

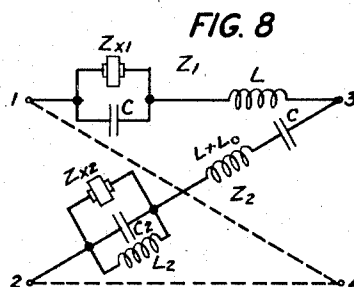
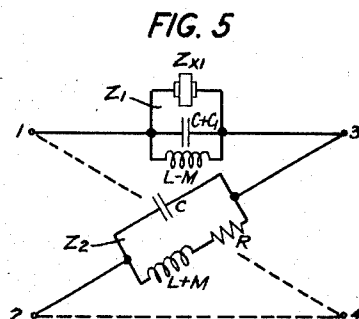
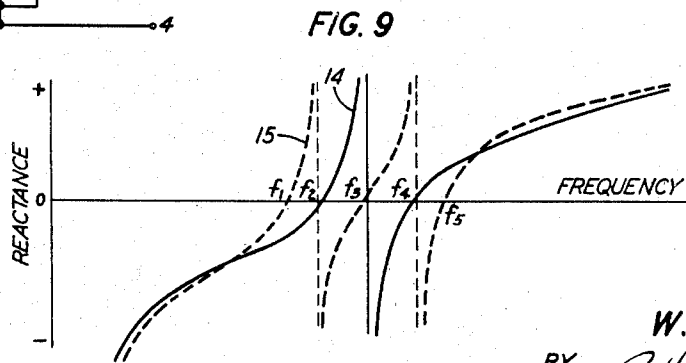
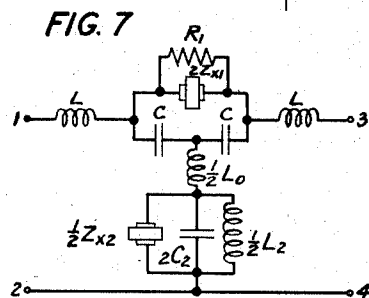
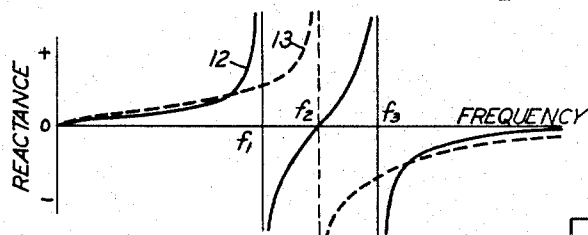
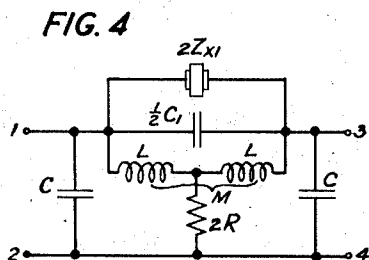
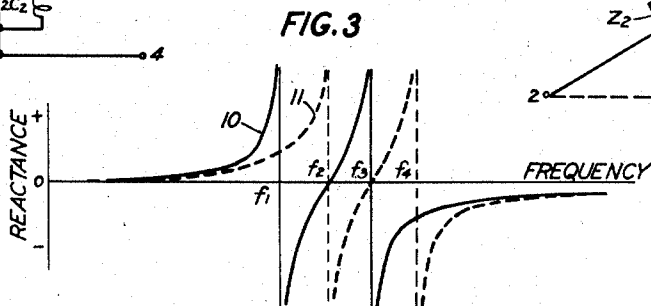
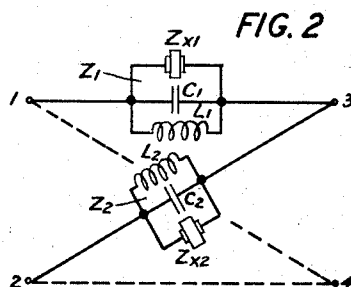
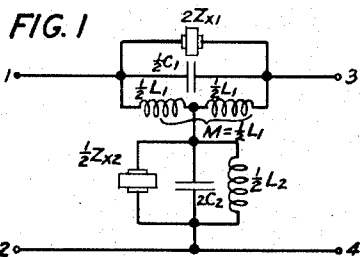
July 24, 1934.

W. P. MASON

1,967,250

WAVE FILTER

Original Filed Oct. 17, 1930



INVENTOR
W. P. MASON
BY *G. H. Stevenson*
ATTORNEY

UNITED STATES PATENT OFFICE

1,967,250

WAVE FILTER

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

Continuation of application Serial No. 489,268,
October 17, 1930. This application January 26,
1933, Serial No. 653,621. In Canada September
19, 1931

4 Claims. (Cl. 178-44)

This invention relates to broad band wave filters in which piezo-electric crystals are used as impedance elements and has for its principal object a reduction in the number of crystal elements required for a desired transmission characteristic.

This application includes subject matter relating to wave filters of the bridged-T type disclosed in my earlier co-pending application Serial No. 489,268, filed October 17, 1930 of which this application is a continuation.

In accordance with the invention, broad band wave filters are provided which not only require a minimum number of piezo-electric crystals but also permit relatively wide transmission bands to be obtained while retaining the sharpness of selectivity characteristic of piezo-electric crystals. In addition the filters of the invention are suitable for use in transmission circuits having one side grounded.

In their circuit arrangement the filters of the invention take the form of a bridged-T network in which the series branches of the T are constituted by simple reactive impedances such as inductances or capacities and the shunt and bridging arms include the piezo-electric elements.

The invention will be more fully understood from the following detailed description and by reference to the appended drawing of which,

Fig. 1 shows one embodiment of the invention;

Fig. 2 represents the lattice prototype of Fig. 1; Fig. 3 shows the impedance characteristics of Fig. 1;

Figs. 4, 5, and 6 show respectively the circuit arrangement, the prototype lattice and the impedance characteristics of a second form of the invention, and

Figs. 7, 8 and 9 show respectively the circuit arrangement, the prototype and the impedance characteristics of a third form.

The filter of Fig. 1, which is of the band-pass type, comprises a T network the series arms of which are constituted by equal inductances of value $\frac{1}{2}L_1$ coupled inductively aiding with unity coupling, and the shunt branch of which includes an inductance $\frac{1}{2}L_2$, a capacity $2C_2$, and a piezo-electric crystal designated by its impedance $\frac{1}{2}Z_{21}$, all connected in parallel. The bridging branch comprises a capacity $\frac{1}{2}C_1$ and a piezo-electric crystal of impedance $2Z_{11}$ connected in parallel. Preferably quartz crystals should be

used in the form of relatively narrow rectangular plates cut perpendicular to the electrical axis of the crystal and with their lengths in the direction of the mechanical axis. Such crystals will vibrate longitudinally when subject to alternating potentials between electrodes on their larger surfaces.

Since this network is symmetrical with respect to its input terminals 1, 2 and its output terminals 3, 4, its properties may be investigated most conveniently from a consideration of the symmetrical lattice network to which it is equivalent. The equivalent lattice, which may be developed by means of the bi-section theorem of A. C. Bartlett, Philosophical Magazine (London) vol. 4, No. 24, November, 1927, p. 902, is shown in Fig. 2. It comprises line impedances Z_1 consisting of a crystal impedance Z_{11} , a capacity C_1 and an inductance L_1 all connected in parallel, and lattice impedances Z_2 made up of a crystal impedance Z_{22} , a capacity C_2 , and an inductance L_2 in parallel. In the Fig. 2 only one line branch and one lattice branch are shown, the other branches being indicated by dotted lines. The branches of the equivalent lattice involve only the same impedance elements as appear in the circuit of Fig. 1.

For practical purposes quartz piezo-electric crystal may be considered as equivalent to an electrical impedance consisting of a simple series resonant circuit shunted by a condenser representing the electrostatic capacity of the crystal electrodes. Each of the impedance Z_1 and Z_2 of the lattice equivalent network may therefore be treated as a parallel combination of series resonant circuits, the paths containing only inductance being considered resonant at zero frequency and those with capacity only being resonant at infinite frequency.

The variation with frequency of the reactances of the Z_1 and Z_2 branches is illustrated by the curves of Fig. 3, curve 10 corresponding to Z_1 and curve 11 to Z_2 . Both branches exhibit the same type of frequency variation, the reactances being characterized by two anti-resonances with an intermediate resonance in addition to resonance at zero and infinite frequencies. The anti-resonances of Z_1 occur at frequencies designated f_1 and f_3 and the resonance at an intermediate frequency f_2 . Since a transmission band will occur wherever the reactances of Z_1 and Z_2 are of

opposite sign it follows that a single transmission band can be provided if Z_2 is so proportioned with respect to Z_1 that its first anti-resonance occurs at f_2 and its resonance at f_3 . The band will then extend from frequency f_1 to the second anti-resonance of Z_2 , designated f_4 . This, of course, will also be the band of the bridged T filter of Fig. 1.

The propagation constant P of the filter is given by the equation:

$$\tanh \frac{P}{2} = \sqrt{\frac{Z_1}{Z_2}} \quad (1)$$

from which it follows that the attenuation at frequencies outside the band will be infinite when Z_1 is equal to Z_2 and will be large so long as the two are nearly equal. To achieve this condition the inductances L_1 and L_2 should be nearly equal and the capacity C_1 plus the electrode capacity of the crystal Z_{e1} should be very nearly equal to the capacity C_2 plus the electrode capacity of Z_{e2} . While these conditions can be met within a variety of circuits they are most conveniently realized in circuits in which the inductance L_1 is proportioned to be anti-resonant with the capacity C_1 plus the associated crystal electrode capacity at the resonance frequency of the crystal, and L_2 is likewise proportioned with respect to its associated capacities. This is, in effect, a neutralization of the shunt capacities, including the electrode capacities in the frequency range of the transmission band. Calculation of the impedance of crystal and inductance combination proportioned in the above manner shows that the critical frequencies of the combination are so related that the intermediate resonance frequency is equal to the geometric mean of the two anti-resonance frequencies. The values of the three frequencies thus increase in accordance with a geometric series. If, therefore, as in Fig. 2, two pairs of such crystals are combined in a lattice network to form a wave filter the condition of frequency coincidence required for the provision of a single band necessarily gives rise to the result that the four critical frequencies of the system have values in accordance with a geometric series. In the case illustrated by Figs. 2 and 3, if each crystal-inductance combination is proportioned as described the critical frequencies will be so related that $f_1 f_3 = f_2^2$ and $f_2 f_4 = f_3^2$, from which it follows that the ratios f_2/f_1 , f_3/f_2 and f_4/f_3 are all constant. It is also found that the condition of capacity neutralization results in a minimum separation of the upper and lower critical frequencies for each crystal and hence results also in a minimum band width in the filter. The value of this minimum depends on the capacities C_1 and C_2 and may be increased up to about 14 per cent of the mean band frequency as these capacities are reduced towards zero. If the two branches are proportioned to have approximately the same effective capacities the inductances L_1 and L_2 will be approximately equal and high attenuation will be obtained. Further, if the coils constituting inductances L_1 and L_2 have substantially equal resistances, the effects of dissipation in the two branches will be balanced and will not affect the sharpness of selectivity due to the crystals.

The values to be used in the bridged-T circuit are obtained from the corresponding lattice values by means of the numerical multipliers indicated in Fig. 1. Thus, the bridging crystal must have twice the impedance of the corresponding lattice crystal and the shunt crystal one-half the impedance of its corresponding lat-

tice crystal. These proportions can be obtained by changing the size of the crystal without altering the dimension which determines its vibration frequency.

The computation of the values of the various circuit elements, including the electrical elements equivalent to the crystal, from the values of the resonance and anti-resonance frequencies can be carried out directly by means of the reactance theorem described by R. M. Foster in the Bell System Technical Journal, Vol. III, No. 2, April 1924, pages 259 to 267. The application of this method of computation to lattice type crystal filters is described in detail in my co-pending application Serial No. 653,622 filed January 26, 1933.

In the modified form of the invention shown in Fig. 4, a single crystal, designated by its impedance $2Z_{e1}$, is used connected in the bridging arm of the T. The T network comprises two loosely coupled inductances L in the series arm and a resistance designated $2R$ in the shunt arm. The coupling of the two inductances in this case is in the opposite sense to that in Fig. 1 so that there is in effect a positive inductance equal to the mutual inductance M added in the shunt arm of the T. The crystal is shunted by a capacity of value $\frac{1}{2}C$, and additional equal capacities C are connected in shunt at each end of the network. The equivalent symmetrical lattice is shown in Fig. 5, the shunting capacities C appearing as shunt condensers in each of the lattice branches and the inductances having the values $L-M$ and $L+M$ in the Z_1 and Z_2 branches, respectively.

The impedance of the Z_1 branch in Fig. 5 is of the same type as in Fig. 2 and consequently the reactance-frequency characteristic will be the same. This is illustrated by curve 12 of Fig. 6 which exhibits anti-resonances at frequencies f_1 and f_3 and a resonance at an intermediate frequency f_2 . The Z_2 branch is essentially a simple anti-resonant circuit including the capacity C and the inductance L increased by the mutual inductance M . This branch should be proportioned to be anti-resonant at frequency f_2 in which case a single transmission band extending from f_1 to f_3 is obtained. Preferably, the inductance $L-M$ of the Z_1 branch and the capacity $C+C_1$ plus the crystal electrode capacity should be anti-resonant at the crystal resonance frequency, that is at f_2 , thus neutralizing the capacity substantially throughout the transmission band. Since the inductance $L+M$ of the Z_2 branch must be anti-resonant with capacity C at the same frequency, this requirement determines the value of M or the degree of coupling. In general, the capacity C_1 may be omitted in which case the difference of the effective capacities of the two branches will be small and the difference of the two inductances likewise small thus making for high attenuation outside the band. It will be noted that the two curves of Fig. 6 cross at frequencies above and below the band. These crossing points correspond to peaks of infinite attenuation and, to provide a sharp cut-off, should be fairly close to the band limits. The capacity C_1 permits the location of these peaks to be controlled to some extent.

The resistance $2R$ is introduced into the shunt branch of the bridged T to neutralize the effect of the coil resistance. If the coils had no mutual inductance, the same shunt inductance would appear in each branch of the lattice network and the dissipative effects would be balanced.

Since mutual inductance is necessary to provide a single transmission band, this balance of the coil resistances is disturbed and the sharpness of cut-off is diminished. The resistance $2R$ should have the value given by the equation

$$\frac{R+r}{r} = \left(\frac{L+M}{L-M} \right)^2 \quad (2)$$

where r is the resistance of the coil windings.

The modification shown in Fig. 7 is characterized by the use of capacities instead of inductances as the series reactances of the T network. In this case, the shunt branch includes a crystal, a capacity and an inductance all in parallel together with a separate series inductance. The bridging impedance is a crystal and two equal inductances are added in series external to the bridged-T. The lattice equivalent is shown in Fig. 8, the Z_1 branches each comprising a crystal impedance Z_{x1} shunted by a capacity C , corresponding to the series impedance of the T and a series inductance L , corresponding to the external inductance. The Z_2 branches include an inductance of value $L+L_0$ and a capacity C as series elements and the parallel combination of crystal impedance Z_{x2} , capacity C_2 , and inductance L_2 . The reactance variation of the Z_1 impedance is shown by curve 14 of Fig. 9 and that of the Z_2 impedance by curve 15, the resonance and anti-resonance frequencies being designated f_1 to f_5 in ascending order. The frequency coincidences indicated by the figure are necessary to provide a single band from f_1 to f_5 .

In proportioning the elements of this network, the parallel combination in the Z_2 branch of the lattice may be designed so that inductance L_2 is anti-resonant with the capacity C_2 plus the crystal electrode capacity at the resonance frequency of the crystal. As already described in connection with Figs. 1 and 2, this will result in a geometric spacing of the critical frequencies of the parallel combination the value of which may be taken as the frequencies f_2 , f_3 , and f_4 of the whole branch. The impedance Z_1 may now be designed so that its critical frequencies coincide with f_2 , f_3 and f_4 . If now, the series combination of inductance $L+L_0$ and capacity C in Z_2 is also made resonant at f_3 frequencies f_2 , f_3 and f_4 will not be disturbed and the additional frequencies f_1 and f_5 will be introduced in symmetrical locations with respect to f_3 . Obviously the additional inductance $\frac{1}{2}L_0$, in the shunt branch of Fig. 7 may be obtained if desired by mutual inductance between the two external inductances in which case no additional dissipation is introduced into the shunt branch.

To balance the effect of dissipation in the inductance L_2 , a high resistance R_1 may be shunted across the bridging crystal. This balance, while not precise, can be adjusted by trial so that prac-

tically all the sharpness of selectivity of a non-dissipative structure is obtained.

It will be observed that in the lattice structure of Fig. 8 the capacity C which forms the series impedance of the T network in Fig. 7 appears as a series element in one impedance and as a shunt element in the other. This condition in general indicates the possibility of the direct conversion of a lattice network into a bridged-T. With this in mind it will be evident that many other bridged-T crystal filters besides those illustrated may be constructed in accordance with the invention.

What is claimed is:

1. A broad band wave filter comprising a pair of equal reactive impedances and a third impedance connected in series shunt relation between a pair of input terminals and a pair of output terminals to form a symmetrical T network, and a fourth impedance including a piezo-electric crystal connected to bridge equal portions of the series arms of said T network, the impedance formed by the parallel combination of said bridging impedance and the series impedances 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 a pair of preassigned frequencies to provide a single transmission band between said frequencies.

2. A broad band wave filter in accordance with claim 1 in which the series branches of the T network are constituted by a pair of equal inductances coupled together by mutual inductance, the total inductance of said inductances being such as to substantially neutralize the effective shunt capacity of the bridging crystal at its resonance frequency.

3. A broad band wave filter in accordance with claim 1 in which the series branches of the T network are constituted by equal capacities and in which equal series inductances are connected to said series branches external to the bridging crystal, said inductances being proportioned to substantially neutralize the effective shunt capacity of the crystal at the crystal resonance frequency.

4. A broad band wave filter in accordance with claim 1 in which the series branches of the T network are constituted by equal inductances inductively coupled in series aiding relation with substantially unity coupling, the total inductance of said inductances being such as to substantially neutralize the effective shunt capacity of the bridging crystal at its resonance frequency, and in which the shunt impedance of the T network comprises a piezo-electric crystal shunted by an inductance.

WARREN P. MASON.