Feb. 16, 1937.

W. R. LUNDRY

2,070,668

WAVE TRANSMISSION NETWORK

Filed Oct. 4, 1935

FIG. 1

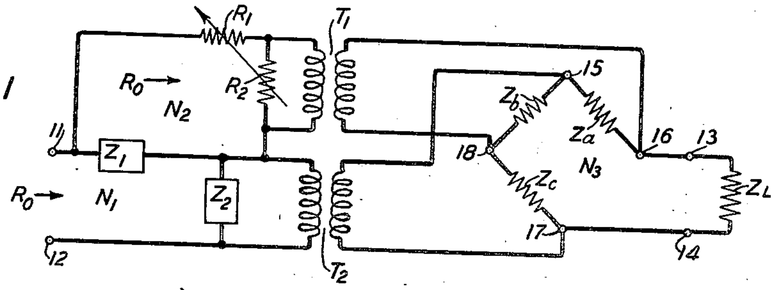


FIG. 3

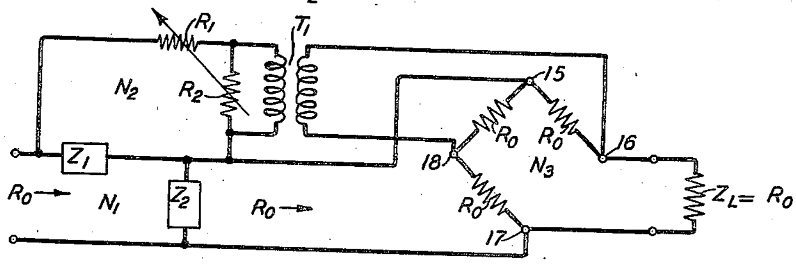


FIG. 4

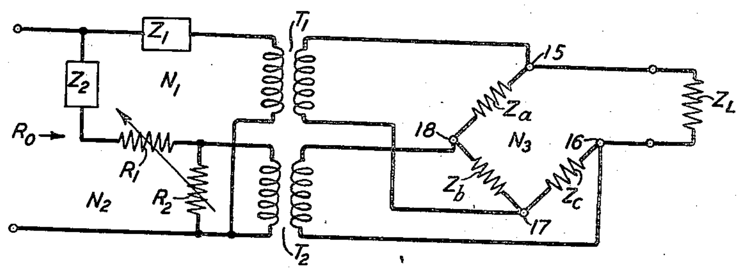


FIG. 5

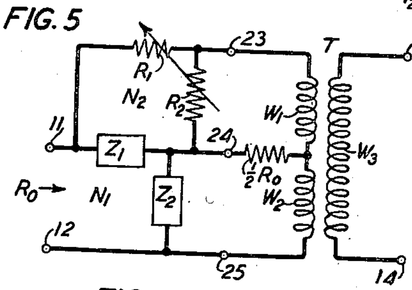


FIG. 2

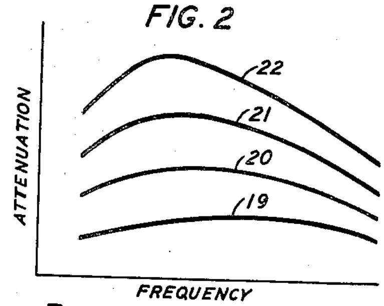


FIG. 6

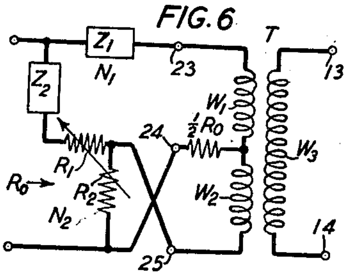
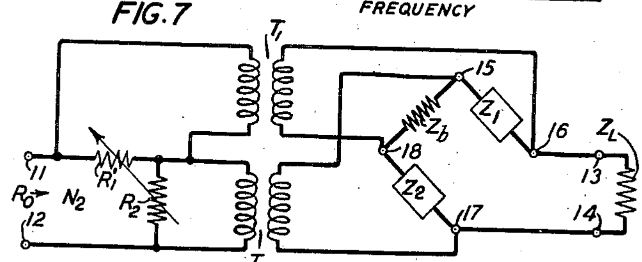


FIG. 7



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WAVE TRANSMISSION NETWORK

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11 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to variable equalizers.

The object of the invention is to equalize the attenuation distortion in a wave transmission system.

A feature of the invention is a variable equalizer having a plurality of impedance branches in which the output voltage of the equalizer and a variable portion of a voltage derived from one of its branches are impressed upon conjugate points of an auxiliary network, the attenuation characteristic of the equalizer being varied by adjusting the relative amplitudes of these two voltages.

In wave transmission systems there is often required a variable equalizer which for one setting will have a certain attenuation-frequency characteristic and for any other setting will have a characteristic the attenuation of which at every frequency bears the same ratio to the original characteristic. Such an equalizer is useful, for example, in compensating for changes of attenuation with temperature in carrier telephone systems.

In accordance with the invention there is provided a variable wave transmission network which will meet the above requirements and yet is comparatively simple in design and construction. The network comprises three partial networks, namely, an equalizer having a plurality of impedance branches, a variable attenuator, and an auxiliary network having two pairs of conjugate terminals. The output voltage of the equalizer is impressed upon one of the pairs of conjugate terminals and a voltage derived from one of the component impedance branches of the equalizer is impressed upon the other pair. The variable attenuator is connected into the circuit in such a way that it is effective in controlling the relative amplitudes of the two voltages just mentioned. By virtue of the conjugate relationship existing between the two sets of terminals, the two voltages may be combined in the auxiliary network in any desired proportions without causing any undesirable reaction in the circuits from which these voltages are derived.

The attenuation characteristic of the network as a whole depends upon the characteristic of the equalizer portion and the setting of the attenuator. As the attenuator is varied there is obtained a family of attenuation curves the ordinates of any one of which at every frequency will be a fixed percentage of the ordinates of any other curve. For example, a certain curve may be obtained for a particular setting, and for another setting a curve which has ordinates twice, or half, as large at every frequency as those of the first curve.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing of which:

Fig. 1 is a schematic diagram showing one form of the variable wave transmission network of the invention in which one of the combining voltages is derived from a series impedance branch;

Fig. 2 shows typical attenuation characteristics obtainable with the network of Fig. 1;

Fig. 3 is a modified form of the network of Fig. 1 in which one of the transformers has been eliminated;

Fig. 4 shows an alternative form for the network of Fig. 1 in which one of the combining voltages is derived from a shunt impedance branch;

Fig. 5 is a schematic diagram of another embodiment of the invention employing a hybrid coil for the auxiliary network;

Fig. 6 is an alternative form for the network shown in Fig. 5; and,

Fig. 7 represents schematically another modified form of the invention.

Referring to the drawing, Fig. 1 shows in schematic form one embodiment of the variable wave transmission network of the invention having a pair of input terminals **11**, **12** and a pair of output terminals **13**, **14**. The impedance Z_L connected to terminals **13** and **14** represents the load impedance into which the network operates. The network comprises as partial networks the equalizer N_1, the variable attenuator N_2 and the auxiliary network N_3. The equalizer N_1 is of the series-shunt type consisting of the impedance branch Z_1 connected in series with the line and an impedance Z_2 connected in shunt with the line. These two impedances have the relationship

$$Z_1Z_2=R_0^2 \qquad (1)$$

where R_0 is the impedance at the input terminals **11**, **12** of the equalizer. The impedances Z_1 and Z_2 may be designed in a well-known manner to give any desired attenuation-frequency characteristic. For a more detailed discussion of the design of these impedance branches, reference is made to chapter 18 of K. S. Johnson's Transmission Circuits for Telephonic Communication published by D. Van Nostrand Company.

In a ladder type equalizer such as N_1 of Fig.

1 in which the first branch is connected in series with the line it is customary to shunt the series impedance Z_1 by a resistance equal to R_0. In accordance with the present invention there is substituted for this resistance just mentioned the variable attenuator N_2 having a series resistance R_1 and a shunt resistance R_2 so designed that its input impedance is equal to R_0 for any setting. Under these conditions the resistances R_1 and R_2 will have the relationship

$$R_1=\frac{R_0^2}{R_0+R_2} \quad (2)$$

The resistances R_1 and R_2 may be varied by means of a unitary control if desired. The output of this variable attenuator N_2 is connected to the primary winding of the transformer T_1 and the output of the equalizer N_1 is connected to the primary winding of the transformer T_2.

In accordance with the invention, the output voltage of the equalizer N_1 and a voltage derived from one of its component impedance branches are impressed upon conjugate points of an auxiliary network. As shown in Fig. 1 this auxiliary network N_3 consists of four impedances Z_a, Z_b, Z_c, and Z_L connected in series to form a bridge. When these four impedances have the relationship

$$\frac{Z_a}{Z_b}=\frac{Z_L}{Z_c} \quad (3)$$

the bridge will have two pairs of terminals, namely, **15**, **17** and **16**, **18** which have a conjugate relationship with respect to each other. By conjugate relationship is meant that an electromotive force impressed upon one pair of terminals will cause no current to flow in the circuit connected to the other set of terminals, and vice versa. The secondary winding of the transformer T_1 is connected to terminals **16** and **18**, and the secondary winding of the transformer T_2 is connected to the terminals **15** and **17** of the bridge network N_3. Because of the conjugate relationship just pointed out, the output voltage of the equalizer N_1 and an adjustable portion of the voltage drop across the impedance branch Z_1 can, in this way, be combined in varying proportions in the load impedance Z_L without the danger of any interaction between the circuits supplying these voltages. The impedance ratios between the primary and secondary windings of the transformers T_1 and T_2 may be given any desired values and thus any desired impedance ratio between the input terminals **11**, **12** and the output terminals **13**, **14** of the network may be provided.

The equalizer N_1 may, for example, be designed to give the attenuation characteristic shown by curve **19** of Fig. 2 when the variable attenuator is set for a small attenuation. Then by increasing the attenuation introduced by the attenuator other characteristics, such as those shown by curves **20**, **21**, and **22** of Fig. 2, may be provided. The number of different characteristics which may be obtained from the equalizer depends only upon the number of different settings provided for the variable attenuator. If the attenuation introduced by the attenuator can be varied continuously, an infinite number of characteristics may be obtained from the network. It will be noted, however, that the attenuation of any one of these curves as shown by Fig. 2 when compared to any of the other curves has the same proportion at every frequency. There is thus provided a family of curves of the same type, any one of which may be selected by the proper adjustment of the variable attenuator.

Fig. 3 shows a modification of the network of Fig. 1 in which the transformer T_2 has been eliminated. In order that this may be done, the impedance of the bridge at the terminals **15** and **17** must be made equal to R_0 so that the network N_1 may work directly into the bridge circuit. This can be conveniently accomplished by making each impedance arm of the bridge equal in magnitude to R_0. Under these circumstances the transformer T_1 will have an impedance ratio of 1 to 1 and the load impedance Z_L should be made equal to R_0.

Fig. 4 shows what may be termed the inverse circuit of Fig. 1. In Fig. 4 the impedance branches Z_1 and Z_2 are the same as those shown in Fig. 1 but the first impedance encountered is a shunt branch followed by the series branch Z_1, and the attenuator N_2 is connected in the shunt branch in series with the impedance Z_2 instead of being connected in parallel with the series impedance branch Z_1. The output voltage of the equalizer N_1 is impressed upon the primary of the transformer T_1 and the output voltage of the attenuator N_2 is impressed upon the primary of the transformer T_2. The portion of the circuit appearing to the right of the transformers in Fig. 4 is the same as that shown in Fig. 1. The network shown in Fig. 4 may be designed to provide the same attenuation characteristics as the network of Fig. 1, but in this case an increase of the attenuation introduced by the variable attenuator will lower, instead of raise, the curves.

In the circuits shown in Figs. 1, 3, and 4 the minimum flat loss introduced by the network is of the order of 6 decibels. This flat loss is caused mainly by the bridge circuit N_3. In the variable equalizer shown schematically in Fig. 5 this flat loss is reduced to approximately 3 decibels by the substitution of the hybrid transformer T for the bridge network N_3. The transformer T has a divided primary consisting of the two equal windings W_1 and W_2 and a secondary winding W_3. An impedance transformation for the network may be provided by making the impedance ratio between the primary and secondary windings of the transformer other than unity. A resistance equal to one-half R_0 is connected between the junction points of the primary windings of the transformer and the terminal **24**. The two pairs of conjugate terminals in the hybrid transformer T are **23**, **24**, and **25**, **24**. The equalizer network N_1 and the attenuator N_2 of Fig. 5 are identical with the same partial networks shown in Fig. 1. In Fig. 5 the output of the equalizer N_1 is connected directly to terminals **24** and **25** of the hybrid transformer T, and the output of the attenuator N_2 is connected directly to terminals **23** and **24**. The load impedance is connected to the output terminals **13** and **14**. The same variety of attenuation characteristics may be obtained from the equalizer shown in Fig. 5 as from the one shown in Fig. 1 except that, as pointed out above, the flat loss is reduced from 6 decibels to 3 decibels.

The variable equalizer shown schematically in Fig. 6 is an alternative structure for the one shown in Fig. 5. In Fig. 6 the attenuator N_2 is connected in series with the shunt impedance Z_2 instead of in parallel with the series branch Z_1. The output of the equalizer N_1 is connected to terminals **23** and **24** of the hybrid transformer

T, and the output of the attenuator N_2 is connected to terminals **24** and **25**.

Fig. 7 shows schematically a modification of the network of the invention in which the flat loss may be reduced to zero. In this circuit the impedance branches Z_1 and Z_2 are substituted for the two opposite impedances Z_a and Z_c of the bridge network N_3. The variable attenuator N_2 has a resistance R_1' connected in series with the line and a resistance R_2 connected in shunt with the line. Both of these resistances are made variable and for every setting of the attenuator will have the relationship

$$R_1'R_2=R_0^2 \qquad (4)$$

where R_0 is the impedance at the input terminals **11** and **12** of the network. If it is not required that the input impedance R_0 be kept a constant value at all frequencies, the shunt resistance R_2 may be omitted. As shown in Fig. 7 the output of the attenuator N_2 is connected to the primary winding of the transformer T_2 and the primary winding of the transformer T_1 is connected in parallel with the resistance R_1'. The secondary of the transformer T_1 is connected to terminals **16** and **18**, and the secondary of the transformer T_2 is connected to the terminals **15** and **17**. These two pairs of terminals have the conjugate relationship with respect to each other discussed above in connection with Fig. 1.

The same variety of attenuation characteristics may be obtained with the network shown in Fig. 7 as with the other networks heretofore discussed but, as already pointed out, the flat loss is eliminated. If the transformers T_1 and T_2 both are of unity ratio, the network will have a constant attenuation when the attenuator is set at 6 decibels. Portions of the characteristics which are concave downward for settings of less than 6 decibels will be concave upward when this setting is exceeded and, conversely, portions which are concave upward will be changed to concave downward. One of the two transformers may be eliminated by making the impedance at one pair of the terminals of the bridge network equal to R_0 as explained above in connection with Fig. 3. When this is done, however, no impedance transformation can be provided in the network as a whole between its input terminals and its output terminals.

What is claimed is:

1. A variable equalizer comprising a network having an impedance branch in series with the line and an impedance branch in shunt with the line, a second network having two pairs of terminals which bear a conjugate relationship with respect to each other, means for impressing the output voltage of said first network upon one of said pairs of terminals, means for impressing a voltage derived from one of said impedance branches upon the other pair of said terminals, and means for adjusting the relative amplitudes of said two voltages, the transmission loss of said equalizer being related to the loss introduced by one of said component networks by a factor substantially independent of frequency but dependent upon the relative amplitudes of said two voltages.

2. A variable equalizer comprising a plurality of impedance branches, a network having two pairs of conjugate terminals, means for impressing the output voltage of the equalizer upon one pair of said terminals, means for impressing a voltage derived from one of said impedance branches upon the other pair of said terminals, and variable means for attenuating one of said voltages, the transmission loss of said equalizer being related to the loss introduced by said impedance branches by a factor substantially independent of frequency but dependent upon the setting of said variable attenuating means.

3. In combination, an equalizer having an impedance branch in series with the line and a second impedance branch in shunt with the line, a network having two pairs of conjugate terminals, means for impressing the output voltage of said equalizer upon one pair of said terminals, means for impressing a voltage derived from one of said impedance branches upon the other pair of said terminals, and a variable attenuator connected in circuit between said one impedance branch and said other pair of terminals, the transmission loss of the entire structure being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the setting of said variable attenuator.

4. A wave transmission network comprising an equalizer having an impedance branch in series with the line and an impedance branch in shunt with the line, a network having two pairs of conjugate terminals, means for impressing the output voltage of said equalizer upon one pair of said terminals, means for impressing a portion of the voltage derived from one of said impedance branches upon the other pair of said terminals, and means for varying the relative amplitudes of said two voltages, the transmission loss of said wave transmission network being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the relative amplitudes of said two voltages.

5. A wave transmission network comprising an equalizer having a plurality of impedance branches, a bridge circuit having two pairs of conjugate terminals, means for impressing the output voltage of said equalizer upon one pair of said terminals, means for impressing a voltage derived from one of said impedance branches upon the other pair of said terminals, and variable means for attenuating one of said voltages, the transmission loss of said wave transmission network being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the setting of said variable attenuating means.

6. A wave transmission network comprising an equalizer having a plurality of impedance branches, a transformer having two primary windings, means for impressing the output voltage of said equalizer upon one of said windings, means for impressing a voltage derived from one of said impedance branches upon the other of said windings, and variable means for attenuating one of said voltages, the transmission loss of said wave transmission network being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the setting of said variable attenuating means.

7. A variable equalizer comprising an attenuator having a plurality of variable impedance branches, a bridge network having two pairs of terminals and two reactive impedance branches, means for impressing the output voltage of said attenuator upon one pair of said terminals, and means for impressing a voltage derived from one of the impedance branches of said attenuator upon the other pair of said terminals, the trans-

mission loss of said equalizer being related to the loss introduced by said two reactive impedance branches by a factor substantially independent of frequency but dependent upon the setting of said attenuator.

8. A variable equalizer comprising one reactive impedance branch in shunt with the line and a second reactive impedance branch in series with the line, a network having two pairs of conjugate terminals, means for impressing the voltage across said one branch upon one of said pairs of terminals, means for impressing the voltage across said second branch upon the other pair of said terminals, and variable means for attenuating said last-mentioned voltage, the transmission loss of said equalizer being related to the loss introduced by said impedance branches by a factor substantially independent of frequency but dependent upon the setting of said variable attenuating means.

9. In combination a variable attenuator, an equalizer having a reactive impedance branch in series with the line and an impedance branch in shunt with the line, said shunt branch comprising a second reactive impedance connected in series with the input of said attenuator, a network having two pairs of conjugate terminals, means for impressing the output voltage of said equalizer upon one pair of said terminals, and means for impressing the output voltage of said attenuator upon the other pair of said terminals, the transmission loss of the entire structure being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the setting of said variable attenuator.

10. A variable equalizer comprising a network having an impedance branch in series with the line and an impedance branch in shunt with the line, a second network having two pairs of terminals which are conjugate with respect to each other, means for impressing the output voltage of said first network upon one of said pairs of terminals, a transformer having its secondary connected to the other pair of said terminals, and a variable attenuator having its input connected to two points in one of said impedance branches and its output connected to the primary of said transformer, the transmission loss of said equalizer being related to the loss introduced by said first mentioned network by a factor substantially independent of frequency but dependent upon the setting of said variable attenuator.

11. A variable wave transmission network comprising an equalizer having an impedance branch in series with the line and an impedance branch in shunt with the line, a bridge consisting of four impedances connected in series and having two pairs of terminals which bear a conjugate relationship with respect to each other, one of said four impedances being the load into which said network works, means for impressing the output voltage of said equalizer upon one pair of said terminals, means for impressing a voltage derived from one of the branches of said equalizer upon the other pair of said terminals, and variable means for attenuating said last-mentioned voltage, the transmission loss of said wave transmission network being related to the loss introduced by said equalizer by a factor substantially independent of frequency but dependent upon the setting of said variable attenuating means.

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