

Aug. 27, 1940.

W. P. MASON

2,212,840

WAVE FILTER

Filed June 17, 1938

FIG. 1

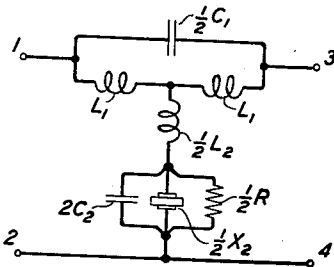


FIG. 2

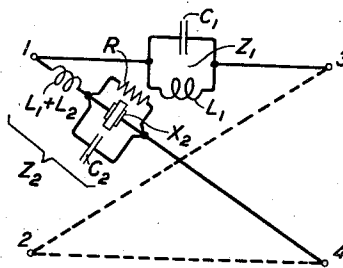


FIG. 4

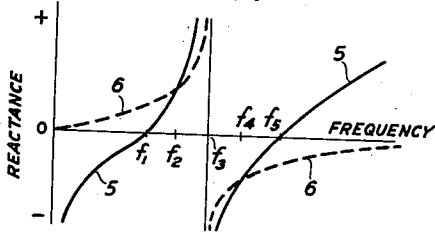


FIG. 6

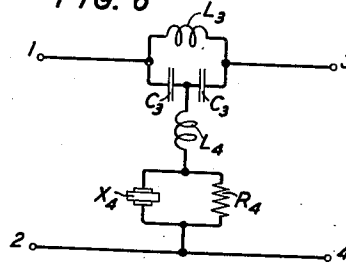


FIG. 5

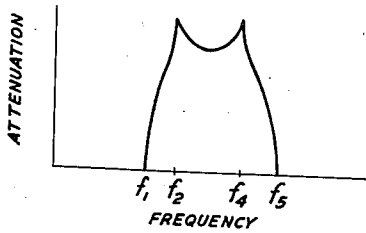


FIG. 7

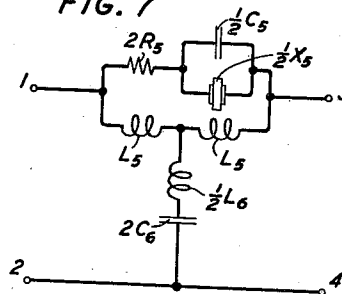


FIG. 9

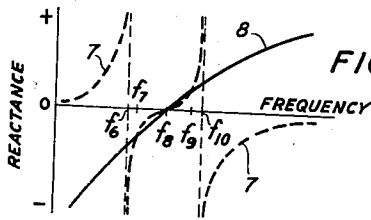


FIG. 8

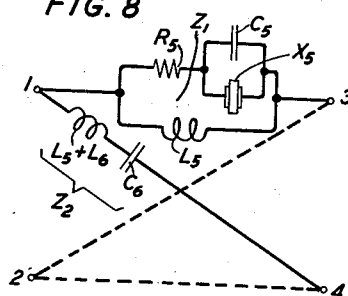
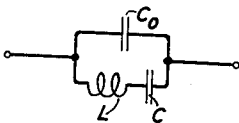


FIG. 3



INVENTOR
W. P. MASON

BY

Ralph P. Holcomb
ATTORNEY

UNITED STATES PATENT OFFICE

2,212,840

WAVE FILTER

Warren P. Mason, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application June 17, 1938, Serial No. 214,359

21 Claims. (Cl. 178-44)

This invention relates to frequency selective wave transmission networks in which piezoelectric crystals are used as impedance elements and more particularly to crystal filters of the band elimination type characterized by a single suppression range bounded by ranges of free transmission.

The principal object of the invention is to suppress a band of frequencies while affecting as little as possible the frequencies to either side of the band.

Other objects are a reduction in the number of component elements required in a band elimination crystal filter and the provision of a filter of this type for use in circuits having one side grounded.

In the United States Patent 1,967,250, issued July 24, 1934, there are disclosed broad band crystal filters of the bridged-T type which have a single transmission band. In accordance with the present invention there are provided wave filters of this type having a single attenuation band with transmission bands on either side. Such filters are useful, for example, in carrier telephone systems where it is desired to suppress a carrier frequency without appreciably affecting the side-bands.

In their circuit arrangement the filters of the invention comprise a pair of equal series impedance branches, an interposed shunt branch and a branch bridging equal portions of the series arms. The series branches are constituted by simple reactive impedances such as inductances or capacitances, and either the shunt branch or the bridging branch includes a piezoelectric crystal. The crystal may be shunted by an added capacitance to narrow the attenuation band, an inductance may be included in the shunt branch to widen the band, and a resistance may be added to one of the branches to improve the suppression at the frequency of maximum attenuation. When the two series impedances are inductances, they may be inductively coupled to provide in effect a third inductance in the shunt branch.

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

Fig. 1 is a schematic circuit of a bridged-T band elimination filter showing one embodiment of the invention;

Fig. 2 shows a lattice network which is equivalent in its transmission properties to the filter in Fig. 1;

Fig. 3 is an equivalent electrical circuit for a piezoelectric crystal;

Fig. 4 shows the reactance characteristics of the different impedance branches of the equivalent lattice shown in Fig. 2;

Fig. 5 represents a typical attenuation characteristic obtainable with the filters of Figs. 1 and 2;

Fig. 6 shows an alternative bridged-T structure for the filter of Fig. 1;

Fig. 7 shows another embodiment of the invention in a bridged-T network;

Fig. 8 is an equivalent lattice for the filter of Fig. 7; and

Fig. 9 represents the reactance characteristics of the impedance branches of the lattice network of Fig. 8.

A band elimination crystal filter in accordance with the invention is shown schematically in Fig. 1 which is a bridged-T structure having a pair of input terminals, 1, 2 and a pair of output terminals 3, 4 by means of which the network may be connected to suitable load impedances. The T-network comprises a pair of equal series inductances each of value L_1 and an interposed shunt branch which includes an inductance

$$\frac{1}{2}L_2$$

in series with the parallel-connected combination comprising a capacitance $2C_2$, a resistance

$$\frac{1}{2}R$$

and a piezoelectric crystal designated by its impedance

$$\frac{1}{2}X_2$$

The bridging branch consists of a capacitance of value

$$\frac{1}{2}C_1$$

connected between the outer terminals of the series inductances L_1 . The network is unbalanced in form and the path connecting terminals 2 and 4 may be grounded or otherwise fixed in potential, if desired.

The crystal used in the filter is preferably of quartz in the form of a relatively narrow rectangular plate cut with its plane perpendicular to the electrical axis and its greater length in the direction of the mechanical axis. The electrodes are applied to the faces perpendicular to the electrical axis and the crystal is mounted so that

it is free to vibrate by expansion and contraction along the mechanical axis in response to alternating potentials applied to the electrodes. Other well-known types of crystal cuts may be employed, and in some instances they may be preferred.

The bridged-T network of Fig. 1 is equivalent in its transmission properties to the symmetrical lattice structure shown schematically in Fig. 2. The equivalence of the two circuits can be demonstrated by an application of A. C. Bartlett's bisection theorem given in the London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, vol. 4, No. 24, November, 1927, page 902. The lattice network consists of two similar series impedance branches Z_1 and two similar lattice branches Z_2 . In this figure and in Fig. 3, for the sake of simplicity, only one series branch and one lattice branch are shown in detail. The other corresponding branches are indicated by dotted lines.

In Fig. 2 each series branch Z_1 consists of an inductance L_1 and a capacitance C_1 connected in parallel. Each lattice branch Z_2 is made up of an inductance, equal in value to the sum of L_1 and L_2 , in series with the parallel combination comprising the capacitance C_2 , the resistance R and the crystal impedance X_2 . It is seen that the equivalent lattice of Fig. 2 is made up of the same component impedance elements that appear in the bridged-T filter of Fig. 1 but some of the values are changed by a factor of two.

For the purpose of filter design a quartz crystal of the type described above may be considered to have the equivalent electrical circuit shown in Fig. 3, comprising a capacitance C_0 in parallel with a branch consisting of an inductance L in series with a capacitance C . The elements of the equivalent circuit may be evaluated in terms of the crystal dimensions from the following formulae:

$$L = \frac{106.1lt}{w} \text{ henries} \quad (1)$$

$$C = \frac{0.322wl}{t10^{14}} \text{ farads} \quad (2)$$

$$C_0 = \frac{40.2wl}{t10^{14}} \text{ farads} \quad (3)$$

in which l , w and t are respectively the length, width and thickness of the crystal plate measured in centimeters.

When the equivalent circuit of Fig. 3 is substituted for the crystal X_2 in Fig. 2 the lattice branch Z_2 of the network is found to have a reactance-frequency characteristic of the type represented by the solid line curve 5 of Fig. 4. The branch has resonances at the frequencies f_1 and f_5 , and an anti-resonance at the intermediate frequency f_3 . The series branch Z_1 has a frequency characteristic such as is shown by the dotted line curve 6, with a single anti-resonance and no resonances at frequencies other than zero and infinity.

The propagation constant P of the filter of Fig. 2 is given by the expression:

$$\tanh \frac{P}{2} = \sqrt{\frac{Z_1}{Z_2}} \quad (4)$$

from which it follows that there will be free transmission in the regions where the reactances Z_1 and Z_2 are of different signs and at attenuation band where these reactances have the same sign, with attenuation peaks where Z_1 is equal to Z_2 . Referring to Fig. 4 it is apparent that, if the

anti-resonance of Z_1 is made to coincide with the anti-resonance of Z_2 , there will be an attenuation band extending from f_1 to f_5 , in the region where the two reactances have the same sign, and peaks of attenuation will occur at the frequencies f_2 and f_4 where the curves 5 and 6 cross. Below f_1 and above f_5 extend transmission bands, since in these regions the reactances are of opposite sign. A typical attenuation characteristic obtainable with the network of Fig. 2 is given in Fig. 5 and, by virtue of the equivalence pointed out above, this also represents the characteristic obtainable with the bridged-T filter of Fig. 1.

The computation of the values of the component circuit elements of Fig. 2, including the electrical elements equivalent to the crystal as given in Fig. 3, from the resonance and anti-resonance frequencies can be carried out directly by an application of the reactance theorem given by R. M. Foster in the Bell System Technical Journal, vol. III, No. 2, April, 1924, pages 259 to 267. The values of the circuit elements to be used in the bridged-T filter are obtained from the values of the elements required for the lattice structure by means of the numerical multipliers indicated in Fig. 1. Thus the crystal in the shunt branch will have one-half the impedance of the corresponding crystal in the lattice network. This proportion can be obtained by changing the size of the crystal without altering the frequency which determines its vibration frequency.

In order to improve the suppression of the filter at the peaks of attenuation it is desirable that the resistive components as well as the reactive components of the series branch Z_1 and the lattice branch Z_2 should balance at these frequencies. The resistance

$$\frac{1}{2}R$$

in the shunt branch of Fig. 1, which appears as the resistance R in the lattice branch of Fig. 2, is added for this purpose. The value of this resistance is so chosen that the resistive components of Z_1 and Z_2 balance as nearly as possible at the frequencies f_2 and f_4 . In this way the height of the attenuation peaks is increased.

In the circuit of Fig. 1 the shunt inductance

$$\frac{1}{2}L_2$$

may be omitted if each series inductance L_1 is increased in value by an amount equal to

$$\frac{1}{2}L_2$$

and the two inductances are connected in the series opposing relationship with a mutual inductance equal to

$$\frac{1}{2}L_2$$

coupling them. This modification will result in a saving of one element without affecting the transmission characteristic of the filter.

Fig. 6 shows an alternative structure for the filter of Fig. 1. Fig. 6 is a bridged-T network in which the equal series arms are constituted by the capacitances C_3 , the bridging branch is the inductance L_3 and the shunt branch consists of an inductance L_4 in series with a crystal X_4 which is shunted by a resistance R_4 . The Z_1 and Z_2 impedance branches of the equivalent lattice will have reactance characteristics of the type shown, respectively, by the curves 6 and 5 of

Fig. 4 and the attenuation characteristics will be of the same type as that given in Fig. 5.

Fig. 7 shows another embodiment of the invention in a bridged-T structure in which the series arms are the inductances L_5 , the shunt branch consists of an inductance of value

$$\frac{1}{2}L_6$$

in series with a capacitance of value $2C_6$, and the bridging branch comprises a resistance $2R_5$ in series with a crystal of impedance

$$\frac{1}{2}X_5$$

shunted by a capacitance

$$\frac{1}{2}C_5$$

As explained above in connection with Fig. 1 the inductance

$$\frac{1}{2}L_6$$

in the shunt branch may be dispensed with by increasing the value of the series inductances L_5 and introducing inductive coupling.

The equivalent lattice for the filter of Fig. 7 is given in Fig. 8, in which the component elements have the values indicated. The reactance characteristics of the series branch Z_1 and the lattice branch Z_2 are given, respectively, by the curves 7 and 8 of Fig. 9. The series branch has anti-resonances at the frequencies f_6 and f_{10} , and a resonance at the intervening frequency f_8 . The lattice branch has but a single resonance and in order to provide a band elimination filter with a single suppression range the resonance frequencies of the two branches are made to coincide. The filter will have the same type of attenuation characteristic as is shown in Fig. 5 with an attenuation band extending from f_6 to f_{10} having peaks at f_7 and f_9 , and free transmission outside of this region. The resistance R_5 is added to help balance the resistive components of the impedance branches of the equivalent lattice and thereby increase the attenuation at the peaks.

In the filters of Figs. 1 and 7 the widest suppression bands are obtained when the capacitances shunting the crystals are omitted, and when this is done the maximum band width is approximately ten per cent of the mid-band frequency. By the addition of shunt capacitances of the required value, such as

$$2C_2 \text{ and } \frac{1}{2}C_5$$

any desired band width less than this may be obtained.

For band widths of about 0.8 per cent or less it will be found that the attenuation distortion in the transmission bands can be reduced and an element can be saved by the elimination of the shunt coils

$$\frac{1}{2}L_2 \text{ and } \frac{1}{2}L_6$$

in the filters of Figs. 1 and 7, respectively. The impedance branches of the equivalent lattice will have the same type of reactance characteristics as given in Figs. 4 and 9 but it will be found desirable to employ a somewhat different distribution of the critical frequencies.

In Fig. 4 the anti-resonance of the series branch Z_1 is moved from f_3 to f_5 and thus made to coincide with the upper resonance of the lattice branch

Z_2 . The limits of the suppression band for the modified filter will then be f_1 and f_3 , with a single peak of attenuation at some intermediate frequency at which the two curves will cross. In Fig. 9 the resonance of the lattice branch Z_2 is moved up to the upper anti-resonance frequency f_{10} of the series branch Z_1 . The band limits for this modified filter will now be f_6 and f_8 , with an attenuation peak at a frequency falling between these two.

What is claimed is:

1. A band elimination wave filter of the bridged-T type comprising a pair of equal series reactances and a shunt impedance branch connected between a pair of input terminals and a pair of output terminals to form a symmetrical T network, and a bridging impedance branch including a reactance of opposite type to said equal reactances connected between the outer terminals thereof, said shunt impedance branch including a piezoelectric crystal and an inductance connected in series, the impedance formed by the parallel combination of said bridging branch and the series reactances of said T network having a different reactance-frequency characteristic from that of the series combination of the series and shunt branches of said T network and being proportioned with respect thereto and to two preassigned frequencies to provide a single attenuation band between said frequencies.

2. A band elimination wave filter of the bridged-T type comprising a pair of input terminals, a pair of output terminals, a bridging impedance branch including a reactance of one type connected directly between an input terminal and an output terminal, a pair of equal reactances of opposite type to said first-mentioned reactance having a common terminal and having their other terminals connected respectively to the terminals of said bridging branch, and a shunt impedance branch having one terminal connected to said common terminal and having connections from its other terminal to the remaining input terminal and output terminal, said shunt impedance branch including a piezoelectric crystal and an inductance connected in series, the impedance formed by the parallel combination of said bridging branch and said equal reactances having a different reactance-frequency characteristic from that of the series combination of one of said equal reactances and said shunt branch and being proportioned with respect thereto and to two preassigned frequencies to provide between said frequencies a single attenuation band bounded on either side by transmission bands.

3. A band elimination wave filter of the bridged-T type having a pair of input terminals and a pair of output terminals, said filter comprising an electrical path between each input terminal and a corresponding output terminal, a pair of equal reactances connected in series in one of said paths, a bridging impedance branch including a reactance of opposite type to said equal reactances connected between the outer terminals thereof, and a shunt impedance branch connected between the junction point of said equal reactances and a point in the other of said paths, said shunt impedance branch including a piezoelectric crystal and an inductance connected in series, the impedance formed by the parallel combination of said bridging branch and said equal reactances having a different reactance-frequency characteristic from that of the series combination of one of said equal reactances and said shunt branch and being proportioned with respect to

thereto and to two preassigned frequencies other than zero or infinity to provide between said frequencies a single attenuation band bounded on each side by a transmission band.

- 5 4. A band elimination wave filter in accordance with claim 1 in which said two preassigned frequencies are other than zero or infinity and said attenuation band is bounded on either side by transmission bands.
- 10 5. A band elimination wave filter in accordance with claim 1 in which said equal series reactances are inductances.
6. A band elimination wave filter in accordance with claim 1 in which said equal series reactances
- 15 are capacitances.
7. A band elimination wave filter in accordance with claim 1 in which said crystal is shunted by an added capacitance to decrease the width of the attenuation band.
- 20 8. A band elimination wave filter in accordance with claim 1 in which an added resistance is included in one of said impedance branches for the purpose of increasing the attenuation of the filter at a peak of attenuation.
- 25 9. A band elimination wave filter in accordance with claim 1 in which said crystal is shunted by an added resistance to increase the height of an attenuation peak.
10. A band elimination wave filter in accordance with claim 1 in which said crystal is shunted by a resistance and an added capacitance.
- 30 11. A band elimination wave filter of the bridged-T type having a pair of input terminals and a pair of output terminals, said filter comprising an electrical path between each input
- 35 terminal and a corresponding output terminal, a pair of equal inductances connected in series in one of said paths, a capacitance connected in parallel with said inductances between the outer
- 40 terminals thereof, and a shunt impedance branch including a piezoelectric crystal and a third inductance in series connected between the junction point of said equal inductances and a point
- 45 in the other of said paths, the component impedance elements constituting said filter being proportioned to provide a single attenuation band.
12. A band elimination wave filter in accordance with claim 11 in which said crystal is shunted by an added capacitance to decrease the width
- 50 of the attenuation band.
13. A band elimination wave filter of the bridged-T type having a pair of input terminals and a pair of output terminals, said filter comprising an electrical path between each input
- 55 terminal and a corresponding output terminal, a pair of equal capacitances connected in series in

one of said paths, an inductance connected in parallel with said capacitances between the outer terminals thereof, and a shunt impedance branch including a piezoelectric crystal in series with a second inductance connected between the junction point of said capacitances and a point in the other of said paths, the component impedance elements constituting said filter being proportioned to provide a single attenuation band.

14. A band elimination wave filter of the bridged-T type having a pair of input terminals and a pair of output terminals, said filter comprising an electrical path between each input terminal and a corresponding output terminal, a pair of equal inductances connected in series in one of said paths, a bridging impedance branch including a piezoelectric crystal connected in parallel with said inductances between the outer terminals thereof, and a shunt impedance branch including a capacitance and a third inductance in series connected between the junction point of said pair of inductances and a point in the other of said paths, the component impedance elements constituting said filter being proportioned to provide a single attenuation band.

15. A band elimination wave filter in accordance with claim 14 in which said crystal is shunted by an added capacitance to decrease the width of the attenuation band.

16. A band elimination wave filter in accordance with claim 14 in which said bridging impedance branch includes a resistance added to increase the height of an attenuation peak.

17. A band elimination wave filter in accordance with claim 14 in which said bridging impedance branch includes an added resistance connected in series with said crystal and an added capacitance connected in shunt with said crystal.

18. A band elimination wave filter in accordance with claim 11 in which a resistance is included in said shunt branch to increase the height of an attenuation peak.

19. A band elimination wave filter in accordance with claim 11 in which a resistance and a second capacitance are connected in shunt with said crystal.

20. A band elimination wave filter in accordance with claim 13 in which said shunt impedance branch includes a resistance added to increase the height of an attenuation peak.

21. A band elimination wave filter in accordance with claim 13 in which a resistance is connected in shunt with said crystal.