WAVE TRANSMISSION NETWORK

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FIG. 1

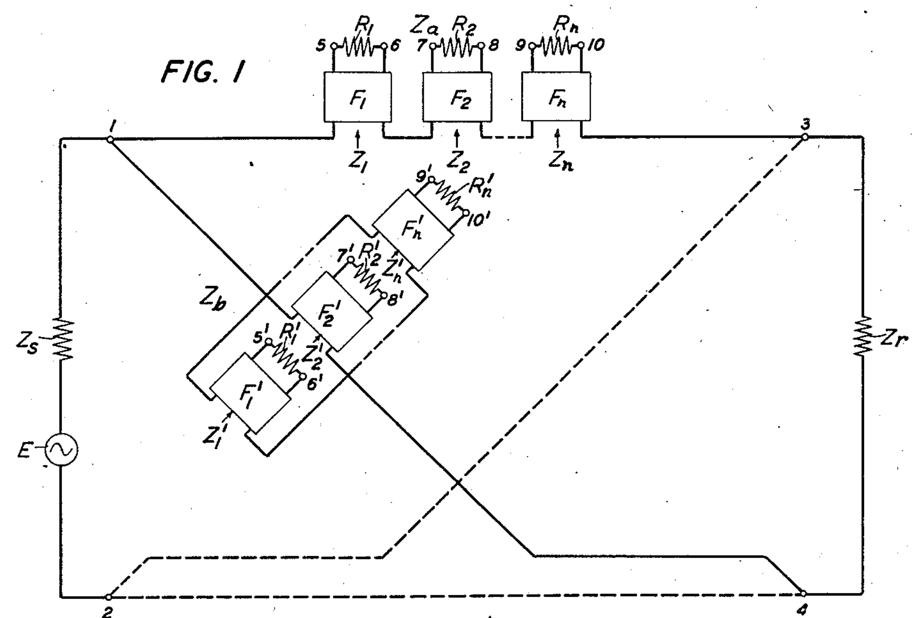

FIG. 2

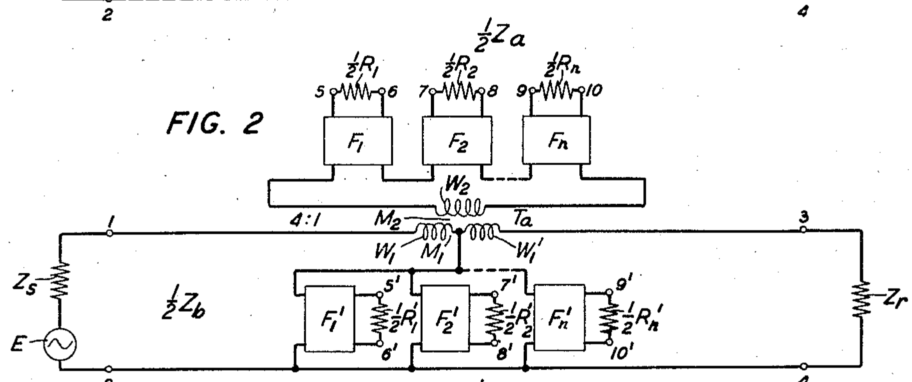

FIG. 3

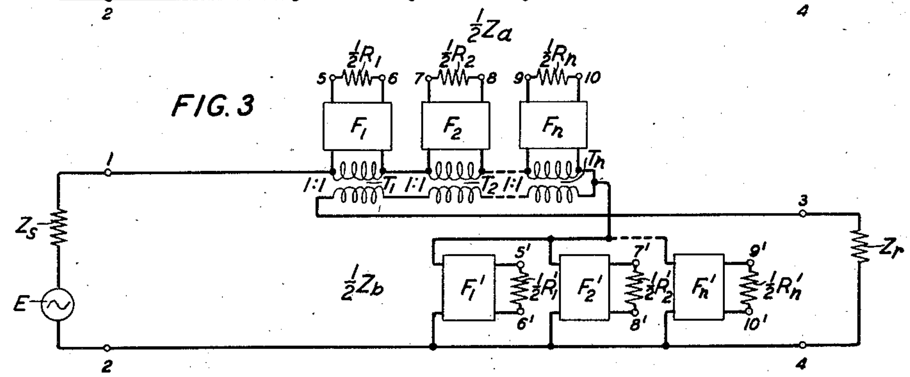

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FIG. 4

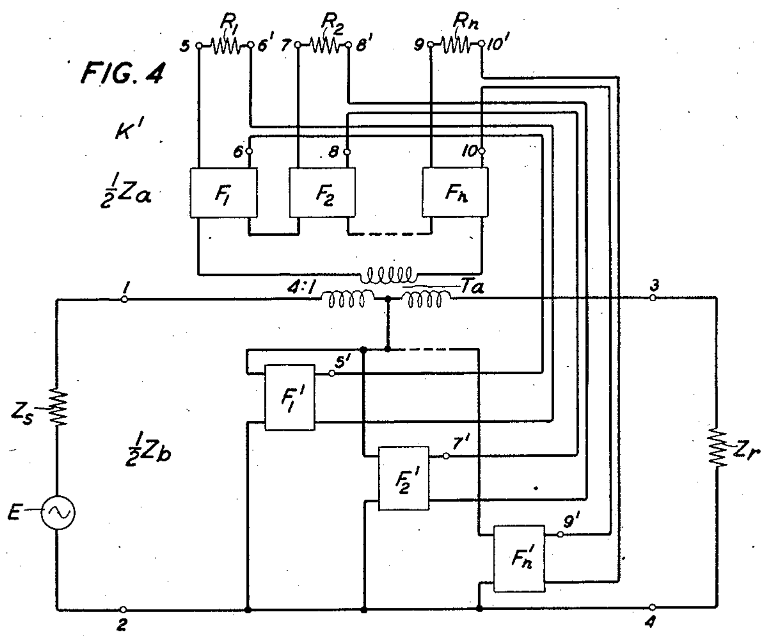

FIG. 5

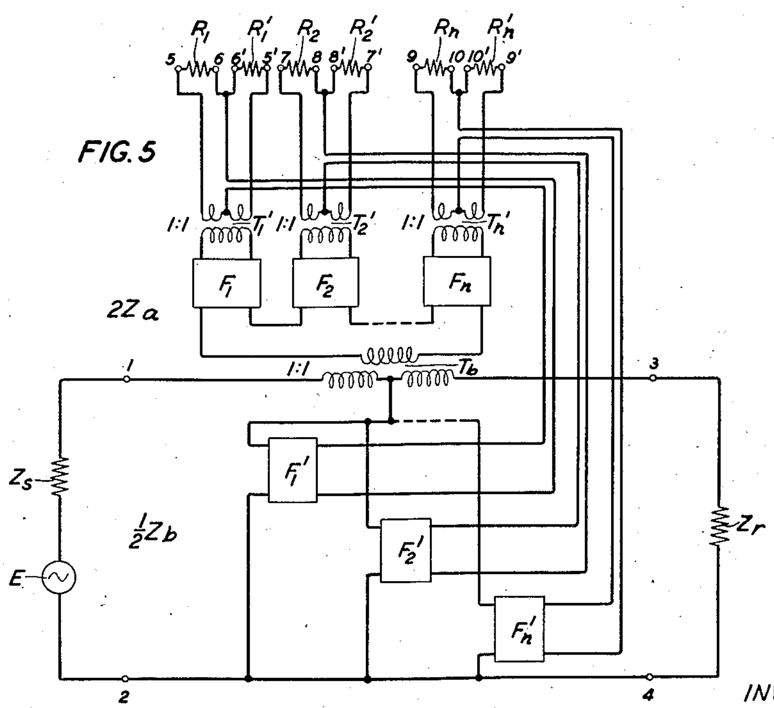

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FIG. 6

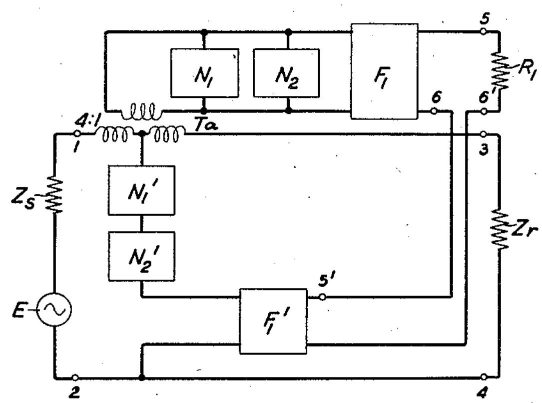

FIG. 8

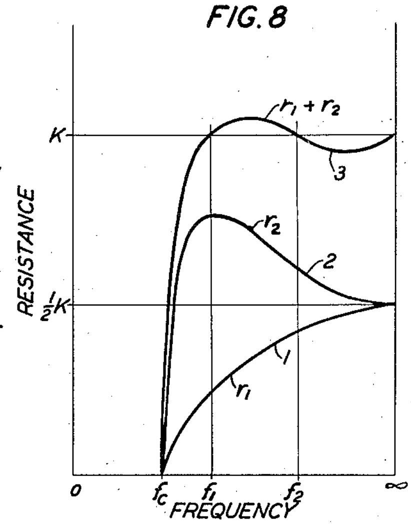

FIG. 7

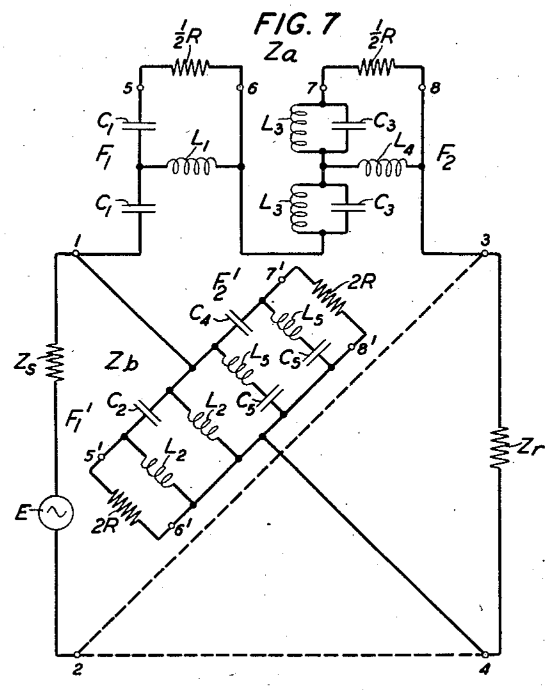

FIG. 9

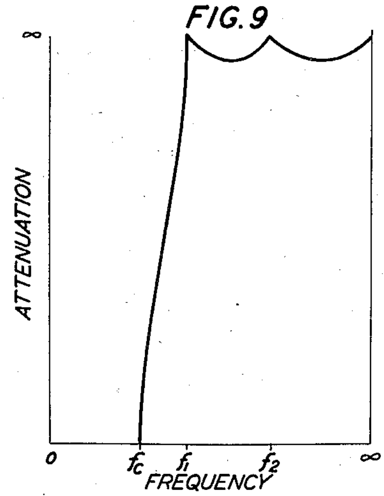

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FIG. 10

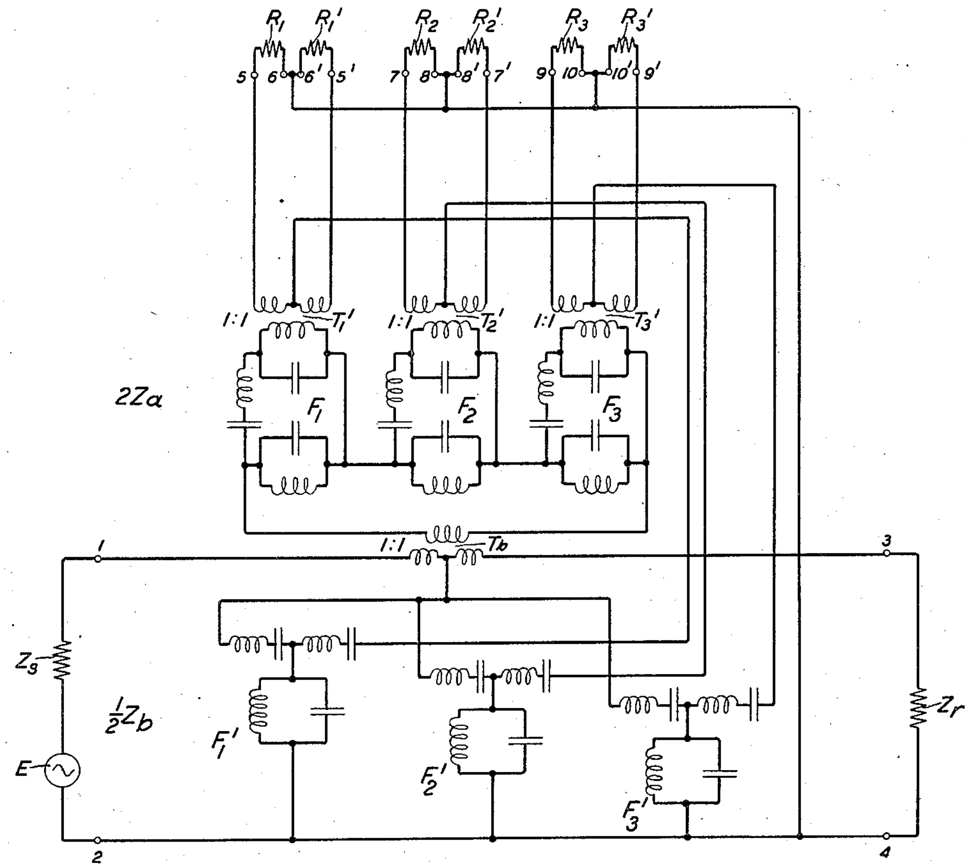

FIG. 11

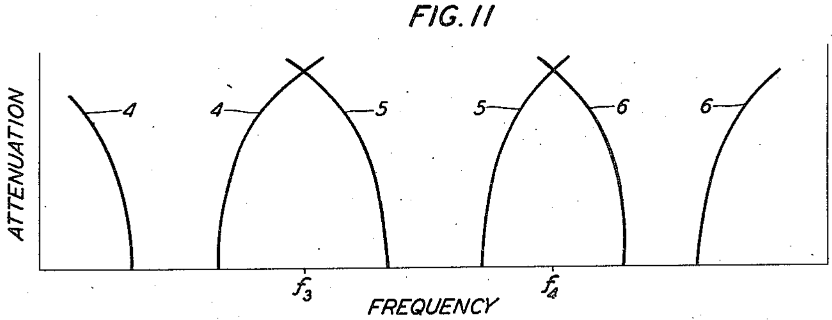

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FIG. 12

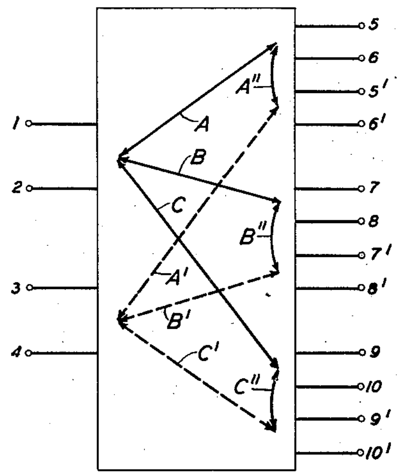

FIG. 13

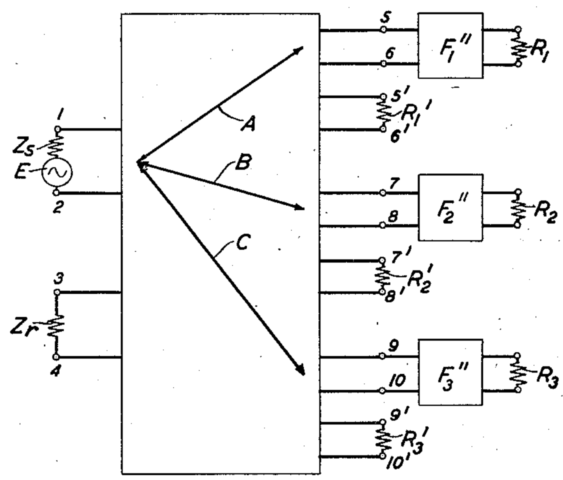

FIG. 14

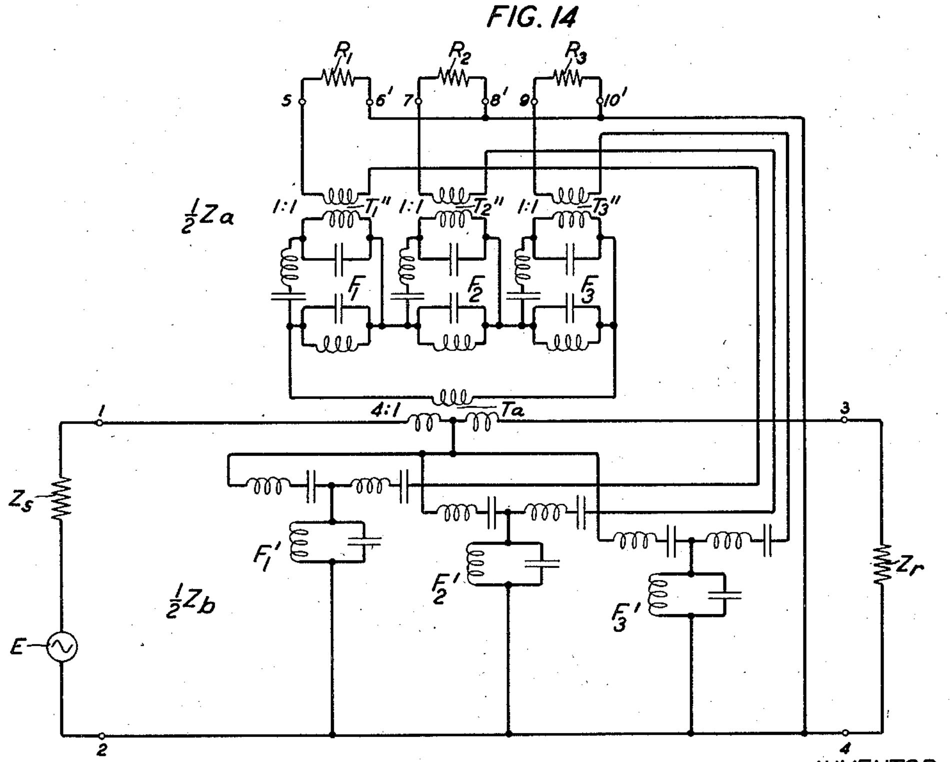

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FIG. 15

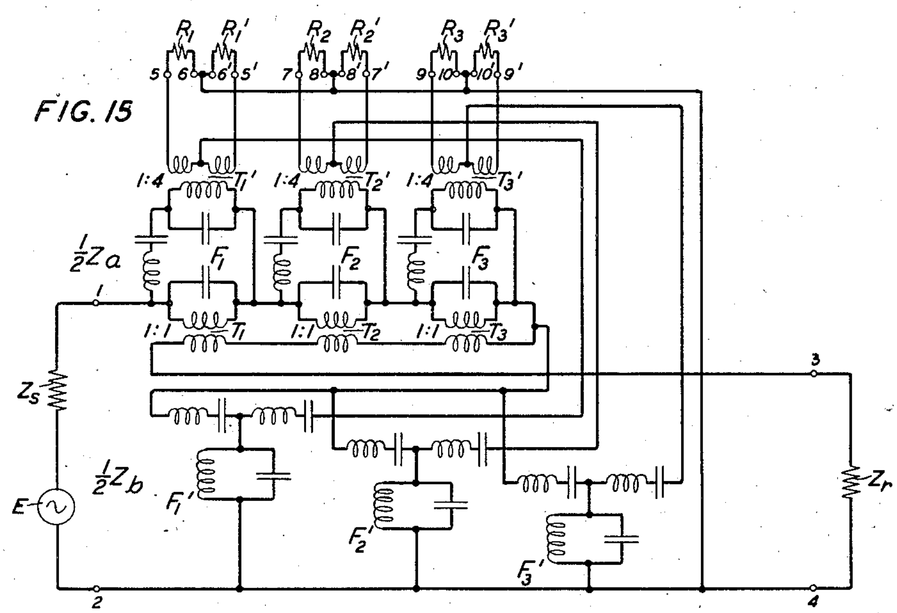

FIG. 16

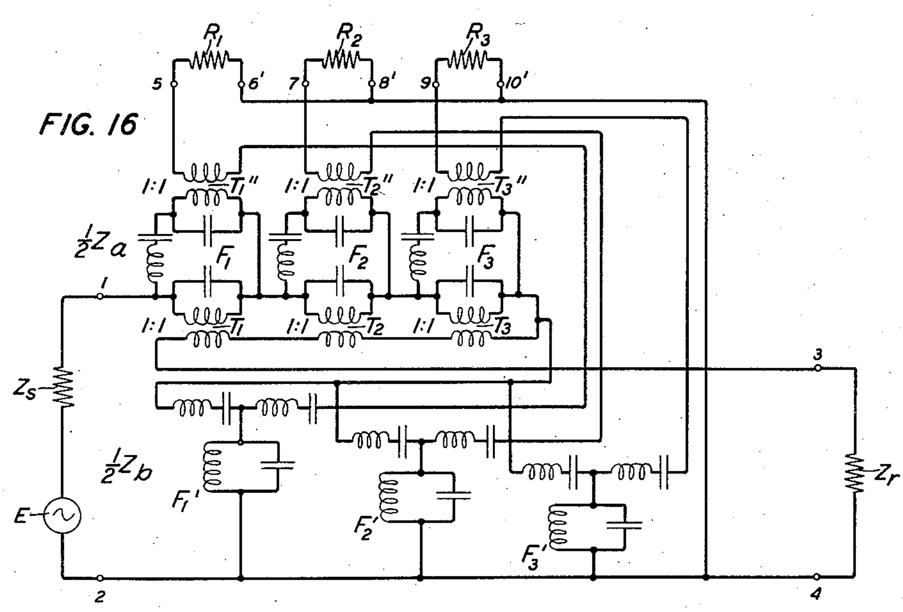

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FIG. 17

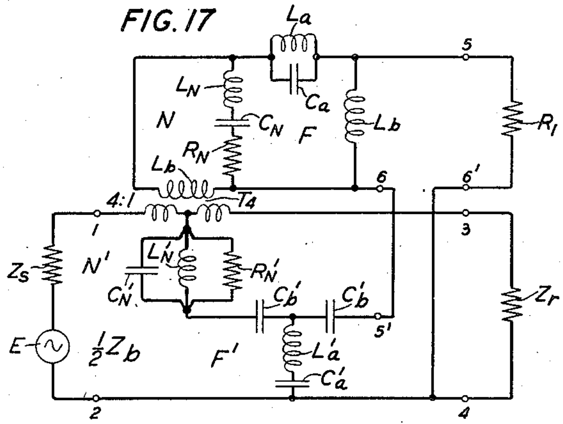

FIG. 18

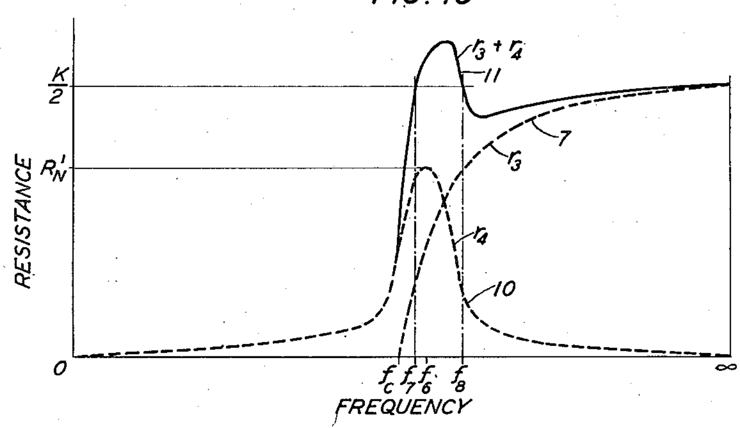

FIG. 19

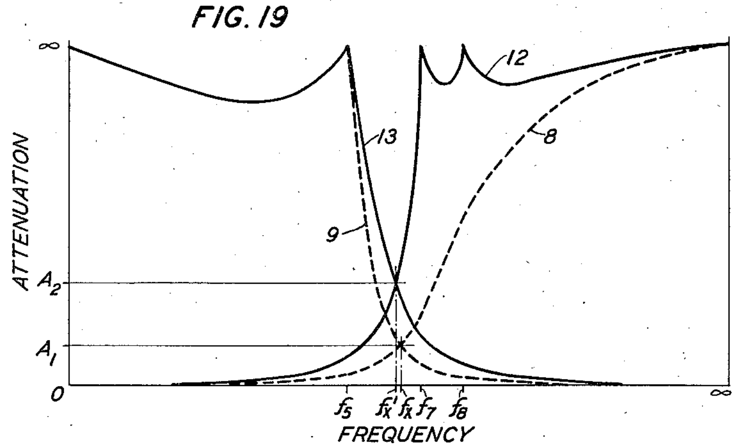

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FIG. 20

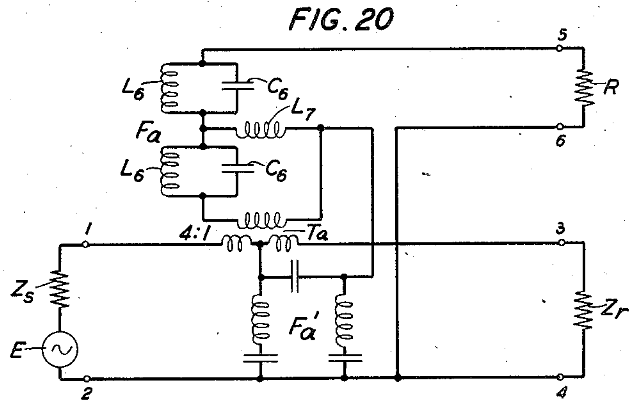


FIG. 21

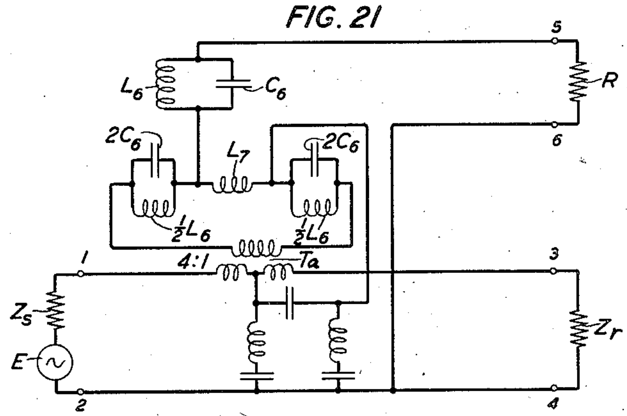
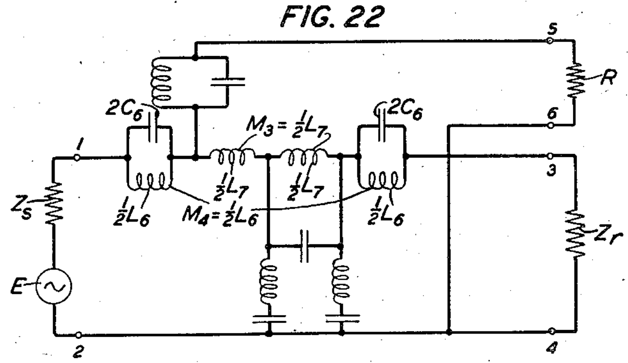


FIG. 22



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Patented June 16, 1936

2,044,047

UNITED STATES PATENT OFFICE

2,044,047

WAVE TRANSMISSION NETWORK

Stephen Bobis, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 10, 1935, Serial No. 1,140

19 Claims. (Cl. 178—44)

This invention relates to selective wave transmission networks having a constant non-reactive characteristic impedance at all frequencies, and more particularly to networks of this type which have a plurality of transmission channels.

An object of the invention is to separate signal currents into a plurality of separate frequency channels.

Another object is to reduce the reflection effects at the junction points between wave filters and their associated terminal loads.

A further object is to increase the attenuation at the cross-over points between the separate channels of a multi-channel wave filter.

A feature of the invention is a selective wave transmission network of the lattice or bridged-T type having at least two impedance branches each of which comprises a plurality of partial networks.

In carrier communication systems, the problem frequently arises of separating signal currents into a number of separate frequency bands. In order to minimize reflection effects the selective networks employed for this purpose should have a characteristic impedance which matches the connected load impedances. In systems of this type, the load impedances are usually constant resistances and, therefore, the characteristic impedance of the filters employed should also be non-reactive and constant with frequency.

In accordance with the present invention there is provided a selective wave transmission network which may have any desired number of separate transmission channels and the characteristic impedance of which at each pair of terminals is a constant pure resistance at all frequencies. The network is of the lattice or bridged-T type and comprises a pair of impedance branches which are adapted to determine the transmission characteristics of the network. Each impedance branch is made up of a plurality of partial networks which may consist of any number of component sections. These partial networks may be either two-terminal or four-terminal structures and may consist only of reactances, or may also comprise dissipative impedance branches. When the partial networks are properly chosen filters, the structure as a whole will provide a plurality of separate transmission channels having a characteristic impedance at each pair of terminals which is a constant pure resistance at all frequencies. Any desired number of channels may be obtained simply by increasing the number of partial networks.

A great variety of attenuation characteristics may be provided for the various channels and the attenuation at the cross-over points between adjacent channels may be made any desired amount. In certain cases it may be found desirable to increase the attenuation in the individual channels by adding auxiliary filters which are effective in those channels only. In a modified form of the bridged-T network no so-called ideal transformer is required. In another form of the invention it is shown how to build a filter having an attenuation characteristic which maintains a consistently high value at all frequencies outside of the transmission band.

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

Fig. 1 shows diagrammatically the network of the invention in the lattice form;

Fig. 2 is a diagrammatic representation of the network of the invention in the bridged-T form;

Fig. 3 is a modified form of the bridged-T network of Fig. 2;

Fig. 4 is a diagrammatic circuit showing how the outputs of the partial networks of Fig. 2 may be combined to provide a multi-channel selective network;

Fig. 5 shows how the network of Fig. 4 may be modified by the addition of three-winding transformers so that at each pair of terminals the characteristic impedance will be a constant pure resistance at all frequencies;

Fig. 6 is a modification of the network shown in Fig. 4 in which some of the partial networks are two-terminal instead of four-terminal structures;

Fig. 7 is a specific embodiment of the network of Fig. 1 in a low-pass filter the attenuation of which at all frequencies outside of the transmission band is maintained at a high value;

Fig. 8 represents the impedance of the partial filters in the line branch of the network of Fig. 7;

Fig. 9 shows a typical attenuation characteristic obtainable with the network of Fig. 7;

Fig. 10 is a specific embodiment of the network of Fig. 5 in a multi-channel band-pass filter;

Fig. 11 gives representative attenuation characteristics for the various channels of the network of Fig. 10;

Fig. 12 is a diagrammatic representation of the transmission channels obtainable in the network of Fig. 10;

Fig. 13 shows diagrammatically how the attenuation of the individual channels may be increased by the addition of auxiliary filters effective only in the individual channels;

Fig. 14 shows the network of Fig. 10 modified in accordance with the general form shown in Fig. 4;

Fig. 15 is a multi-channel band-pass structure following the modified bridged-T form of Fig. 3;

Fig. 16 shows how the network of Fig. 15 may be modified when it is not required that the characteristic impedance be a constant pure resistance at each pair of terminals;

Fig. 17 is a specific embodiment of the network of Fig. 6 when the auxiliary partial networks contain dissipative impedance branches;

Fig. 18 represents the impedance of the partial networks in the bridging branch of the network of Fig. 17;

Fig. 19 shows typical attenuation characteristics obtainable with the wave filter of Fig. 17;

Fig. 20 is a specific embodiment of a network in accordance with Fig. 4 when each impedance branch consists of only a single partial network;

Fig. 21 shows how the partial network in the bridging branch of the structure of Fig. 20 may be made partly balanced and partly unbalanced; and

Fig. 22 is a modification of the network of Fig. 21 in which the ideal transformer has been eliminated.

One general form of the network of the invention is represented diagrammatically by the symmetrical lattice structure of Fig. 1, which comprises a pair of equal line impedances Z_a and a pair of diagonal impedances Z_b connected between a pair of input terminals **1**, **2** and a pair of output terminals **3**, **4**. Only one line impedance Z_a is shown, the one connected between terminals **2** and **4** being indicated by the dotted line, and in like manner the dotted line connecting terminals **2** and **3** represents a second diagonal impedance branch Z_b. A source of electromotive force E is shown in series with the load impedance Z_s connected to the input terminals, and the impedance Z_r represents the load connected to the output terminals. The impedances Z_s and Z_r may represent, for example, sections of transmission line or other terminal loads of suitable impedance.

The line impedance branch Z_a comprises a plurality of partial networks $F_1, F_2 \ldots F_n$ connected in series at one end. The diagonal branch Z_b is made up of a like number of partial networks $F_1', F_2' \ldots F_n'$ connected in parallel. The partial networks forming the line impedance branch may, if desired, be connected in parallel, in which case the corresponding partial filters in the diagonal impedance branch will be connected in series. Or, again, the line branch may be made up of a number of partial networks connected in series together with other partial networks connected in parallel, so long as the diagonal branch contains their inverse structures, connected in inverse relationship. Each partial network may, for example, be a four-terminal wave filter comprising any number of component sections, which may be all of the same type or may be of different types. The distant end of each of these partial networks is terminated in a resistance chosen to match the characteristic impedance of the network as nearly as possible.

The partial filters F_1 and F_1' are so designed that the product of the impedance Z_1 looking into the input terminals of F_1 times Z_1', the impedance looking into the input terminals of F_1', is a constant quantity at all frequencies. This can be accomplished by making the filter F_1' an inverse structure with respect to the filter F_1. Each of the other partial networks connected in series in the Z_a impedance branch likewise has its inverse structure connected in parallel in the Z_b impedance branch. It follows, therefore, that the product of the impedance of the line branch Z_a times the impedance of the diagonal branch Z_b will be a constant quantity at all frequencies, and therefore the characteristic impedance K of the lattice structure at terminals **1**, **2** and **3**, **4**, which is given by the equation

$$K=\sqrt{Z_aZ_b} \qquad (1)$$

will also be a constant quantity at all frequencies, both within and without the transmission band of the network as a whole.

The propagation constant P of the network of Fig. 1 is given by the expression

$$\tanh\frac{P}{2}=\sqrt{\frac{Z_a}{Z_b}} \qquad (2)$$

An inspection of Equation (2) shows that in the regions where Z_a and Z_b are of the same sign,

$$\tanh\frac{P}{2}$$

is real and therefore the structure attenuates the energy passing through it, and where Z_a and Z_b are purely reactive but of opposite sign,

$$\tanh\frac{P}{2}$$

is imaginary, and therefore in this region the structure freely transmits energy.

If each one of the partial networks $F_1, F_2 \ldots F_n$ in the line branch and each corresponding inverse structure $F_1', F_2' \ldots F_n'$ in the diagonal branch is a wave filter having one or more transmission bands, the structure as a whole will have one or more corresponding attenuation bands, since the impedance of each partial network will be a pure resistance within its transmission band and the impedances of the branches Z_a and Z_b will be substantially pure non-reactive impedances of the same sign, and therefore

$$\tanh\frac{P}{2}$$

is real. On the other hand, where the partial networks are attenuating, the impedances Z_a and Z_b are substantially only reactive and of opposite sign, and therefore the structure as a whole will transmit freely the frequencies lying within this region. To summarize, the lattice network of Fig. 1 will have its transmission band located where the partial networks have attenuation bands, and the network as a whole will have attenuating regions located where the transmission bands of the partial networks occur.

Since the characteristic impedance of the network of Fig. 1 is a constant pure resistance at terminals **1**, **2**, and **3**, **4**, there must be a dissipative load to absorb the incoming energy at all frequencies. In the transmitting bands of the network as a whole the energy supplied by the source E is dissipated in the load impedance Z_r. In the attenuating bands of the network as a whole, which correspond to the transmitting bands of the partial filters, this energy is dissipated in the terminating resistances $R_1, R_2 \ldots R_n$ and $R_1', R_2' \ldots R_n'$. There will, therefore, be transmission bands between terminals **1** and **2** and the terminating loads of the partial networks and also corresponding transmission bands from the terminals **3** and **4** to the same terminating loads. As will be fully explained hereinafter the output energy from these various partial networks may be combined and in this way a plurality of transmission channels may be provided having characteristic impedances which are constant pure resistances at all frequencies.

A second form of the invention is shown in the bridged-T network of Fig. 2, which is the electrical equivalent of the lattice structure shown in Fig. 1. The network of Fig. 2 has a bridging branch comprising the partial filters F_1, F_2 . . . F_n connected in series at one end, and a shunt branch comprising the inverse partial filters F_1', F_2'. . . F_n' connected in parallel. The bridging branch may, of course, consist of parallel connected partial filters, and the shunt branch of series connected partial filters. The two impedance branches are coupled by means of a so-called ideal transformer T_a having three windings of large self-inductance and close coupling. The primary comprises two equal windings W_1 and W_1' connected series aiding with mutual inductance M_1 effective between them equal to the self-inductance of each winding. The secondary consists of a third winding W_2 which is equal in inductance to $\frac{1}{4}(W_1+W_1')$ and is coupled to the primary by mutual inductance

$$M_2=\sqrt{W_2+\frac{1}{4}(W_1+W_1')}$$

The transformer T_a will have a 4:1 impedance ratio between primary and secondary. By means of Bartlett's bi-section theorem given in the Philosophical Magazine, (London) vol. 4, page 902, November 1927, it may be shown that the bridged-T network of Fig. 2 is the electrical equivalent of the lattice structure shown in Fig. 1, and therefore the bridged-T network will have the same transmission and attenuation channels described above in connection with Fig. 1.

The partial filters in the bridging branch of the bridged-T network are designed on the basis of a characteristic impedance equal to one-half that of the corresponding filters in the line branch of the lattice network and therefore the bridging branch of the bridged-T structure will have a total impedance equal to $\frac{1}{2}Z_a$. Also the shunt branch of the bridged-T structure will have component partial filters which have characteristic impedances equal to one-half of the characteristic impedance of the corresponding networks in the diagonal branch of the lattice structure shown in Fig. 1, and therefore the total impedance of the shunt branch of the bridged-T network will be $\frac{1}{2}Z_b$. The partial networks in the bridging branch of the bridged-T network are terminated respectively in the resistances $\frac{1}{2}R_1$, $\frac{1}{2}R_2$ . . . $\frac{1}{2}R_n$ and the corresponding inverse filters in the shunt branch are terminated respectively in the resistances $\frac{1}{2}R_1'$, $\frac{1}{2}R_2'$. . . $\frac{1}{2}R_n'$.

A modified form of the bridged-T network of Fig. 2 is shown in Fig. 3, in which the coupling transformer T_a is replaced by n coupling transformers T_1, T_2 . . . T_n, one associated with each partial filter in the bridging branch. These coupling transformers are of the so-called ideal type described above and have an impedance ratio of 1:1. The primary windings are all connected in series, with a partial filter connected to each primary, and the secondary windings are also connected in series. The partial filters F_1, F_2 . . . F_n have a characteristic impedance which is the same as that of the corresponding partial filters in the bridging impedance branch of the network of Fig. 2 and these filters are terminated, respectively, in the resistances $\frac{1}{2}R_1$, $\frac{1}{2}R_2$ . . . $\frac{1}{2}R_n$. The shunt branch of the modified bridged-T network of Fig. 3 is identical with the shunt branch of the network of Fig. 2. When the partial networks F_1, F_2 . . . F_n have initial impedance branches which comprise shunt inductances, the ideal transformers T_1, T_2 . . . T_n may be replaced by transformers having finite winding inductances, as will be fully explained hereinafter.

When the partial filters F_1, F_2 . . . F_n of the bridging branch of the network of Fig. 2 are, for example, band-pass filters and the corresponding networks F_1', F_2'. . . F_n' in the shunt branch of the network are inverse structures passing the same bands of frequencies, respectively, as the corresponding partial filters in the bridging branch, the output energy from the various partial filters may be combined as shown in Fig. 4 to provide a plurality of separate transmission channels. If K' is the characteristic impedance of each of the partial filters F_1, F_2 . . . F_n, and K'' is the characteristic impedance of the partial filters F_1', F_2'. . . F_n' these two quantities must satisfy the equation

$$K'K''=\frac{K^2}{4} \tag{3}$$

where K represents the characteristic impedance of the network as a whole at terminals **1** and **2**.

All of the partial filters may, for example, be designed on the basis of the same characteristic impedance, in which case

$$K'=K''=\frac{K}{2} \tag{4}$$

In every case, however, all of the terminating impedances of the partial filters are equal to each other, and each is equal to

$$\frac{K}{2}$$

In equation form,

$$\frac{R_1}{2}=\frac{R_2}{2}=\frac{R_n}{2}=\frac{R_1'}{2}=\frac{R_2'}{2}=\frac{R_n'}{2}=\frac{K}{2} \tag{5}$$

The terminating impedance

$$\frac{R_1}{2}$$

of the partial filter F_1 may now be connected in series with the terminating impedance

$$\frac{R_1'}{2}$$

of the partial filter F_1', as shown in Fig. 4, to form a band-pass channel between terminals **1**, **2** and terminals **5**, **6'**, as will be more fully explained below in connection with a specific example. The output terminals **5'** and **6** of the partial filters are connected directly together. The energy outputs from the other partial filters may be combined in like manner to form additional transmission channels, the number of possible channels corresponding to the number of pairs of partial networks.

In the network shown in Fig. 4 the characteristic impedance looking in at the output terminals of the various channels will not be a constant pure resistance at all frequencies, but may be made so by resorting to the construction shown in Fig. 5. The network of this figure requires the addition of a three-winding ideal transformer having an impedance ratio of 1:1 in each separate channel. The two output impedances R_1 and R_1' are connected in series across the secondary of the transformer T_1' in the first channel. One output terminal of the partial filter F_1' is connected to the junction point between the two impedances just mentioned and the other output terminal of F_1' is connected to the mid-point of the divided secondary winding of the transformer T_1'. In Fig. 5 the ideal transformer T_b has an impedance ratio of 1:1, and the partial filters $F_1, F_2 \ldots F_n$ are designed on the basis of a characteristic impedance K' equal to 2K. With this construction, the network will have a characteristic impedance at each pair of terminals which is a constant pure resistance at all frequencies.

Certain of the partial networks of Fig. 4 may be only two-terminal impedances which may contain dissipative elements or may comprise only reactances. As shown in Fig. 6, for example, the bridging branch is made up of a partial filter F_1 and the two two-terminal impedances N_1 and N_2 connected in parallel. The shunt branch consists of the inverse networks F_1', N_1' and N_2' connected in series. These auxiliary two-terminal networks may be used for the purpose of increasing the attenuation in the various channels at the cross-over frequencies, as will be explained by means of an example hereinafter.

A number of more specific embodiments of the invention will now be described as illustrative examples. An example of the lattice structure of Fig. 1 is shown in Fig. 7, in which each line impedance branch consists of the two partial filters F_1 and F_2 connected in series and each diagonal impedance branch is made up of the inverse structures F_1' and F_2' connected in parallel. More than two partial filters may be used in each impedance branch and each partial filter may comprise any number of sections either of the same kind or of different types.

In Fig. 7 all of the partial filters are of the high-pass type, with the cut-off frequency placed at f_c. The network as a whole, therefore, will have a characteristic impedance at terminals 1, 2 and also at terminals 3, 4 which is a constant pure resistance at all frequencies. Furthermore, the network will have a low-pass transmission channel between terminals 1, 2 and 3, 4 which will freely pass all frequencies lying between zero and f_c. The attenuation in this channel will depend upon the balance between the impedances of the branches Z_a and Z_b. In accordance with the invention the partial filters are so designed that the impedances Z_a and Z_b are made equal to each other throughout the transmission bands of the partial filters. If a sufficient number of partial filters are used and each partial filter is composed of an infinite number of sections this equality can be made exact, and as a result the attenuation of the network as a whole will be infinite over the entire attenuating region.

Even if each impedance branch consists of only two single-section partial filters, as shown in Fig. 7, by proper design, this condition of equality may be closely approximated and a sustained high attenuation may be provided. In Fig. 7 the partial filter F_1 is a single-section, constant-k type, high-pass filter with mid-series termination at each end. The design parameters for this filter are the cut-off frequency f_c and its characteristic impedance K', which is equal to

$$\frac{K}{2}$$

where K is the characteristic impedance of the network as a whole. The filter comprises two equal series capacitances C_1 and an interposed shunt inductance L_1. The inverse structure F_1' in the diagonal branch of the network is a single-section, mid-shunt terminated, constant-k, high-pass filter having two shunt inductances L_2 and an interposed series capacitance C_2. The design parameters for this filter are the cut-off f_c and the characteristic impedance K'' which is equal to

$$\frac{K^2}{K'}=2K$$

The partial filter F_2 is a mid-series terminated, shunt-derived, m-type section in which the peak of attenuation occurs at a frequency slightly below the cut-off frequency. Each series branch of the filter comprises an inductance L_3 in parallel with the capacitance C_3 and the shunt impedance branch consists of the inductance L_4. The partial filter F_2' which comprises the inverse structure located in the diagonal impedance branch is a mid-shunt terminated, series-derived, m-type section, the characteristic impedance of which is equal to 2K. Each shunt branch consists of a capacitance C_5 in series with an inductance L_5, and the interposed series branch is constituted by the capacitance C_4.

If each partial filter has an infinite number of sections, the best results will be obtained by making the partial filter F_1 of the constant-k type (in which $m=1$) and designing the m-derived partial filter F_2 on the basis of an m equal to about 0.332. As the number of sections is reduced the value of these m's should also be decreased. This may be done by decreasing the m of the filter F_1, that is, by making this filter an m-derived type in which m is less than unity, or by decreasing the m of the filter F_2, or by decreasing the m's of both of these filters.

When terminated in a resistance ½R equal to ½K the filter F_1 will have an input impedance which has a resistive component r_1 of the type shown by curve 1 of Fig. 8, which starts at zero at the cut-off frequency f_c and rises to a value ½K at infinite frequency. In the same region the impedance of the filter F_2 will have a resistive component r_2 of the form shown by curve 2 of Fig. 8, which starts at zero at the cut-off frequency, rises to a maximum and then falls to a value ½K at infinite frequency. The sum of the curves 1 and 2 is shown by the curve 3 which, it will be noted, very soon after the cut-off frequency rises to a value K, from which it deviates only slightly between that frequency and infinite frequency. The curve cuts the K line at the frequencies f_1 and f_2. The impedance of the Z_b branch will be equal to K at these same frequencies and therefore attenuation peaks will occur at these frequencies as well as at infinite frequency, as shown by the typical attenuation characteristic of Fig. 9. Between these attenuation peaks the attenuation curve will maintain a constantly high value since the impedances of the branches Z_a and Z_b deviate but slightly from equality throughout this entire frequency range.

A specific embodiment of the network of Fig. 5 is shown in the network of Fig. 10, which is a band-pass filter having three separate channels. The bridging impedance branch comprises three partial filters F_1, F_2 and F_3 connected in series at one end, and the shunt branch comprises the inverse structures F_1', F_2' and F_3' connected in parallel. The filters F_1, F_2 and F_3 are unbalanced, mid-shunt terminated, constant-k, band-pass filters designed on the basis of a characteristic impedance equal to 2K and having their transmission bands spaced as desired. The partial filters may have the transmission characteristics shown, respectively, by curves 4, 5 and 6 of Fig. 11. At the two cross-over points f_3 and f_4 the attenuation may be made any desired amount either by proper spacing of the individual channels or by increasing the number of sections in each partial filter.

The principal transmission paths in the multiband multi-channel constant resistance filter of Fig. 10 are shown diagrammatically in Fig. 12. Energy applied to terminals 1, 2 falling within the transmission bands of the partial filters will be transmitted to the loads connected, respectively, to the terminals 5, 6, the terminals 7, 8 and the terminals 9, 10 as indicated by the solid line arrows A, B and C in the figure. The transmission characteristics of these channels will be determined by the propagation constants of the partial filters and will be of the type shown by the curves of Fig. 11, modified slightly due to the presence of the associated partial filters. Energy applied to terminals 1 and 2 which falls between and outside of the channels just described will be dissipated in the load connected to terminals 3 and 4 and therefore between these two sets of terminals there will be a multi-channel band-pass characteristic in which the transmitted bands correspond with the attenuated regions of the partial filters. On the other hand, if energy is applied to terminals 3, 4 that part which falls within the transmission bands of the partial filters will be freely transmitted to the loads connected respectively to the terminals 5', 6', terminals 7', 8' and terminals 9', 10' as shown by the dotted line arrows A', B' and C', while the energy falling between and outside of these bands will be transmitted to the load connected to terminals 1 and 2. There will also be a transmission path between terminals 5, 6 and terminals 5', 6' for the frequencies passed by the partial filter F_1 as shown by the arrow A'' in Fig. 12, and there will be similar paths for the frequencies passed, respectively, by the partial filters F_2 and F_3 as indicated by the arrows B'' and C''. When each of the connected loads of Fig. 10 is a resistance equal in value to K the characteristic impedance at each pair of terminals will be a constant pure resistance at all frequencies.

The network of Fig. 10 is well adapted for use in a communication system to separate the carrier frequencies into their separate channels. The line carrying all of the frequencies may, for example, be connected to terminals 1, 2 and three channels connected respectively to terminals 5, 6, terminals 7, 8 and terminals 9, 10. Resistances equal in value to K are connected respectively to the other pair of terminals. The transmission channels A, B and C of Fig. 12 may then be utilized to separate the incoming frequencies into their respective channels.

The attenuation in channel A may be increased by the addition of an auxiliary filter F_1'', between the terminals 5 and 6 and the connected load represented by R_1 as shown in Fig. 13. This auxiliary filter is effective only in channel A and by means of it the attenuation in this channel may be increased to any required extent. If the filter F_1'' is itself a constant-resistance structure, that is, one having a characteristic impedance K which is a constant pure resistance at all frequencies, the constant resistance properties of the main network will not be disturbed thereby. Similar auxiliary filters F_2'' and F_3'' may be introduced, respectively, into the channels B and C as shown diagrammatically in Fig. 13.

If it is not required that all of the channels have a constant resistance characteristic impedance, the network of Fig. 10 may be modified as shown by the network of Fig. 14, in which the resistances R_1', R_2' and R_3' have been eliminated and the three-winding transformers T_1', T_2' and T_3' have been replaced by the two-winding transformers T_1'', T_2'' and T_3'' having a unity impedance ratio. This network will have the transmission paths indicated by the arrows A, B, C and A', B', C' in Fig. 12. The characteristic impedance at terminals 1, 2 will be a constant pure resistance at all frequencies but at terminals 5, 6', terminals 7, 8' and terminals 9, 10' the characteristic impedance will be similar to that of the respective partial filters F_1, F_2 and F_3, but will be more constant within the transmission bands. The network of Fig. 14 follows the general type of that shown in Fig. 4. In Fig. 14 the ideal transformer T_a has an impedance ratio of 4:1 and the partial filters F_1, F_2 and F_3 are designed on the basis of a characteristic impedance K' equal to

$$\frac{K}{2}$$

A modified bridged-T network of the type represented by Fig. 3 is shown in Fig. 15 having three partial filters F_1, F_2 and F_3 in the bridging branch and the corresponding inverse filter structures F_1', F_2' and F_3' in the shunt branch, the two impedance branches being coupled by means of the three transformers T_1, T_2 and T_3. The partial filters are of the same type as those described in connection with Fig. 14. The primary of the transformer T_1 is formed by the initial shunt inductance of the partial filter F_1. This transformer has a 1:1 impedance ratio and therefore its secondary winding has a self-inductance equal to that of the primary, assuming perfect coupling. The coupling transformers T_2 and T_3 are formed in a similar manner and thus no transformers of the ideal type are required in the construction of this network. The output transformer T_1' has its primary winding formed by the final shunt inductance of the partial filter F_1. This transformer has an impedance ratio of 1:4 with a divided secondary winding tapped at the mid-point as shown. The other two output transformers T_2' and T_3' are constructed in a similar manner. The network will have the same transmission paths as those shown in Fig. 12 and will have a characteristic impedance at each pair of terminals which is a constant pure resistance at all frequencies.

If it is not necessary that the characteristic impedance of all the channels be a constant pure resistance at all frequencies, the network of Fig. 15 may be modified as shown in Fig. 16, in which the three-winding transformers T_1', T_2' and T_3' are replaced by the two-winding transformers T_1'', T_2'' and T_3'' having impedance ratios of 1:1. This network will have a constant resistance characteristic impedance at terminals 1, 2 but at terminals 5, 6', terminals 7, 8' and terminals 9, 10' the characteristic impedance will be that of a constant-k type band-pass filter but will be somewhat more uniform in the transmission band.

A specific example of the network of Fig. 6 is shown in Fig. 17. The bridging branch comprises a dissipative two-terminal auxiliary impedance N and a four-terminal partial filter F connected in parallel. The corresponding inverse structures N′ and F′ are connected in series in the shunt impedance branch. The partial filter F is a single-section, high-pass filter of the m-derived type having a mid-shunt termination at each end. Each shunt impedance branch consists of an inductance L_b, and the interposed series branch comprises an inductance L_a and a capacitance C_a connected in parallel. The filter is designed on the basis of a characteristic impedance equal to K′. The cut-off frequency f_c and the peak of attenuation, which occurs at the frequency f_5, are placed as required. The filter F′ is a high-pass filter of inverse structure and has a characteristic impedance K″ related to K′ by the expression

$$K'K''=\frac{K^2}{4}$$

where K is the characteristic impedance of the network as a whole at terminals 1 and 2. The impedance K′ may be chosen equal to

$$\frac{K}{2}$$

or it may be given a value either larger or smaller than this. Once K′ is determined, the value of K″ is found from the above equation.

The auxiliary network N in the bridging branch consists of an inductance L_N, a capacitance C_N and a resistance R_N, all connected in series with each other and in parallel with the filter F. The inductance L_N and the capacitance C_N are designed to resonate at a frequency slightly above the cut-off f_c of the filter F, as will be explained more fully below. The inverse auxiliary network N′ comprises an inductance L_N', a capacitance C_N' and a resistance R_N' connected in parallel with each other and in series with the partial filter F′. When the elements in the network N have been determined the values of the elements in the inverse structure N′ may be found from the relationship

$$\frac{L_N}{C_N'}=\frac{L_N'}{C_N}=R_N R_N'=\frac{K^2}{4} \qquad (6)$$

In Fig. 17 the bridging impedance branch is coupled to the shunt impedance branch by means of the transformer T_4 which has a divided primary winding and an impedance ratio of 4:1 between primary and secondary. The secondary winding is the inductance L_b, which also constitutes a shunt inductance of the partial filter F, and thus only finite winding inductances are required for the transformer T_4.

If the partial filter F′ has a characteristic impedance equal to ½K the resistance component r_3 in the transmission range will be of the form shown by the dotted line curve 7 of Fig. 18, starting from zero at the cut-off frequency f_c and rising to a value equal to ½K at infinite frequency. If the auxiliary networks N and N′ are omitted, the network as a whole will have a low-pass transmission channel between terminals 1, 2 and terminals 3, 4 of the form indicated by the dotted line curve 8 of Fig. 19, dependent upon the impedance match between the bridging and shunt branches, and rising to an infinite value at infinite frequency. Between terminals 1, 2 and terminals 5, 6 the network will have a high-pass transmission channel of the type shown by curve 9 of Fig. 19, having a peak of attenuation at the frequency f_5 and rising again to an infinite value at zero frequency. These two curves cross each other at the frequency f_x, at which point the attenuation A_1 is approximately 3 decibels. The cross-over point f_x will occur approximately at the cut-off frequency f_c.

By the addition of the auxiliary networks N and N′ the attenuation at the cross-over point may be increased to any desired value, and one or more peaks of attenuation may be introduced into the low-pass channel. If, for example, the inductance L_N' and the capacitance C_N' of the network N′ are assigned values such that the parallel combination is anti-resonant at a frequency f_6, slightly higher than the cut-off frequency f_c, the resistive component r_4 of the impedance of the network N′ will be of the form shown by curve 10 of Fig. 18, rising to a value R_N' at or near the frequency f_6. The sum of the resistive components r_3 and r_4, represented by the solid line curve 11 of Fig. 18, cuts the

$$\frac{K}{2}$$

line at the frequencies f_7 and f_8. The low-pass channel will now have peaks of attenuation at these two frequencies, as shown by the solid line curve 12 of Fig. 19, and the attenuation of the high-pass channel will be slightly modified as indicated by the solid line curve 13. The two curves will now cross each other at the frequency f_x', at which point the attenuation is increased from A_1 to a new value A_2. In this way the attenuation in the low-pass channel is sharpened above the cut-off and the attenuation at the cross-over point may be made any required amount.

Fig. 20 shows a network of the bridged-T type in which the bridging branch comprises a single full section of a shunt-derived, m-type, high-pass filter F_a terminated mid-series at each end, and the shunt branch consists of a filter F_a' which has the inverse structure of the filter F_a. The filter F_a' consists of a full section of the series-derived, m-type terminated mid-shunt at both ends. Filters F_a and F_a' are both high-pass filters having the cut-off frequency chosen as required. The filter F_a is coupled to the filter F_a' by means of the transformer T_a which is of the ideal type and has an impedance ratio 4:1, the primary being divided into two equal windings. The outputs of the filters F_a and F_a' are connected in series to form a high-pass transmission channel between terminals 1, 2 and terminals 5, 6. There will also be a low-pass channel between terminals 1, 2 and terminals 3, 4. The network will have a characteristic impedance at terminals 1 and 2 which is a constant pure resistance at all frequencies, but at terminals 3, 4 and terminals 5, 6 it will not be a constant resistance structure.

The first impedance branch of the filter F_a comprising the inductance L_6 and the capacitance C_6 may be divided into two equal portions, one of which is placed in the other side of the line as shown in Fig. 21. The filter F_a is thus made partly balanced and partly unbalanced, that is to say, it comprises a half section of the balanced type and a half section of the unbalanced type.

It will be noted that the secondary of the transformer T_a has connected across it the three inductances ½L_6, L_7 and ½L_6. In accordance with the invention, transformers may be substituted for these three inductances and the ideal transformer T_a eliminated. Fig. 22 shows how this may be done. The inductance L_7 is divided into two equal portions each equal to ½L_7 with a mutual inductance M_3 equal to ½L_7 effective therebetween. Likewise the two inductances $\frac{1}{2}L_6$ and $\frac{1}{2}L_6$ are coupled by mutual inductance M_4 equal to $\frac{1}{2}L_6$. The network of Fig. 22 will have the same transmission characteristics as the networks of Figs. 20 and 21, but as pointed out the transformers employed require winding inductances of only finite value.

What is claimed is:

1. In a multi-channel wave transmission network comprising a plurality of impedance branches, two impedance branches adapted to determine the transmission characteristics of the network, one of said impedance branches comprising a plurality of partial networks, the other of said impedance branches comprising a plurality of other partial networks having structures which are inverse with respect to said first-mentioned partial networks, and the output of each of said partial networks in said one branch being combined with the output of said corresponding partial network in said other branch to provide a separate transmission channel.

2. In a multi-channel wave transmission network having a plurality of impedance branches, two impedance branches adapted to determine the transmission characteristics of the network, one of said branches comprising a plurality of partial filters connected in series at their input terminals, the other of said branches comprising a plurality of other partial filters connected in parallel at their input terminals, the structure of one of said branches being inverse with respect to the structure of said other branch, and the product of the impedances of said two branches being at all frequencies a constant real quantity equal in magnitude to the square of the characteristic impedance of said transmission network.

3. In a multi-channel wave transmission network having a plurality of impedance branches, two impedance branches adapted to determine the transmission characteristics of the network, one of said branches comprising a plurality of partial filters connected in series at their input terminals, the other of said branches comprising a plurality of other partial filters connected in parallel at their input terminals, and the product of the impedances of said two branches being a constant quantity at all frequencies.

4. A wave transmission network having a plurality of pairs of terminals, a plurality of transmission channels, and two branches adapted to determine the transmission characteristics of the network, the characteristic impedance at each of said pairs of terminals being a constant pure resistance equal to K at all frequencies, one of said branches comprising a plurality of partial filters connected in series at their input terminals, the other of said branches comprising a plurality of other partial filters connected in parallel at their input terminals, and each of said partial filters in said one branch being so proportioned with respect to a filter in said other branch that the product of their impedances is a constant quantity equal to K^2 at all frequencies.

5. A selective wave transmission network of the lattice type having a pair of input terminals and a pair of output terminals, said network comprising a line impedance branch connected between an input terminal and an associated output terminal, and a diagonal impedance branch connected between said input terminal and the other of said output terminals, said line branch comprising a plurality of four-terminal partial filters connected in series at one end, said diagonal branch comprising an equal number of other four-terminal partial filters of inverse structure with respect to said partial filters in said line branch connected in parallel at one end, each of said partial filters being terminated in a resistive load impedance, and the product of the impedance of said line branch multiplied by the impedance of said diagonal branch being a constant quantity at all frequencies.

6. A multi-channel selective wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a plurality of partial filters, said shunt branch comprising a plurality of other partial filters, the output of each of said partial filters in said bridging branch being combined with the output of a corresponding partial filter in said shunt branch to provide a separate transmission channel, and the product of the impedance of said bridging branch multiplied by the impedance of said shunt branch being a constant quantity at all frequencies.

7. A multi-channel wave transmission network of the bridged-T type comprising a bridging impedance branch consisting of a plurality of partial filters, and a shunt impedance branch consisting of a plurality of other partial filters of inverse structure with respect to said first-mentioned partial filters, said bridging branch being inductively coupled to said shunt branch by means of a three-winding transformer, the output of each of said partial filters in said bridging branch being combined with the output of said corresponding partial filter in said shunt branch to provide a separate transmission channel, and the impedance of said network being constant in magnitude and non-reactive in character at all frequencies.

8. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising an impedance path between an input terminal and an associated output terminal, a plurality of transformers having their primaries connected in series between said input terminal and the mid-point of said impedance path, and their secondaries connected in series between said mid-point and said output terminal, a plurality of partial filters connected, respectively, to said primaries, and a shunt impedance branch connected on one side to said mid-point and on the other side to said remaining input and output terminals, said shunt branch comprising a plurality of other partial filters, and said partial filters in said shunt branch having structures which are inverse with respect to said first-mentioned partial filters.

9. A multi-channel wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch inductively coupled by means of a transformer, said bridging branch comprising a plurality of partial filters, said shunt branch comprising a plurality of other partial filters having structures which are inverse with respect to said first-mentioned partial filters, and the output of each of said partial filters in said bridging branch being combined with the output of said corresponding partial filter in said shunt branch to provide a separate transmission channel.

10. A multi-channel wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch inductively coupled by means of a transformer, said bridging branch comprising a plurality of

partial filters, said shunt branch comprising a plurality of other partial filters having structures which are inverse with respect to said first-mentioned partial filters, and the output of each of said partial filters in said bridging branch being combined by means of a three-winding transformer with the output of said corresponding partial filter in said shunt branch to provide a separate transmission channel having a characteristic impedance which is a constant pure resistance at all frequencies.

11. A multi-channel wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch inductively coupled by means of a three-winding transformer, said bridging branch comprising a partial filter and a dissipative network, said shunt branch comprising a second partial filter and a second dissipative network, the structure of said shunt branch being inverse with respect to the structure of said bridging branch, and the output of said first partial filter being combined with the output of said second partial filter to form a transmission channel.

12. A wave transmission network of the lattice type comprising a line impedance branch and a diagonal impedance branch, each of said impedance branches comprising a plurality of partial filters having the same cut-off frequency, the partial filters in one of said branches having a structure which is inverse with respect to the structure of said partial filters in said other impedance branch, and the impedance of each of said branches being substantially a constant pure resistance throughout the entire transmission band of said partial filters.

13. A wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch, said bridging branch comprising a plurality of partial filters, said shunt branch comprising a plurality of other partial filters having a structure which is inverse with respect to said partial filters comprising said bridging branch, the output of each of said partial filters in said bridging branch being combined with the output of said corresponding filter in said shunt branch by means of a transformer to provide a separate transmission channel, and one winding of each of said transformers constituting a shunt inductance element of the partial filter with which said transformer is associated.

14. A wave transmission network of the bridged-T type comprising a bridging impedance branch and a shunt impedance branch inductively coupled by means of a three-winding transformer, said bridging branch comprising a plurality of band filters adapted to pass different transmission bands, said shunt branch comprising a plurality of filters having structures which are inverse with respect to said first mentioned filters, and the output of each of said filters in said bridging branch being combined with the output of the corresponding filter in said shunt branch by means of a transformer to provide a separate transmission channel.

15. A wave transmission network having an impedance path comprising a plurality of transformers having their primary windings and their secondary windings connected respectively in series between an input terminal and an output terminal, a shunt branch comprising a plurality of partial filters connected to the mid-point of said impedance path, and a plurality of other partial filters of inverse structure connected respectively to the primaries of said transformers, the output of each of said last-mentioned filters being combined by means of a three-winding transformer with the output of the said corresponding filter in said shunt branch to form a separate transmission channel having a characteristic impedance which is a constant pure resistance at all frequencies.

16. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising an impedance path connected between an input terminal and an associated output terminal, and a shunt impedance path having connections on one side to the mid-point of said first-mentioned path and connections on the other side of each of said remaining terminals, said first-mentioned path comprising a plurality of transformers having their primary windings connected in series between said input terminal and said mid-point and having their secondary windings connected in series between said mid-point and said associated output terminal, and a plurality of band filters adapted to pass different transmission bands connected respectively to the primary windings of said transformers, said shunt impedance path comprising a plurality of filters having structures which are inverse with respect to said first-mentioned partial filters, and the output of each of said first-mentioned partial filters being combined with the output of said corresponding filter in said shunt path by means of a transformer to provide a separate transmission channel.

17. A multi-channel wave transmission network having a pair of input terminals, a pair of output terminals, and impedance paths connecting each of said input terminals with its associated output terminal, said network comprising a partial filter connected at one end between the mid-point of one of said paths and a point in the other of said paths, and a second partial filter having a structure which is inverse with respect to said first-mentioned partial filter, said second partial filter having an initial balanced half section of the ladder type comprising a pair of equal series inductance inductively coupled with unity coupling factor followed by an adjacent shunt branch comprising a second pair of equal inductances also coupled with unity coupling, all of said inductances being connected in series in one of said impedance paths, and the outputs of said partial filters being combined to provide a separate transmission channel.

18. A wave transmission network of the bridged-T type comprising a bridging branch and a shunt branch inductively coupled, said bridging branch comprising a partial filter and a dissipative network, said shunt branch comprising a second partial filter and a second dissipative network, the structure of said shunt branch being inverse with respect to the structure of said bridging branch, the output of said first partial filter being combined with the output of said second partial filter, said transmission network having two contiguous transmission channels, and said dissipative networks being so designed as to increase the attenuation at the cross-over point between said two transmission channels.

19. A wave transmission network of the bridged-T type having a pair of input terminals and two pairs of output terminals, said network comprising a bridging branch and a shunt branch inductively coupled, said bridging branch comprising a partial filter and a dissipative network, said shunt branch comprising a second partial

filter and a second dissipative network, the structure of said shunt branch being the inverse of the structure of said bridging branch, said transmission network having a transmission channel between said input terminals and a pair of said output terminals the attenuation of which is dependent upon the impedance balance between said bridging branch and said shunt branch, the outputs of said partial filters being combined to provide a second transmission channel between said input terminals and the other pair of said output terminals the attenuation of which is dependent upon the propagation constants of said partial filters, and said dissipative networks being adapted to steepen the slope of the attenuation of said first-mentioned channel near the cutoff frequency.

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