

Jan. 12, 1943.

A. T. STARR

2,308,397

CRYSTAL FILTER CIRCUIT

Filed Nov. 13, 1940

2 Sheets-Sheet 1

Fig. 1

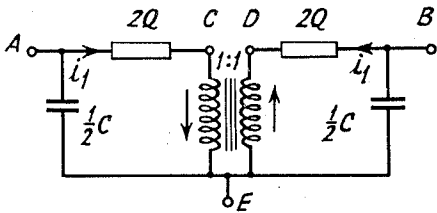


Fig. 2

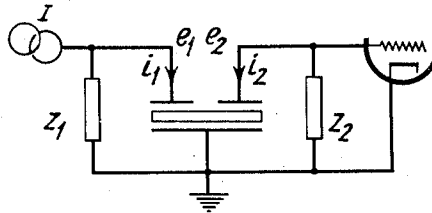


Fig. 3a

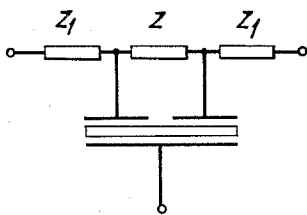


Fig. 3b

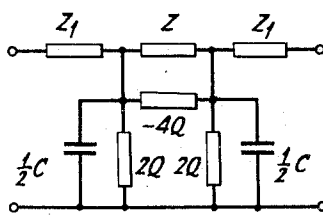


Fig. 3c

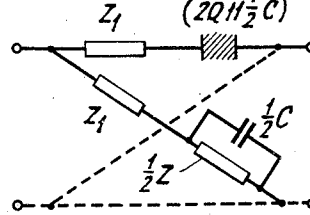


Fig. 3d

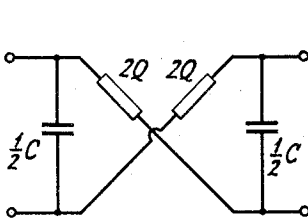


Fig. 3e

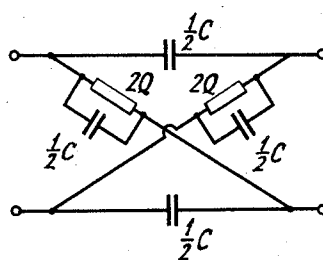


Fig. 4

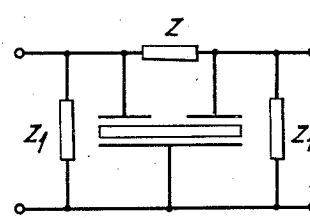


Fig. 5

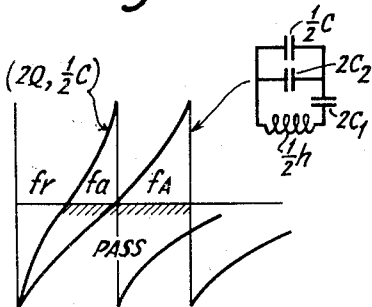
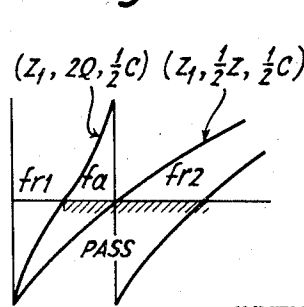


Fig. 6



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Fig. 7

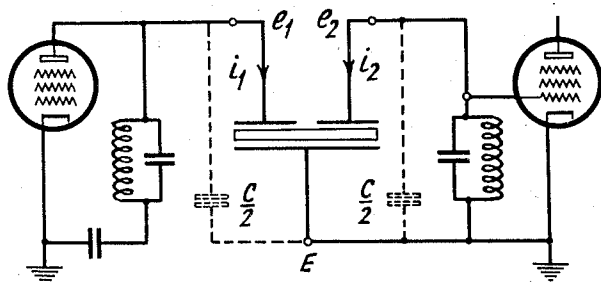


Fig. 8

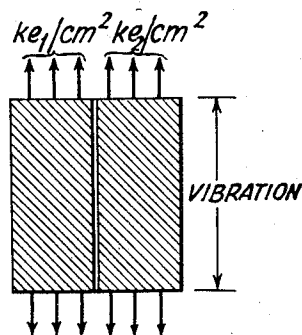


Fig. 9

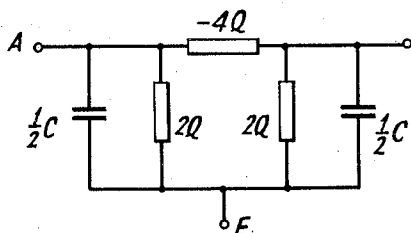
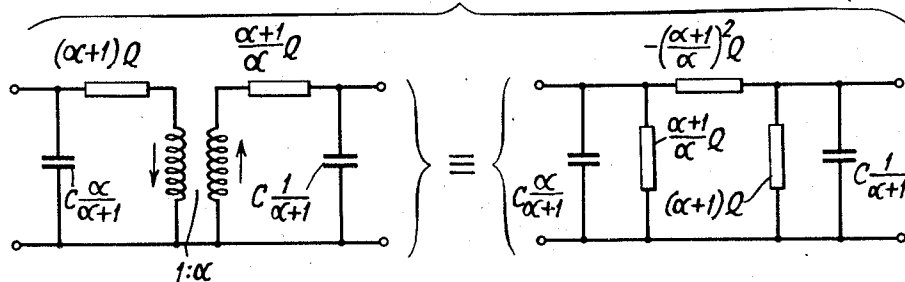


Fig. 10



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CRYSTAL FILTER CIRCUIT

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2 Claims. (Cl. 178-44)

The present invention relates to electric filter circuits, particularly to crystal filter circuits.

The use of three-electrode piezo-electric crystals, that is, piezo-electric crystals having two electrodes on one face separated by a narrow gap and one electrode on the other face, as coupling elements between circuits is known. The present invention arises out of the realization that three-electrode piezo-electric crystals have certain advantages which render them particularly suitable as elements in the construction and organization of filter circuits. For instance, where piezo-electric crystals, as ordinarily used, are employed in the construction of filter circuits, particularly of narrow pass-band filter circuits, the designs are complicated by the necessity of neutralizing the electrostatic capacitance of the crystal, but it is realized that the use of three electrode crystals, in accordance with the present invention would result in an automatic neutralization of this capacitance.

According to the invention in its broadest aspect a filter circuit includes a three-electrode piezo-electric crystal having on one side two electrodes of equal or unequal area separated by a separating gap and together with the separating gap, covering the whole or part of said one side and on the other side a single electrode covering the whole or part of said other side, said filter circuit having input and output terminals, one input terminal being connected to one of said electrodes on said one side of the crystal plate and one output terminal being connected to the other of said electrodes on said one side and the other input and output terminals being connected together and to the electrode on the said other side of said crystal, and an impedance connected between the two electrodes on said one side of the crystal.

According to a feature of the present invention, a filter circuit includes an input terminal, an output terminal, a second output terminal, a three-electrode piezo-electric crystal, having on one side two electrodes of equal or unequal area separated by a separating gap and together with the separating gap, covering the whole or part of said one side and on the other side a single electrode covering the whole or part of said other side, a first connection between the first said input terminal and one of said electrodes on said one side of said crystal, a second connection between the first said output terminal and the other of said electrodes on said one side of said crystal, a direct connection between said second input terminal and said second output terminal,

a connection between the electrode on the said other side of said crystal and said direct connection, an impedance connecting said first and said second connections, and impedances in the input and output circuits. The last mentioned impedances may be connected one in the first said connection and the other in the second said connection so that the three said impedances are in series, or they may be connected one between the first said connection and said direct connection and the other between the second said connection and said direct connection. The impedances may be of any suitable form, for example, crystals, inductances, or capacitances, or networks including such elements. Preferably, though not necessarily, the electrodes of the three-electrode piezo-electric crystal may be formed by plating the surfaces of the crystal, and the areas of the two electrodes on one side may have any desired ratio according to the design of filter of which the crystal constitutes an element. Moreover the two electrodes on one side, together with the separating gap may cover the whole of one side and the third electrode on the other side may cover the whole of the other side, or the surfaces may be partially plated as described in British Patent 538,946/1941. Although usually, with a proper design of crystal holder direct capacitance between the two electrodes on one side of the crystal is very small and thus renders such unnecessary, an earthed screening electrode may, if desired, be placed between the two electrodes on said one side of the crystal still further to reduce any direct capacitance between these two electrodes.

The invention will be further described in connection with the accompanying drawings wherein Figures 1 to 7 inclusive, 9 and 10 represent diagrammatically different features of the invention in schematic circuit form, while Fig. 8 shows in cross-section a piezo-electric crystal the mode of vibration in which is diagrammatically represented.

Referring first to Figs. 7 and 8, suppose the lower electrode to be at earth potential and the left and right hand upper electrodes to have potentials e_1 and e_2 the piezo-electric effect manifests itself as a force of ke_1 per cm^2 and ke_2 per cm^2 on the edges of the halves of the crystal.

Applying St. Venant's "principle of the elastic equivalence of statically equipollent systems of loads" it will be found, even though the crystal is by no means a long narrow bar, for which the principle holds very closely, that the error is not appreciable even for wide crystals, al-

though there must be some error. The application of the principle states that the crystal plate moves as though an average force of $\frac{1}{2}k(e_1+e_2)$ acts on the edges. There is then a charge liberated per square centimeter of the electrode surface which is proportional to $\frac{1}{2}(e_1+e_2)$. The constant of proportionality is found by considering the case of a fully plated crystal, for which total current=voltage÷Q, where Q is either the impedance of a line or the series resonant circuit of the usual approximation. This means that i_1 and i_2 must be equal and such that their sum is given by

$$i_1+i_2=\frac{1}{2}(e_1+e_2)/Q$$

This holds even when one plate is open-circuited, for in such a case the current will flow through the electrostatic capacitance, represented dotted in Fig. 7 at C/2, across the plate concerned.

The equations of the three-electrode crystal may thus be written as

$$i_1=i_2 \quad (1)$$

$$e_1+e_2=4Qi_1 \quad (2)$$

The network can be drawn in pictorial form by rewriting the equations as

$$i_1=i_2$$

and

$$e_2=-(e_1-4Qi_1)$$

or

$$(e_2-2Qi_2)=-(e_1-2Qi_1)$$

The latter form is chosen because of the symmetry. It is then clear that the complete system, including the electrostatic capacitance, may be represented by the equivalent networks of Figs. 1 and 9. These figures relate to the case in which the upper electrodes have equal areas.

If the upper electrodes have areas having the ratio $\alpha:1$ the equations become

$$i_1=\alpha i_2$$

and

$$\alpha e_1+e_2=(\alpha+1)^2 Qi_1$$

Fig. 10 then represents the equivalent network and may be compared with Figs. 1 and 9.

In Fig. 1 CED is an ideal transformer, series-aiding in the direction shown. If the potential of A is e_1 , that of C is (e_1-2Qi_1) and hence that of D is $-(e_1-2Qi_1)$ and is clearly equal to (e_2-2Qi_1) or (e_2-2Qi_2) . The directions of the currents are as shown. The ideal transformer CED corresponds to the use of St. Venant's principle.

If, as represented in Fig. 2, a constant source of current, such as a pentode, supplies the crystal in shunt with a load Z_1 , and if a second valve has a grid load Z_2 , and if the electrostatic capacitance $\frac{1}{2}C$ are assumed to be included respectively in Z_1 and Z_2 , then

$$e_1=(I-i_1)Z_1$$

$$e_2=-i_2Z_2$$

$$i_1=i_2$$

$$e_1+e_2=4Qi_1$$

solving for e_2

$$e_2=I \frac{Z_1 Z_2}{4Q+Z_1+Z_2}$$

The effect is thus of having a tuned circuit coupling of inductance $4L$, and decrement due to the crystal. The band width may be varied by mistuning the side circuits.

If an admittance Y be connected across the upper electrodes,

$$e_2=I \frac{1-4QY}{(4Y+Y_1+Y_2)+4Q(Y_1Y_2+Y_1Y+Y_2Y)}$$

When Y is zero this expression reduces to that given above, but when Y is not zero there is seen to be considerable difference.

At frequencies well off-tune, Q is very large and then

$$e_2=I \frac{Y}{Y_1Y_2+Y_1Y+Y_2Y}$$

If Y is at all comparable with Y_1 and Y_2 (Y_1 and Y_2 being the admittances of Z_1 and Z_2) the response becomes like that of an unneutralized crystal circuit, with a finite response away from the resonant frequency, and a dip and rise near the resonant frequency.

Filters in accordance with the invention may take the forms shown in Figs. 3a and 4 wherein an impedance Z is placed between the upper electrodes, and impedance Z_1 are included in the input and output connections. Figs. 3b and 3c are the equivalent networks of Fig. 3a. The difference between Fig. 3a and Fig. 4 is the positioning of Z_1 Z_1 .

It will be noted that with $Z=\infty$ and $Z_1=0$ Fig. 3c becomes 3d or 3e so that the latter hold for general and not only for restricted equivalence. Fig. 3e is the lattice equivalent of the neutralized crystal (see "Electric Circuits and Wave Filters," A. T. Starr, 2nd edition, Figures 174 and 335. Z_1 could, as in Fig. 4, be in parallel at the input and output and then the equivalent lattice has Z_1 as a shunt arm in its four branches.

Since Fig. 3c represents a general lattice, an unbalanced equivalent of any balanced circuit arrangement can be obtained by the use of a circuit employing a three-electrode crystal.

As stated, the impedances (Z and Z_1) may take various forms. Thus, if Z is a crystal and Z_1 an inductance, the network becomes the unbalanced form of the balanced lattice broad-band filter so often used in high grade crystal filters for carrier telephony and single side band working. Z_1 may be a series or shunt arm. Among the advantages to be derived from this filter may be mentioned that a filter with an impedance approximately one-quarter of the lattice form can be constructed. Thus for a filter with an unsymmetrical attenuation characteristic, one crystal has a low impedance and the other a high, and the impedance is then limited by the low impedance crystal. It is seen from Fig. 3c that the equivalent lattice must have crystals of impedance Q and $\frac{1}{4}Z$, while the three-electrode crystal system has crystals of impedance Q and Z . If, therefore, the Z arm be chosen as the low impedance crystal, the impedance of the filter can be one fourth of the value in the lattice form. Moreover the high impedance crystal will have rather more plating than that in the lattice form (in which its plating is rather scanty) and it will have only one pair of electrodes.

In the case of a filter in which $Z_1=0$ and Z is a series-tuned circuit (L_1C_1) with parallel capacitance (C_2) the crystal arm has a zero at f_r and a pole at $f_a=f_r(1+\frac{1}{2}r)$. If L_1C_1 resonates at f_2 a broad pass band from f_r to f_a is produced, where f_r is the resonant frequency of the crystal and

$$f_a=1/2\pi\sqrt{L_1C_1} \left[\frac{(2C_2+\frac{1}{2}C_4)}{(2C_2+\frac{1}{2}C_4+2C_1)} \right]^{1/2}$$

The impedances of the arms are shown in Fig. 5. The upper cut-off can be varied by varying C_2 . Such a filter is easy to construct and to adjust.

It will have an asymmetrical phase shift characteristic.

If Z is a crystal, a narrow band filter, suitable for telegraphy is obtained.

Making Z_1 an inductance and Z a capacitance, characteristics and the broad pass band are as shown in Fig. 6. This is a convenient filter since the cut-off points are determined by one arm only.

The source and loads may be parallel tuned circuits in which case the width of the pass-band can be varied by mis-tuning of the side circuits.

I claim:

1. A filter network having an input terminal, an output terminal and a return lead common to the input and output circuits thereof, a first impedance connected between said input and output

terminals, a second impedance connected between the input terminal and said return lead, a third impedance connected between said output terminal and said return lead, and a piezo-electric device having on one side two electrodes connected respectively to the input and output terminals, and on the other side a single electrode connected to said common return lead, said two electrodes on the one side of said piezo-electric device being of different areas the ratio between which is adjusted to provide a balance between the input and output impedances of said filter network.

2. A filter network according to claim 1 in which the first said impedance is inductive.

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