

June 9, 1936.

S. BOBIS

2,043,345

WAVE TRANSMISSION NETWORK

Filed March 6, 1934

4 Sheets-Sheet 1

FIG. 1

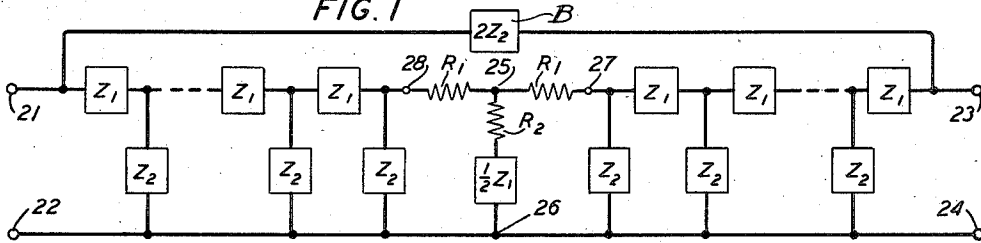


FIG. 2

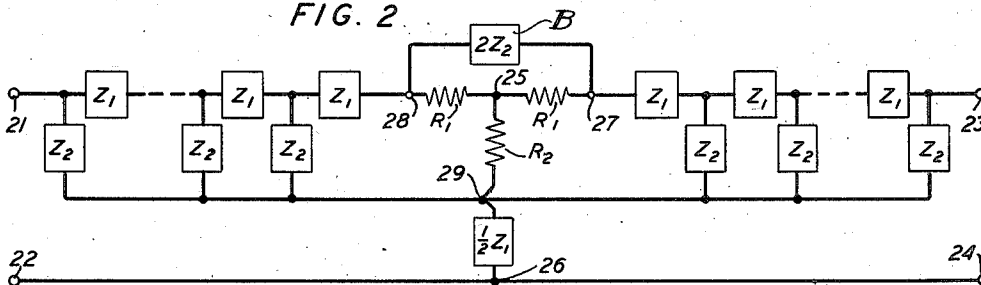
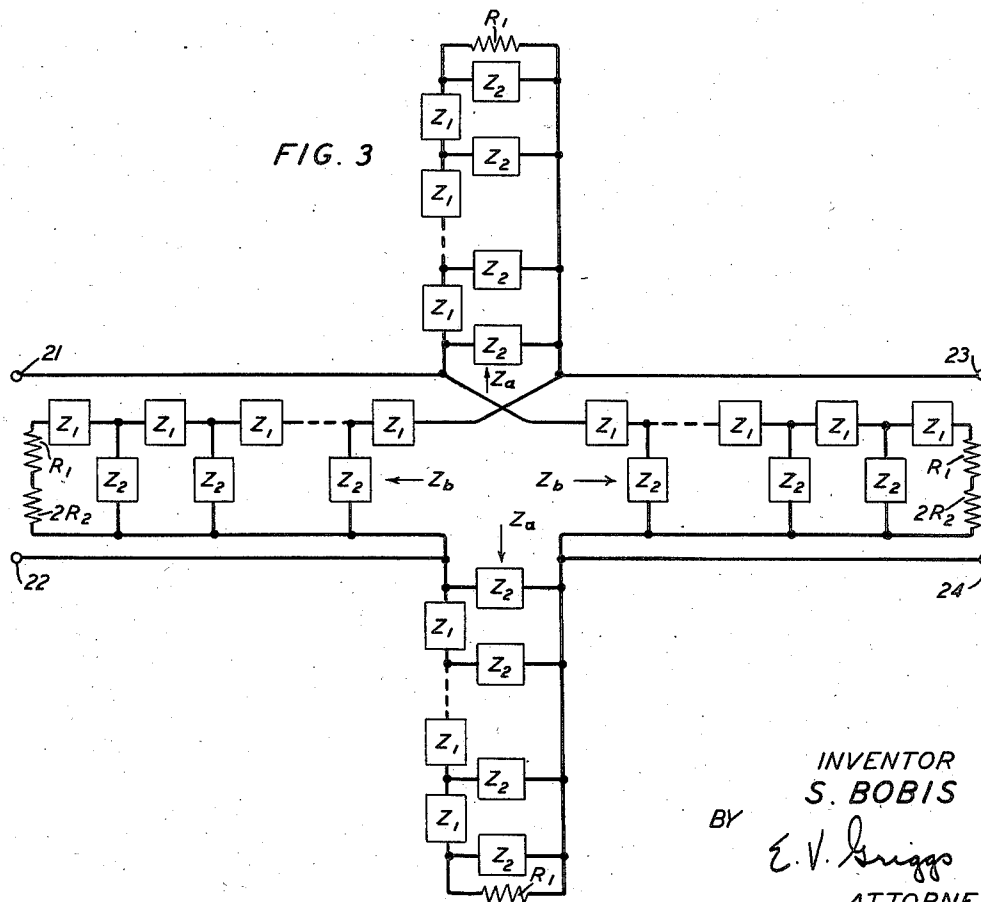


FIG. 3



INVENTOR
S. BOBIS

BY

E. V. Briggs

ATTORNEY

June 9, 1936.

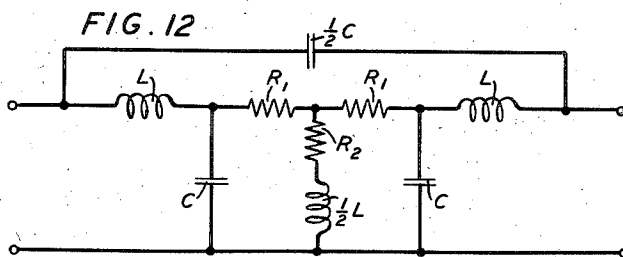
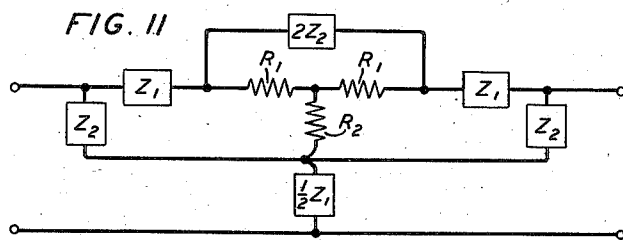
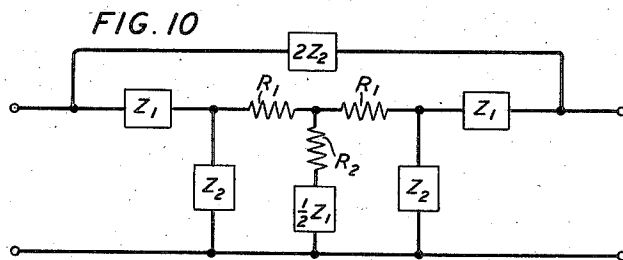
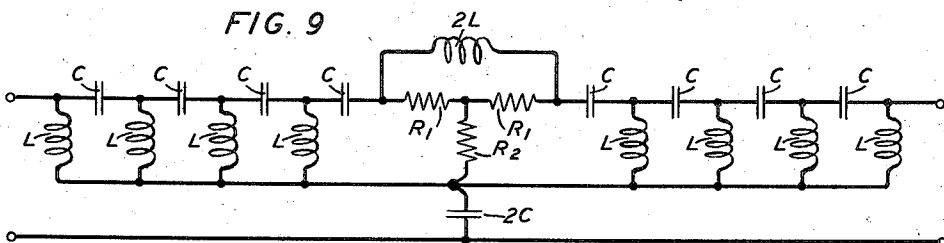
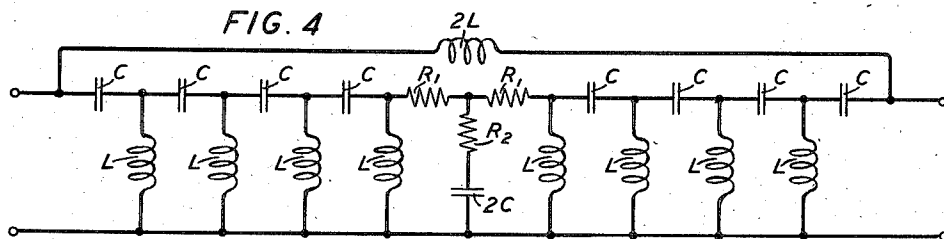
S. BOBIS

2,043,345

WAVE TRANSMISSION NETWORK

Filed March 6, 1934.

4 Sheets-Sheet 2



INVENTOR
S. BOBIS
BY
E. V. Snigg
ATTORNEY

June 9, 1936.

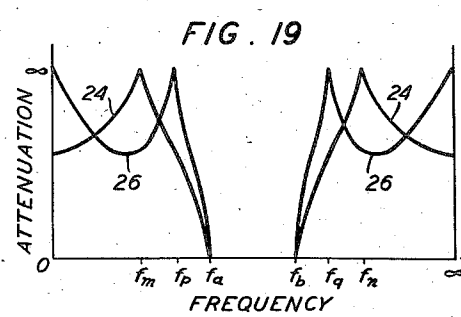
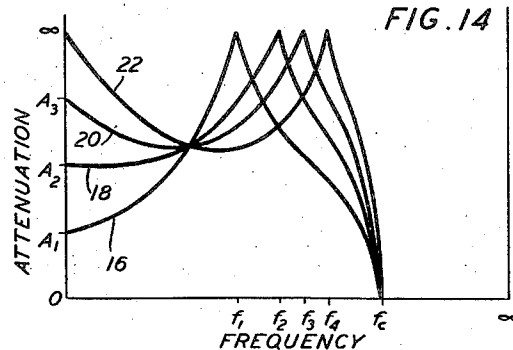
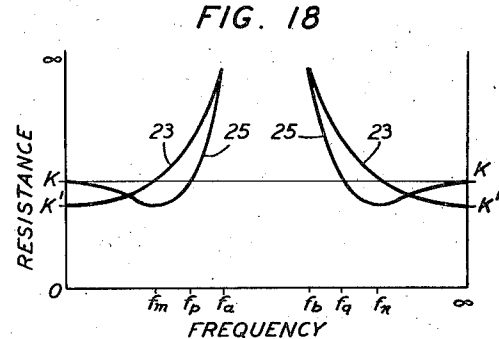
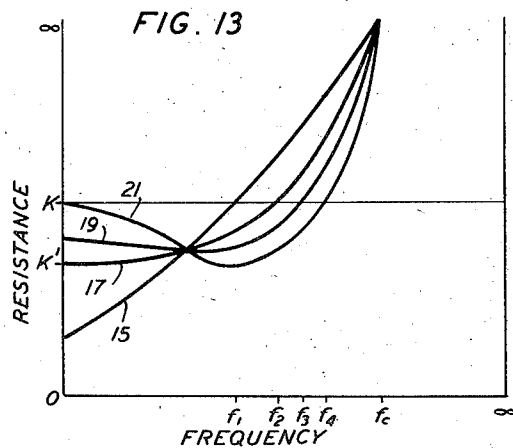
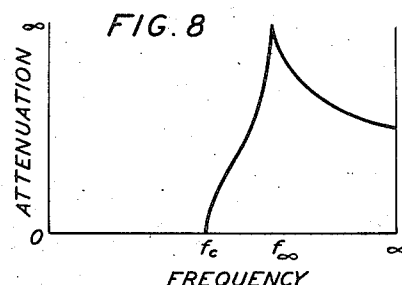
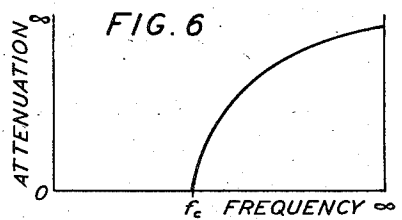
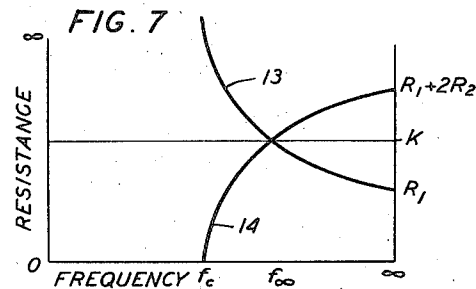
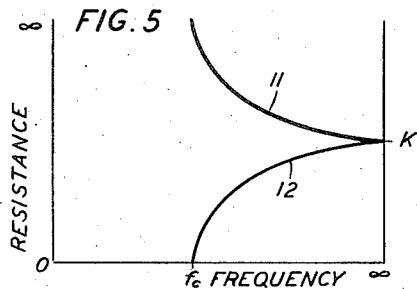
S. BOBIS

2,043,345

WAVE TRANSMISSION NETWORK

Filed March 6, 1934

4 Sheets-Sheet 3



INVENTOR
S. BOBIS
BY
E. V. Briggs
ATTORNEY

June 9, 1936.

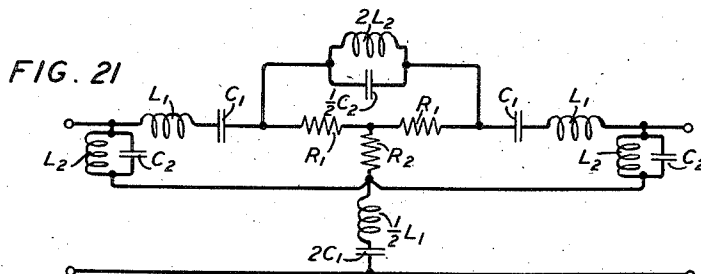
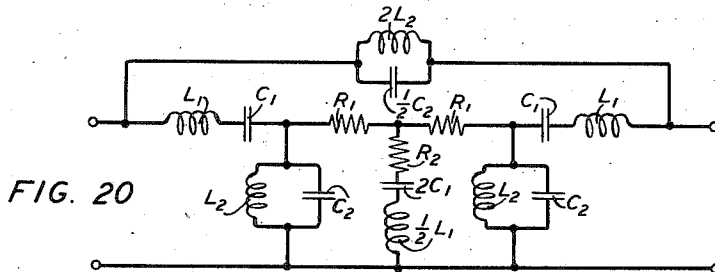
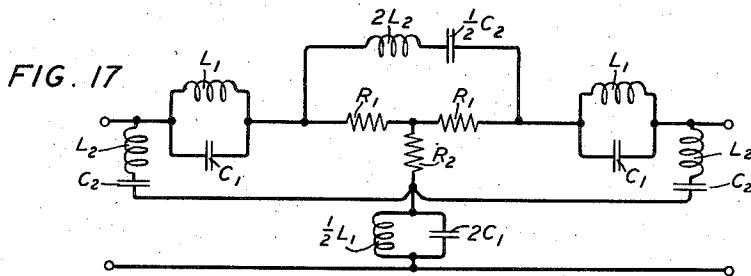
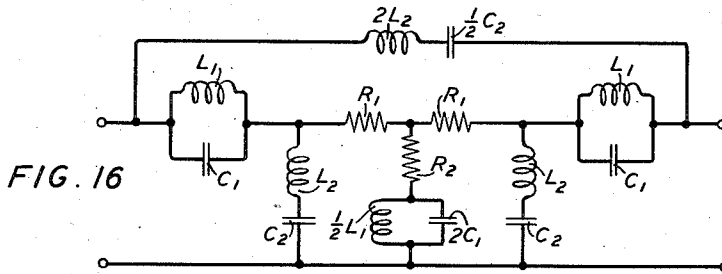
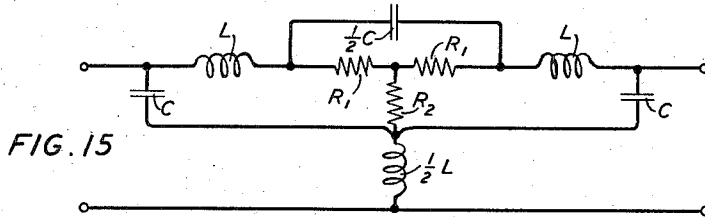
S. BOBIS

2,043,345

WAVE TRANSMISSION NETWORK

Filed March 6, 1934

4 Sheets-Sheet 4



INVENTOR
S. BOBIS
BY *E. V. Briggs*
ATTORNEY

UNITED STATES PATENT OFFICE

2,043,345

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 March 6, 1934, Serial No. 714,346

20 Claims. (Cl. 178—44)

This invention relates to selective wave transmission networks which have a constant non-reactive characteristic impedance at all frequencies, and more particularly to such networks of the unbalanced type having means for providing peaks of attenuation.

An object of the invention is to improve the attenuation characteristics of wave filters of the type having a characteristic impedance which is a constant resistance both within and without the transmission band.

Another object is to improve the impedance characteristics of wave filters which are designed for use in unbalanced systems.

A feature of the invention is an unbalanced wave filter having a constant, non-reactive characteristic impedance at all frequencies and having means within itself for providing peaks of attenuation.

In order to avoid reflection effects at the points of junction between a wave filter and its associated load impedances it is often found desirable that the characteristic impedance of the filter should be a constant resistance both within and without the transmission band. Constant resistance filters also offer a decided economic advantage when it is required to connect in tandem a number of separate sections to form a composite structure, because when filters of this type are employed the component sections need not have the same cut-off frequency. Thus the same type of section may be used to form different composite filters which may or may not have the same transmission bands. Some of the sections may have their cut-off frequencies located well within the attenuating region of the composite structures, thus reducing the phase distortion in the transmission band of the filter as a whole and simplifying the problem of delay equalization. Heretofore it has been known how to build constant-resistance filters but it has not been known how to provide peaks in their attenuation characteristics, nor how conveniently to adapt such filters for use in unbalanced systems one side of which is grounded or otherwise maintained at a fixed potential. In accordance with the present invention there is provided a wave filter of the unbalanced type having a constant, non-reactive characteristic impedance at all frequencies, both within and without the transmission band, and having internal means for providing peaks of attenuation at one or more selected points in the attenuating region.

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

Figs. 1 and 2 are alternative configurations showing the constant resistance networks of the invention in their most general form;

Fig. 3 is a lattice-type network which is the electrical equivalent of the structures shown in Figs. 1 and 2;

Fig. 4 is a low-pass filter in accordance with the invention in which each ladder-type partial network comprises four sections;

Figs. 5 and 7 represent typical impedance characteristics of the partial networks of Fig. 4;

Figs. 6 and 8 illustrate diagrammatically the attenuation characteristics obtainable from the network of Fig. 4 when the partial networks have the impedances shown respectively in Figs. 5 and 7;

Fig. 9 gives an alternative configuration for the filter of Fig. 4, following the general form shown in Fig. 2;

Figs. 10 and 11 represent the preferred forms of the networks of the invention, in accordance with the general forms shown respectively in Figs. 1 and 2;

Fig. 12 is a high-pass filter in accordance with the form of the invention shown in Fig. 10;

Fig. 13 represents typical impedance characteristics of the partial networks of Fig. 12;

Fig. 14 gives the attenuation characteristics obtainable with the network shown in Fig. 12 when the partial networks have the impedances represented by Fig. 13;

Fig. 15 is a high-pass filter of the form shown in Fig. 11, and is an alternative configuration for the structure of Fig. 12;

Figs. 16 and 17 are band-pass filters of the form shown respectively in Figs. 10 and 11;

Fig. 18 gives typical impedance characteristics of the partial networks of Figs. 16 and 17;

Fig. 19 shows the attenuation characteristics obtainable with the filters shown in Figs. 16 and 17 when the partial networks have the impedances represented by Fig. 18; and

Figs. 20 and 21 illustrate band-elimination filters according to the forms shown in Figs. 10 and 11, respectively.

One form of the invention is shown schematically in Fig. 1, which is an unbalanced wave transmission network of the bridged type having a pair of input terminals 21, 22 and a pair of output terminals 23, 24 by means of which the network may be connected between two sections of transmission line or to other load impedances of suitable magnitude. The path between terminals 22 and 24 may be grounded or otherwise fixed in potential, if desired. The impedance path between terminals 21 and 23 comprises a pair of equal resistances R_1, R_1 connected in series. A branch impedance consisting of a third resistance R_2 in series with an impedance of value $\frac{1}{2}Z_1$ is connected from the common terminal 25 of the series resistances R_1, R_1 to a point 26 in the grounded side of the network. To the right of the central

portion of the network, between the points 26, 27 and the output terminals 23, 24, there extends a ladder-type partial network of any desired number of sections comprising series impedances Z_1 and alternately disposed shunt impedances Z_2 . This ladder-type network is a filter of the constant- k type, such as is described in U. S. patent to G. A. Campbell No. 1,227,113 issued May 22, 1917. A similar partial network extends to the left of the central portion, between the points 26, 28 and the input terminals 21, 22. The main network is completed by a bridging branch B consisting of the impedance equal to $2Z_2$ connected between terminals 21 and 23. The method of designing the partial networks and the method of proportioning the resistances R_1 and R_2 will be fully explained hereinafter.

A second form of the invention is shown schematically in Fig. 2 which is an unbalanced, bridged-type network the central portion of which is similar to the one shown in Fig. 1, comprising a pair of equal series resistances R_1 , R_1 and a shunt branch consisting of a resistance R_2 in series with an impedance $\frac{1}{2}Z_1$ connected from the common terminal 25 to a point 26 in the grounded side of the network. However, the equi-potential side of the partial networks which extend to the right and to the left of the central portion in Fig. 2 is connected to the junction point 29 of the resistance R_2 and the impedance $\frac{1}{2}Z_1$ of the shunt branch, instead of being connected directly to the grounded side of the main network as is done in Fig. 1. Also, the bridging branch B in Fig. 2 is connected between the outer terminals 27, 28 of the series resistances R_1 , R_1 instead of bridging the terminals 21, 23 of the main network as in Fig. 1.

The transmission properties of the bridged-type networks of the invention are most conveniently studied by considering their electrically equivalent lattice structures, which may be obtained, for example, by means of Bartlett's bisection theorem given in the Philosophical Magazine (London), vol. 4, page 902, November, 1927. Each of the networks shown in Figs. 1 and 2 has the same equivalent lattice structure, as given in Fig. 3, comprising a pair of equal impedances which may be designated Z_a , Z_a one in series with each side of the line, and a second pair of equal lattice impedance branches designated Z_b , Z_b connected diagonally between the input terminals 21, 22 and the output terminals 23, 24 of the network. Each of the component impedance branches of the lattice network consists of a ladder-type partial network comprising a number of impedances Z_1 in series and alternately disposed shunt impedances Z_2 , the distant end of the partial network being terminated in a resistance, which in the Z_a branch is equal to R_1 and in the Z_b branch is equal to $R_1 + 2R_2$.

The propagation constant P and the characteristic impedance K of the lattice network of Fig. 3 are given by the expressions

$$\tanh \frac{P}{2} = \sqrt{\frac{Z_a}{Z_b}} \quad (1)$$

and

$$K = \sqrt{Z_a Z_b} \quad (2)$$

It is apparent from Equation (2) that, in order to make the characteristic impedance K a constant resistance at all frequencies, it is necessary that the branch impedances Z_a , Z_b should be inverse with respect to K^2 over the entire frequency range.

Also, an inspection of Equation (1) 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 is attenuating, and where Z_a and Z_b are purely reactive but of opposite sign

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

is imaginary, hence the structure is transmitting energy.

As stated above, the partial networks are of the constant- k type and may be either low-pass, high-pass, band-pass or band-elimination structures. The design parameters of the partial networks are the cut-off frequency f_c and the characteristic impedance K' . The cut-off frequency f_c , which is the same as the cut-off of the network as a whole, is chosen as required and, in the case of the multi-section partial networks shown in Figs. 1 and 2, the characteristic impedance K' is made equal to K , the characteristic impedance of the network as a whole.

It will be noted in Fig. 3 that one pair of impedance branches Z_a , Z_a consist of ladder-type networks in which the first branch is the shunt impedance Z_2 while in the lattice impedances Z_b , Z_b the first branch is the series impedance Z_1 . Since the partial networks are of the same type and have the same cut-off frequencies but have, respectively, shunt and series terminations, the impedances Z_a and Z_b will be inherently inverse with respect to K^2 throughout the whole frequency range, both within and without the transmission band. The impedances Z_a and Z_b will be purely resistive and of course of the same sign in the transmission band of the partial networks, and therefore the lattice structure will attenuate in this range. On the other hand, where the partial networks are attenuating, the impedances Z_a , Z_b are purely reactive and of opposite sign, and therefore the lattice structure will transmit freely the frequencies lying within this region. To restate the proposition simply, the lattice network of Fig. 3 will have its transmission band located where the ladder partial structures are attenuating and the attenuating region of the lattice will coincide with the transmission band of the partial structures. By virtue of the equivalence pointed out above, these same criteria as to the location of transmitting and attenuating regions apply also to the networks of Figs. 1 and 2.

Some of the more specific structures will now be considered. For example, if the ladder-type partial networks of Fig. 1 are high-pass filters consisting of four sections each there will result the network shown in Fig. 4, in which the series impedances are the capacitances C and the shunt impedances are the inductances L . The bridging branch consists of an inductance of value $2L$ and the impedance in series with the resistance R_2 is a capacitance of value $2C$. If the value of the resistance R_1 is equal to K , the characteristic impedance of the network as a whole, and if R_2 is made zero, the branches Z_a , Z_b of the equivalent lattice structure will have the impedance characteristics shown symbolically in Fig. 5 by the curves 11 and 12 respectively. The network of Fig. 4 is a low-pass filter, with cut-off at f_c , the cut-off frequency of the partial networks, and has an attenuation characteristic which starts at f_c and rises to infinity at an infinite frequency, as shown symbolically in Fig. 6. If it is desired

to have a peak of attenuation located at a finite frequency this may be done by introducing the resistance R_2 and decreasing the value of R_1 , always maintaining the relationship

$$R_1(R_1 + 2R_2) = K^2 \quad (3)$$

Thus the value of the resistance R_1 may range between the values of zero and K , while at the same time R_2 ranges between infinity and zero.

When the resistance R_2 is introduced, the characteristics of the equivalent lattice impedances Z_a , Z_b will be as shown in Fig. 7. As indicated by curve 13, the impedance Z_a will fall from infinity at the cut-off f_c to a value equal to R_1 at infinite frequency, and the impedance of Z_b will rise from zero at f_c to a value equal to $R_1 + 2R_2$ at infinite frequency, as shown by curve 14. There must necessarily be a crossing of the two curves at a finite frequency, as at f^∞ , and this will give the location of the attenuation peak in the transmission characteristic of the network, as shown in Fig. 8. The location of this peak of attenuation may be shifted at will by properly proportioning the values of the resistances R_1 and R_2 . As the value of the resistance R_1 is decreased the frequency of infinite attenuation f^∞ moves nearer and nearer to the cut-off f_c .

Fig. 9 shows an alternative configuration for the network of Fig. 4, designed in accordance with the circuit of Fig. 2. The same component elements are used but the circuit arrangement is different. The network of Fig. 9 will have the same transmission characteristics as the network shown in Fig. 4, and attenuation peaks may be obtained at finite frequencies in the same manner as described above.

In the preferred form of the networks of the invention each ladder-type partial network consists of only a single series impedance and a single shunt impedance, as shown in Figs. 10 and 11, which correspond to the types shown, respectively in Figs. 1 and 2. The feature of the constant, non-reactive characteristic impedance is maintained in these forms of the invention, but as the number of sections in the partial networks is decreased the sharpness of the cut-off in the attenuation characteristic is somewhat impaired. However, the simpler structures will suffice for most purposes of frequency selection encountered in practical installations.

Networks of the form shown in Figs. 10 and 11 offer an advantage over the more elaborate structures described above in that the former may be designed to have attenuation peaks at finite frequencies and additional peaks at zero or infinite frequency, as will be explained hereinafter. The design parameters of the partial networks in Figs. 10 and 11 are the cut-off frequency f_c , which is the same as the cut-off of the network as a whole, and the characteristic impedance K' . In this case, however, the characteristic impedances K' and K'' of the partial networks shown, respectively, as the impedance branches Z_a and Z_b in the equivalent circuit of Fig. 3 are not made equal to the characteristic impedance K of the network as a whole, but are given by the expressions

$$K' = \frac{K}{\sqrt{2}} \quad (4)$$

and

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

peak at some finite frequency, and may have additional peaks located at zero or infinite frequency. The values of the resistances R_1 and R_2 may fall anywhere within the ranges previously given, so long as they always satisfy Equation (3). The case where R_1 is equal to K and R_2 is zero is of particular importance because under these conditions an attenuation peak will occur at a finite frequency and a second peak at zero or infinite frequency, depending upon whether the filter is of the high-pass or low-pass variety. In the case of a band-pass filter a peak may be obtained on each side of the transmission band as well as two additional peaks, one located at zero and the other at infinite frequency.

If the partial networks of the circuit shown in Fig. 10 are low-pass filters of the constant- k type there will be obtained the network shown in Fig. 12, a high-pass filter in which the series impedances are the inductances L and the shunt impedances are the capacitances C . The bridging branch consists of a capacitance of value $\frac{1}{2}C$ and the impedance in series with the resistance R_2 is an inductance of value $\frac{1}{2}L$. If R_1 is given a value less than K' the impedance Z_a of the series arm of the equivalent lattice structure will be as shown symbolically in Fig. 13 by curve 15, and a peak of attenuation will occur at the frequency f_1 where the impedance Z_a equals K . For the sake of simplicity the impedance Z_b , which is the inverse of the impedance Z_a with respect to K , is not given in Fig. 13, but it will cross curve 15 at the frequency f_1 . The resulting attenuation characteristic of the network of Fig. 12 is given in Fig. 14 by curve 16, where it is seen that the attenuation is a finite value A_1 at zero frequency, rises to a peak at the frequency f_1 and falls off to zero at the cut-off, above which extends the transmission band.

If R_1 is made equal to K' the impedance of Z_a 40 will be as shown by curve 17 of Fig. 13 which crosses the K line at the frequency f_2 , indicating an attenuation peak at this point. Curve 18 of Fig. 14 gives the corresponding attenuation characteristic, starting at a value A_2 at zero frequency and rising to a peak at f_2 . When R_1 is given a value falling between K and K' the impedance Z_a will be of the form represented by curve 19 of Fig. 13, equalling K at the frequency f_3 . The attenuation characteristic resulting is 50 given in Fig. 14 by curve 20, which starts at a value A_3 at zero frequency, falls to a minimum and then rises to a peak at the frequency f_3 .

If R_1 is made equal to K and R_2 is zero, which is the preferred embodiment of the invention, the 55 impedance Z_a will be as shown in Fig. 13 by curve 21, which crosses the K line twice, once at zero frequency and again at f_4 , indicating peaks of attenuation at two points. The corresponding attenuation characteristic, given by curve 22 of Fig. 60 14, starts at infinity at zero frequency, falls to a minimum and then rises again to a peak at the frequency f_4 . It will be noted that as the value of the resistance R_1 is increased the peak of attenuation is moved progressively closer to the cut-off frequency f_c , making it possible to obtain a more steeply rising attenuation characteristic at the cut-off. It may be observed further that when R_1 falls between zero and K' the attenuation characteristic starts at some finite value at 70 zero frequency and steadily rises to a maximum at the peak frequency, whereas if R_1 falls between K' and K the attenuation starts at a finite value, falls to a minimum and then rises until the peak is reached.

These networks will always have an attenuation

An alternative configuration for the network of Fig. 12 is given in Fig. 15, which follows the form of Fig. 11.

Figs. 16 and 17 show band-pass filters in accordance with Figs. 10 and 11, respectively. The partial networks are band-elimination filters of the constant- k type designed on the basis of a characteristic impedance K' equal to

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

with the cut-off frequencies located at f_a and f_b , the cut-offs of the filter as a whole. When the resistance R_1 is equal to K' the impedance Z_a in the two transmission bands of the partial networks will have the form shown in Fig. 18 by curve 23, becoming equal to K at the two frequencies f_m and f_n , at which points peaks of attenuation will occur. Curve 24 of Fig. 19 gives the resulting attenuation characteristic, which has a finite value at zero frequency, rises to a peak at f_m , falls to zero at the lower cut-off f_a , again rises from the upper cut-off f_b to the second peak at f_n and then falls away to a finite value at infinite frequency. If R_1 is made equal to K and R_2 is zero the impedance Z_a will be as shown by curve 25 of Fig. 18 and the corresponding attenuation characteristic, given by curve 26 of Fig. 19, will have an infinite value at both zero and infinite frequency as well as having the two attenuation peaks located, respectively, at the frequencies f_p and f_q . The peaks of attenuation may be placed at other frequencies, if desired, by properly choosing the values of R_1 and R_2 , always maintaining the relationship expressed by Equation (3).

Figs. 20 and 21 show band-elimination filters which follow the structures shown, respectively, in Figs. 10 and 11. Peaks may be provided in the attenuation characteristics of these networks in the same manner as described above in connection with the other types of filters.

What is claimed is:

1. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and a respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one-half on either side thereof, a shunt branch connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

2. A wave transmission network having a pair of input terminals, and a pair of output terminals, said network comprising an electrical path between each input terminal and its respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one-half on either side thereof, a shunt branch comprising a resistance connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal

connected to a point in said shunt branch, and a bridging branch connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

3. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising a T-network consisting of a pair of equal series resistances in one side of the line and a shunt impedance branch connected between the common terminal of said series resistances and the other side of the line, a pair of similar ladder-type partial networks connected to said T-network and extending to either side thereof, and a bridging branch connected between an input terminal and a respectively associated output terminal.

4. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising electrical paths between each input terminal and a corresponding output terminal, a pair of equal resistances connected in series in one of said paths, an even number of series impedances Z_1 connected in series with said resistances, one-half on either side thereof, a shunt branch comprising an impedance of value $\frac{1}{2}Z_1$ connected between the junction point of said resistances and a point in the other of said paths, a plurality of shunt impedances Z_2 alternately disposed with respect to said series impedances, all of said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch of value $2Z_2$ connected from a point in said first mentioned path on one side of said resistances to a symmetrically located point on the other side of said resistances, the impedances Z_1 and Z_2 having a product that is a constant quantity at all frequencies.

5. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a plurality of series impedances connected in series with said resistances, one-half on either side thereof, a plurality of shunt impedances alternately disposed with respect to said series impedances, one of said shunt impedances being connected to each junction point formed in said first mentioned path and all of said shunt impedances having a common terminal connected to a point in said other path, and a bridging branch connected between an input terminal and a respectively associated output terminal.

6. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a bridging branch connected in parallel with said resistances between the outer terminals thereof, a shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances connected in series with said resistances, one-half on either side thereof, and a plurality of shunt impedances alternately disposed with respect to said series impedances, all of said shunt impedances having a common terminal connected to a point in said shunt branch.

7. A wave transmission network comprising a pair of input terminals and a pair of output terminals

minals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a pair of equal impedances connected in series with said resistances, one on either side thereof, a shunt branch connected between the common terminal of said pair of resistances and a point in the other of said paths, said shunt branch comprising a resistance connected in series with an impedance of the same type as said series impedances, a pair of equal shunt impedances alternately disposed with respect to said series impedances, each of said shunt impedances being connected between a terminal of one of said series impedances and a point in the other of said paths, and a bridging branch connected between an input terminal and a respectively associated output terminal of said network.

8. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal impedances connected in series in one of said paths, a pair of equal resistances connected in series between said pair of equal impedances, a shunt branch connected between the common terminal of said resistances and a point in the other of said paths, said shunt branch comprising a resistance connected in series with an impedance of the same type as said pair of equal impedances, a second pair of equal impedances having a common terminal connected to a point in said shunt branch, the other terminals of said second pair of equal impedances being connected respectively to symmetrically located points in said first mentioned path, and a bridging branch connected in parallel with said pair of equal resistances between the outer terminals thereof, said bridging branch comprising an impedance of the same type as said last mentioned pair of equal impedances.

9. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a pair of equal impedances Z_1 , Z_1 connected in series with said resistances, one on either side thereof, a shunt branch connected between the common terminal of said resistances and a point in the other of said paths, said shunt branch comprising an impedance equal to $\frac{1}{2}Z_1$, a second pair of equal impedances Z_2 , Z_2 , one being connected between each outer terminal of said pair of resistances and a point in the other of said paths, and an impedance equal to $2Z_2$ connected between an input terminal and a respectively associated output terminal, the impedances Z_1 and Z_2 having a product that is a constant quantity at all frequencies.

10. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal impedances Z_1 , Z_1 connected in series in one of said paths, a pair of equal resistances connected in series between said pair of equal impedances, a shunt branch connected between the common terminal of said pair of resistances and a point in the other of said paths, said shunt branch comprising an impedance equal to $\frac{1}{2}Z_1$,

a second pair of equal impedances Z_2 , Z_2 having a common terminal connected to a point in said shunt branch and having their other terminals connected respectively to an input terminal and a respectively associated output terminal, and an impedance equal to $2Z_2$ connected in parallel with said pair of resistances between the outer terminals thereof, the impedances Z_1 and Z_2 having a product that is a constant quantity at all frequencies.

11. A wave transmission network having a constant non-reactive characteristic impedance over a wide range of frequencies both within and without the transmission range, said network comprising a pair of input terminals and a pair of output terminals, an electrical path between each input terminal and a respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one half on either side thereof, a shunt branch connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

12. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising electrical paths between each input terminal and a respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one-half on either side thereof, a shunt branch of the same type as said series impedances connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

13. A wave transmission network having a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one-half on either side thereof, a shunt branch connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch of the same type as said plurality of equal shunt impedances connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

14. A wave transmission network having a pair of input terminals and a pair of output terminals,

said network comprising an electrical path between each input terminal and the respectively associated output terminal, a pair of resistances connected in series in one of said paths, a plurality of equal series impedances connected in series with said resistances, one-half on either side thereof, a shunt branch of the same type as said series impedances connected between the junction point of said resistances and a point in the other of said paths, a plurality of equal shunt impedances alternately disposed with respect to said series impedances, said shunt impedances having a common terminal connected to a point in said shunt branch, and a bridging branch of the same type as said plurality of equal shunt impedances connected from a point in said first mentioned path on one side of said resistances to the corresponding point on the other side of said resistances.

15. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a bridging branch connected in parallel with said resistances between the outer terminals thereof, a shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances of the same type as said shunt branch connected in series with said resistances, one-half on either side thereof, and a plurality of shunt impedances of the same type as said bridging branch alternately disposed with respect to said series impedances, all of said shunt impedances having a common terminal connected to a point in said shunt branch.

16. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a bridging branch connected in parallel with said resistances between the outer terminals thereof, a shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances of the same type as said shunt branch connected in series with said resistances, one-half on either side thereof, and a plurality of shunt impedances alternately disposed with respect to said series impedances, all of said shunt impedances having a common terminal connected to a point in said shunt branch.

17. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a bridging branch connected in parallel with said resistances between the outer terminals thereof, a

shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances connected in series with said resistances, one-half on either side thereof, and a plurality of shunt impedances of the same type as said bridging branch alternately disposed with respect to said series impedances, all of said shunt impedances having a common terminal connected to a point in said shunt branch.

18. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances of the same type as said shunt branch connected in series with said resistances, one-half on either side thereof, a plurality of shunt impedances alternately disposed with respect to said series impedances, and a bridging branch of the same type as said plurality of shunt impedances connected between an input terminal and a respectively associated output terminal.

19. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a central shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances of the same type as said central shunt branch connected in series with said resistances, one-half on either side thereof, a plurality of shunt impedances alternately disposed with respect to said series impedances, and a bridging branch connected between an input terminal and a respectively associated output terminal.

20. A wave transmission network comprising a pair of input terminals and a pair of output terminals, said network comprising an electrical path between each input terminal and the corresponding output terminal, a pair of equal resistances connected in series in one of said paths, a shunt branch connected between the common terminal of said series resistances and a point in the other of said paths, a plurality of series impedances connected in series with said resistances, one-half on either side thereof, a plurality of shunt impedances alternately disposed with respect to said series impedances, and a bridging branch of the same type as said plurality of shunt impedances connected between an input terminal and a respectively associated output terminal.

STEPHEN BOBIS.