedance.

14. An electrical network comprising a number of impedance elements at least two of which have substantially equivalent impedance characteristics, and a single negative impedance device simultaneously coupled to and cooperating with said equivalent impedance elements to produce between the terminals of each what is effectively the same negative impedance.

15. In combination, two signal line sections, a network coupling said sections for signal transmission therebetween and compensating for signal distorting characteristics of said line sections, said network comprising at least two similar impedance arms, a single negative impedance device, and means for coupling said negative impedance element to each of said similar arms.

In witness whereof, I hereunto subscribe my name this 18th day of September, 1928.

WARREN P. MASON.