

June 2, 1953

M. C. TOURNIER
BAND PASS FILTER

2,640,879

Filed July 23, 1947

3 Sheets-Sheet 1

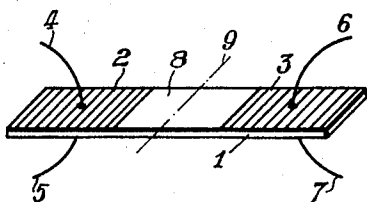


FIG. 1

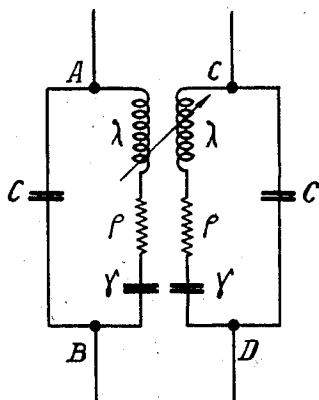


FIG. 2

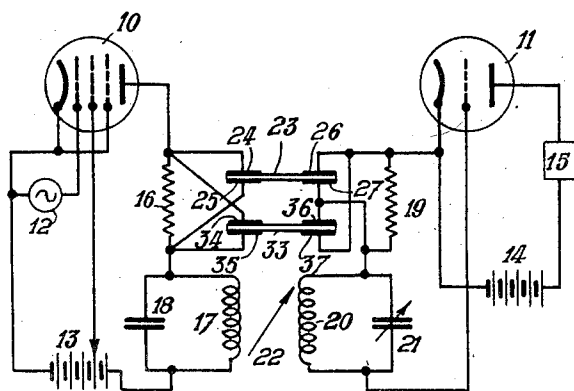


FIG. 3

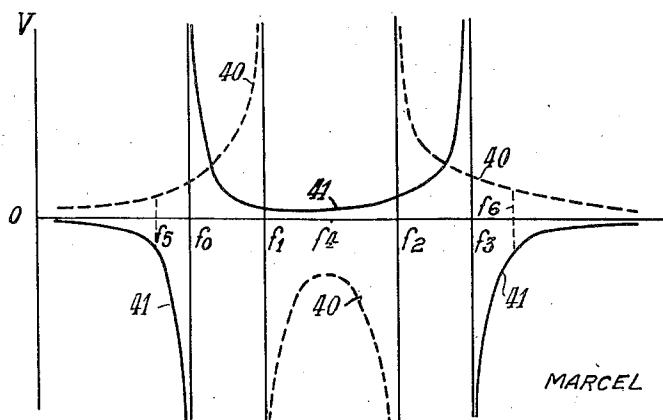


FIG. 4

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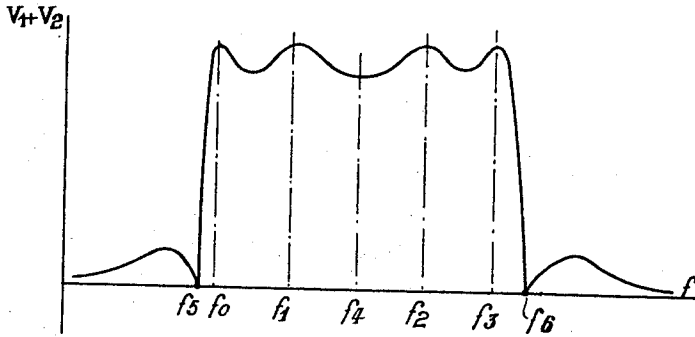


FIG. 5

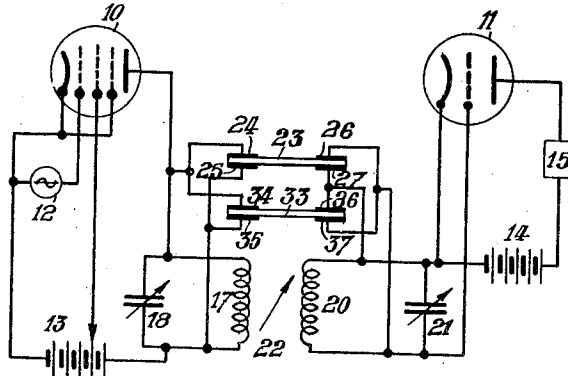


FIG. 6

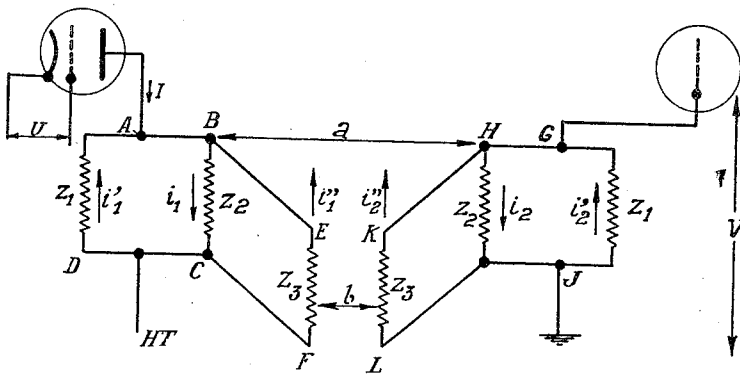


FIG. 8

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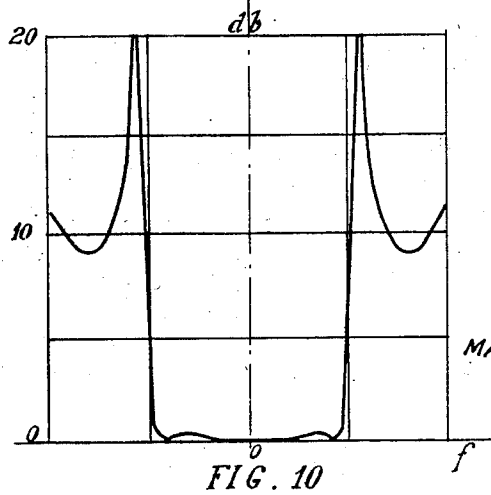
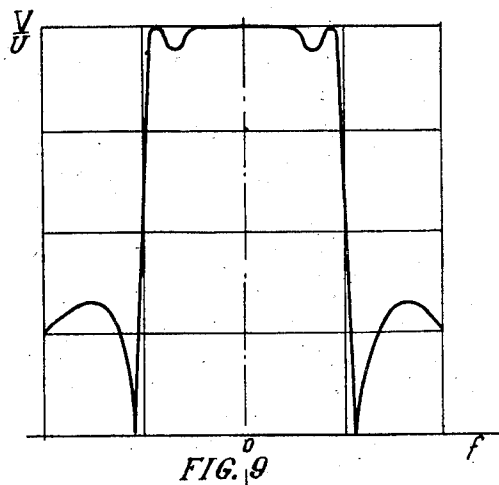
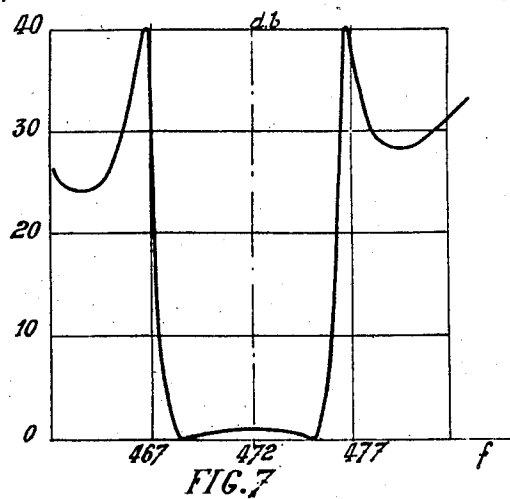
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3 Sheets-Sheet 3



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BAND PASS FILTER

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3 Claims. (Cl. 178—44)

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The present invention relates to electric wave filters, and more particularly to electric wave filters comprising electro-mechanical vibrating elements such as piezo-electric crystals.

The invention relates more specifically to piezo-electric crystals arranged to be used in radio broadcasting receivers.

In the usual type of radio broadcasting receivers in effect for example in receivers of the super-heterodyne type, there are one or more mean frequency stages which are always tuned to a particular frequency, as a rule 472 kilocycles. This means frequency transformers at present used and having a variable selectivity permit in the position of high selectivity of the elimination of emissions which are neighbouring on those which it is desired to isolate. As a rule, in this position of high selectivity the receiver has a band which is too narrow, and the musical tone of the whole is poor. In the second position, or position of low selectivity the tone is adequate, but the selectivity disappears, and it is only possible in this case to receive powerful stations to the exclusion of others.

It is, therefore, desirable to obtain a mean frequency filter with a very clear cut-off which will permit reception with low variations in the attenuation of a frequency band of approximately 8 to 9 kilocycles, whilst reaching outside this band, and as near as possible at its limits an attenuation which is sufficient to eliminate the following neighbouring receptions.

The invention has in particular the object of the embodiment of a mean frequency filter corresponding to the above conditions, that is to say, having sufficient pass band width with clear limits and a reduced attenuation which is substantially constant in the transmission band.

It should, moreover, be possible to insert such a filter in a radio receiver with its input terminals in the output or anode circuit of a valve, for example, pentode, and its output terminals in the input circuit, or grid, of the following valve. This filter would then appear as a quadripole without direct electric connection between its input terminals and its output terminals so as to permit of such a connection, the input terminals being connected conductively between themselves and the output terminals, which makes it possible to maintain at their respective normal potentials electrodes to which these terminals are connected.

This filter also has input impedance and very high output impedances so as to permit the stage to have an output of a high value.

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A filter in accordance with the invention, will consequently, consist of a mean frequency transformer consisting of two similar circuits coupled by mutual induction and placed respectively in anti-resonators in the output or anode circuit or anode of a valve, and in the input or grid circuit of the following valve, associated with two piezo-electric elements in the form of piezo-electric resonance transformers as will be explained in detail later on, one of these piezo-electric elements having a resonance which is slightly less at the first resonance frequency, or lowest resonance frequency of the mean frequency transformer, and the other a resonance frequency which is slightly higher than the second resonance frequency or the highest resonance frequency of the mean frequency transformer.

In a first embodiment in accordance with the invention a circuit oscillating in anti-resonance is placed in series with a resistance of a high value in the output or anode circuit of a valve and another anti-resonant oscillating circuit in series with a resistance of an identical high value are placed in the grid or input circuit of the valve following. The two oscillating circuits are inductively coupled one to the other and two piezo-electric elements arranged in resonance transformers are connected respectively in parallel at the input side at the terminals of the first resistance of high value, and in parallel with their respective inverse connections at the terminals of the other high value resistance on the output side.

In a second embodiment in accordance with the invention, the arrangement of the oscillating circuits which are inductively coupled is the same, but the piezo-electric transformers are associated to the said oscillating circuits by connecting respectively their inputs and their outputs in shunt to the said oscillating circuits, the same inversion of the piezo-electric transformer connections being provided for on the output side of the whole of the transformer.

The invention will be explained in greater detail in the following description in relation to the attached drawings in which:

Figure 1 represents an embodiment of the piezo-electric transformer employed in the circuits of the invention;

Figure 2 represents a method of electric representation equivalent to the piezo-electric transformer of Figure 1;

Figure 3 represents an example of the coupling device according to the invention;

Figures 4 and 5 represents respectively the po-

tentials at the terminals of the secondary for the electro-magnetic transformer assumed alone, and the piezo-electric transformers and for the whole of the coupling in Figure 3 in absolute values;

Figure 6 represents another embodiment of the coupling device according to the invention;

Figure 7 represents an attenuation curve as a function of the frequency obtained experimentally with the mounting in Figure 6.

Figure 8 represents an electric circuit diagram which may be taken as an equivalent to the circuit in Figure 6.

Figures 9 and 10 represent curves relative to the diagram of Figure 8.

An example of the piezo-electric transformer as used in the present invention is diagrammatically shown in Figure 1. In this figure 1 represents a layer of piezo-electric crystal covered at either end with metallic layers 2 and 3 of even surface and in the nodal points of which are fixed the lead-in electrodes 4, 5 and the lead-out electrodes 6, 7 by any suitable means, for example, by means of clamping pins or conducting lozenges to this on the surface of the crystal and soldered to electric connecting wires.

For the particular use considered of a crystal of this kind the sheet may be thin, for example 0.5 mm. in thickness approximately, cut in a plate of crystal of a section termed X, that is to say, with the electric axis X perpendicular to the sheet. The direction of the greater length of the crystal forms an angle of 18° with the electrical axis in a straight crystal. This makes it possible to have a simple type of vibration in the crystal which comprises straight nodal lines which are parallel to the small sides of the crystal. The length of the crystals may be in the neighbourhood of 16.5 mm., and their width 5 mm. In these conditions the actual frequency of the crystal is in the neighbourhood of 158 kilocycles and the vibration frequency on the harmonic three is 472 kilocycles approximately, which corresponds to the usual mean frequency of broadcast receiver sets of the superheterodyne type. It is, therefore, possible to determine with precision the nodal lines corresponding to the partial 3 and the electrodes 4, 5 and 6, 7 are fixed at these points. The whole is then metalised. Then the metal is stripped off at the edges of the crystal and from the middle section 8 of the length of the crystal.

In this way a piezo-electric resonance transformer is thus made. This quadripole in effect presents the characteristics of a transformer in this sense that the primary and secondary are electrically insulated. Any current in the primary circuit 4, 5 having for its origin changes liberated by the piezo-electric effect is accomplished by the phenomenon of an electro-motive force between 5 and 6 at the secondary end of the passage of a current if the connections 6 and 7 are connected to any impedance.

If between the input connections 5 and 6 an alternative electro-motive force of a constant amplitude is applied, and in this way the frequency is varied progressively and if the potential at the terminals is measured a curve of a hyperbolic nature is generally obtained which has a change in direction in the sign of the electro-motive force collected at the secondary for the frequency where the resonance of the piezo-electric transformer takes place. At this frequency as the crystal is very slightly damped it may be found that the potential at the terminals of the secondary which is in phase with the primary po-

tential in front of this resonance frequency suddenly changes phase, a change which persists throughout all the frequencies which are greater than the resonance frequency of the crystal.

The piezo-electric transformer in Figure 1 may, moreover, be electrically represented as indicated in the diagram in Figure 2. Assuming the crystal of Figure 1 to be divided into two equal parts following the line 9 in this figure the electrical properties of each half crystal may be represented by those of two identical circuits incapable of reacting on one another. Nevertheless, in assuming now that a mechanical contact is created between two points where they are cut, a part of the kinetic energy of each crystal can pass into the other end and there would, therefore, be an exchange of mechanical energy similar to the exchange of electro-magnetic energy between two circuits by mutual induction. The existence of this mechanical coupling modifies the period of each circuit. When the two half crystals are joined up completely again in such a way as to reconstitute the original crystal everything happens as though the coefficient of mutual coupling of the two equivalent circuits became equal to a whole.

In this case, however, the distribution of the elongations is not the same as in the initial case and the action is as though the equivalent self-inductances of each half were changed. The new natural period of resonance of the system is the period of resonance of the mechanical system.

The result of this is that an electric transformer such as that of Figure 1, may be effectively considered as equivalent to the circuit diagram in Figure 2, that is to say to the diagram consisting of equivalent electric circuits of two quartz crystals coupled by the mutual induction of their self-inductances. As known, the equivalent circuit diagram of a piezo-electric element consists in a capacity γ in series with a resistance ρ and a self-inductance λ , the whole being shunted by a capacity C.

Having thus defined the nature and electric action of a piezo electric transformer the coupled circuits of the invention appear more clearly. A first example of a coupling device under the invention in the case of a coupling of a pentode stage, for example, to a mean frequency stage according to a superheterodyne broadcast radio receiver, is given in Figure 3.

In this Figure 3, 10 represents a pentode valve and 11 a triode valve of the mean frequency stage following the superheterodyne. The pentode valve 10 is shown in the usual way with its cathode directly connected to the suppression grid, and an alternating supply source 12 between its cathode and its control grid. A battery 13 supplies the necessary continuous potentials for its screen grid and its plate. The valve 11 is represented with its plate battery 14 feeding its plate across a suitable operating circuit 15.

A resistance 16 of high value and an oscillating circuit consisting of an inductance 17 and capacity 18 are inserted in series in the plate circuit of the pentode 10. A resistance 19 of the same value as the resistance 16 and the oscillating circuit 20—21 identical with the oscillating circuit 17—18 are also introduced into the control circuit of the valve 11.

The two oscillating anti-resonant circuits 17—18 and 20—21 are coupled by a mutual induction unit as shown in 22.

Two piezo-electric transformers of the type described above 23 and 33 are connected to the terminals of the resistances 16 and 19 in the manner shown. These two piezo-electric transformers have their input terminals or primaries 24—25 and 34—35 connected respectively and in the same direction to the terminals of the resistance 16, whilst their input or secondary terminals 26—27, 36—37 are crossed and connected at the terminals of the resistance 19.

If it is assumed that the voltage V has been measured separately at the terminals of the secondary of the electromagnetic transformer constituted by the two oscillating circuits coupled in the absence of the crystal, and that it has been possible to make the attenuation of the windings very low, the curve which will give this potential at the terminals of the secondaries will be such as shown by a dotted line at 40 in Figure 4 of the drawings, assuming that the electromotive force applied by the source 12 is maintained constant, whilst its frequency is varied.

It will be seen that on this curve where the frequencies are shown in the abscissae of the frequency 0 to the frequency f_1 the phase of the secondary potential is substantially constant, and this potential follows a law which is approximately indicated by the first branch of the curve. At f_1 a first resonance is produced where the phase changes by 180° the potential at the terminals of the secondary change in sign and passes by a minimum, and then for a second resonance frequency f_2 changes in sign again on a new inversion of phase of 180° .

By re-adding these piezo-electric transformers 23 and 33 into the circuit, each of these transformers will have its own resonance frequency, one of these crystals will be adjusted in such a manner as to have a resonance frequency f_0 lower than f_1 and the other a resonance frequency f_3 higher than f_2 . The curve of these transformers is indicated by a continuous line 41 in Figure 4.

The direction of the mutual induction is selected in such a way that for frequencies comprised between 0 and f_0 the potential given by the circuit and that given by the crystals is in opposite direction.

In these conditions for a frequency f_5 which is less than the frequency f_0 of the resonance of the first transformer 23, the two differences of potential given by the circuit and by the crystal 23 will be annulled between 0 and f_1 , but the potential given by the circuit is greater than that given by the crystal so that the resulting potential is not zero in all the other points but is inferior to the potential given by the circuit.

Between f_0 and f_1 the crystal being very slightly damped the resulting potential climbs very quickly to the neighbourhood of f_0 . Between f_0 and f_1 the two potentials are of the same sign, the increase in the potential of a circuit compensates the lowering of the potential of the crystal. The left-hand side of the mean frequency curve is thus corrected by the crystal up to the frequency f_4 . As from the frequency f_4 the crystal 33 comes into play. In the central region of the band-pass in the neighbourhood of f_4 the potentials given by the crystal may moreover be neglected with relation to the potential given by the circuits.

Once f_2 is passed at the moment where the curve of the circuit re-descends the second crystal enters into vibration and its potential compensates the drop in potential of the circuit as

from f_2 , where it is no longer negligible on condition that the crystal 33 be connected in the suitable direction. It will be seen that the second crystal should before its resonance give a positive potential since the first should give a negative potential. The two pairs of electrodes of the crystals at the side of the secondary should, therefore, be crossed or more particularly inverted in relation to the connections of the electrodes of the crystals on the primary side. The pairs of electrodes on the secondary side should, therefore be crossed as shown in Figure 3 if the pairs of corresponding electrodes of the primary side are in the same direction.

At f_3 the sum of the potentials given by the circuit and by the crystal drops very suddenly and at f_6 the potentials being equal and of opposite direction cancel one another out. Nevertheless, beyond f_6 the resulting potential is not zero, the potential given by the circuit being greater than that given by the crystal, but is less than the potential given by the circuit.

The aspect of the curve of the resulting potentials given at the secondary by the circuit and the crystals is shown in Figure 5. These resultant potentials being shown in absolute values in the ordinates as a function of the frequency in the abscissae. It will be clearly seen from this figure that the response curve of the mean frequency at the input and output of the pass band has been corrected by the use of these crystals.

In practice, if the piezo electric transformers had a very low attenuation like the circuit, the four maxima of the curve of the Figure 5 at frequencies f_0 , f_1 , f_2 , f_3 would be very high and the attenuation would be infinite at the points f_5 and f_6 . As this does not as a rule occur it is necessary to choose the rate of the attenuation of the crystals and of the circuit suitably in order that the maxima and minima should be sufficiently adjacent in the pass band and that the attenuation should be still sufficiently great in the regions above for f_5 and f_6 on either side of the pass band. This can be done in a known manner and, consequently, will not be described in detail in the present description.

The device shown in Figure 3, nevertheless in some cases has the disadvantage of having no symmetry with relation to the whole unit. When such symmetry is desired it can be ensured by modifying this device in the manner shown by Figure 6.

In this figure the elements corresponding to those in Figure 3 have been designated by the same numerical reference. Nevertheless, the high valve resistances 16 and 19 have been suppressed and the primary and secondary piezo electric transformer connections 23 and 33 have been connected directly in shunt on the oscillating circuit 17—18 and 20—21.

Experience obtained by the applicant has shown that with a circuit of this kind not only does everything happen from the standpoint of the curve of the resulting variations on the secondary side, in the same way as for the diagram in Figure 3, but also the best practical results can be obtained as will be seen by comparing the curves of Figures 7 and 10 the attenuation curve as a function of the frequency of Figure 7 being a curve obtained experimentally with the mounting of the Figure 6 and the curve in Figure 10 being a curve calculated in an embodiment chosen according to a process of the invention which will be explained in greater detail.

In order to determine the component elements of the circuit of Figure 6 in effect whilst verifying that this circuit gives results qualitatively equivalent to the circuit in Figure 3, consideration may be given to the plan of the electric circuit in Figure 8. This diagram is equivalent from the electrical standpoint to the circuit in Figure 6, the primary voltage of the source 12 being indicated at U, the capacity of the circuit 17—18 being represented by the impedance Z1 of the primary side, itself and its resistance by Z2, and the piezo-electric impedance of each half of a crystal by Z3. The same notations are reproduced on the secondary side where Z1 represents the capacity of the circuit 20—21, Z2 the self-inductance and the resistance of the circuit and Z3 the piezo-electric impedance of the other half of the crystal. The outgoing potential is called V. The impedances Z2 are assumed to be coupled with a coupling coefficient a , and the impedances Z3 equally coupled with a coefficient of coupling b , the two circuits being assumed to be identical. The laws of Kirchhoff make it possible to write the relations between the currents and the potentials. These equations are the following, the currents and nodes being shown at Figure 8.

At node A:

$$(1) \quad I = i_1 - i'_1 - i''_1$$

At node G:

$$(2) \quad i_2 = i'_2 + i''_2$$

The equation of the value is

$$(3) \quad I = g U$$

g being the slope therefore

$$(4) \quad V = -Z_1 i'_2$$

In the closed circuit ABCD there is obtained:

$$(5) \quad Z_2 i_1 + Z_1 i'_1 + a i_2 = 0$$

In the circuit A.E.F.D.:

$$(6) \quad Z_3 i''_1 - Z_1 i'_1 + b i''_2 = 0$$

In the circuit GHIJ:

$$(7) \quad Z_2 i_2 + Z_1 i'_2 + a i_1 = 0$$

In the circuit GKLJ:

$$(8) \quad Z_3 i''_2 - Z_1 i'_2 + b i''_1 = 0$$

The solving of a system of eight equations of this kind will not be given in detail since such calculations are well known. Finally, the following relationship between the primary potential U and the secondary potential V is obtained:

$$(9) \quad \frac{V}{U} = g Z_1^2 \frac{[ab(a+b) - aZ_3^2 - bZ_2^2]}{[Z_1^2 - (Z_1 + Z_2 + a \times Z_1 + Z_3 + b)][Z_1^2 - (Z_1 + Z_2 - a)(Z_1 + Z_3 - b)]}$$

and it will be seen by giving the constants of the circuit and those of the crystal it is possible to find the ratio

$$\frac{V}{U}$$

in amplitude and in phase in respect to each frequency.

The function

$$\frac{V}{U}$$

however depends upon a large number of variables, the problem to be solved is to obtain a band filter, and to determine for that the relative values of the different quantities which intervene in the problem in order that the attenuation in the band should be more or less constant, and that the infinite points of the attenuation should be close to the border lines of the filter.

The complete numerical characters being very long and complicated they may be amplified, allowing for the real order of magnitude of the quantities which come into the problem and neglecting the small quantities in respect of the broad principles.

$$(10) \quad Z_1 = R + j\omega L$$

$$Z_2 = -\frac{j}{C\omega}$$

$$Z_3 = \rho + j\left(\omega\lambda - \frac{1}{\gamma\omega}\right)$$

$$a = j\omega M$$

$$b = j\omega\lambda$$

It will be admitted that the electro-magnetic coupling is very weak and the piezo electric coupling tight, therefore $j\omega M$ will be negligible with regard to the smallest value which Z_1 can take, that is to say R.

$$(11) \quad \text{Hence } (Z_1 + Z_2 + a) \doteq \doteq (Z_1 + Z_2) \doteq (Z_1 + Z_2 - a)$$

The symbol $\doteq$ signifies "slightly different" as known.

The second form of

$$\frac{V}{U}$$

is, therefore

$$(12) \quad \frac{V}{U} = g Z_1^2 \frac{[ab(a+b) - aZ_3^2 - bZ_2^2]}{[Z_1^2 - (Z_1 + Z_2)(Z_1 + Z_2 + b)][Z_1^2 - (Z_1 + Z_2)(Z_1 + Z_3 - b)]}$$

with

$$= Z_1 + Z_3 + b = \rho + j\left(2\omega\lambda - \frac{1}{\gamma\omega} - \frac{1}{C\omega}\right)$$

Calling ω_2 the resonance pulsation of the piezo-electric transducer

$$(13) \quad (Z_1 + Z_3 + b) = 2\omega_2\lambda(\eta_2 + j\alpha_2)$$

It will be assumed here that the crystal is very little damped and η_2 will be neglected, hence:

$$(14) \quad (Z_1 + Z_3 + b) = 2j\omega_2\lambda\alpha_2$$

and

$$(15) \quad (Z_1 + Z_3 - b) = -\left(\frac{j}{\gamma\omega} + \frac{j}{C\omega}\right) \doteq -2j\omega_2\lambda$$

All this analysis is made on the supposition that

a single crystal is in shunt on the circuit. Actually, as crystals are very little damped and as they vibrate in a narrow frequency field each of them only operates in a half-band, and it is therefore necessary to show them both simultaneously in the calculations, an examination should be made as to what happens in the half of a band and equal values taken for the symmetrical values of the other half and the direction of the electrodes will be assumed as having been suitably chosen, as mentioned above.

The third form of the expression

$$\frac{U}{V}$$

is, therefore:

$$(16) \quad \frac{V}{U} = \frac{gZ_1^2}{\omega^2 L^2} \frac{ab(a+b) - aZ_3^2 - bZ_2^2}{[Z_1 - \omega L(\eta_1 + j\alpha_1)2j\omega_2\lambda\alpha_2][Z_1^2 + \omega L(\eta_1 + j\alpha_1)2j\omega_2\lambda]}$$

but

$$(18) \quad Z_1 = -\frac{j}{C\omega} = -j\omega_1 L$$

$$\frac{V}{U} = \frac{g}{\omega_1^2 L^2} \frac{ab(a+b) - aZ_3^2 - bZ_2^2}{\left[1 + 2j\frac{\lambda}{L}(\eta_1 + j\alpha_1)\alpha_2\right] \left[1 - 2j\frac{\lambda}{L}(\eta_1 + j\alpha_1)\right]}$$

In order that the resonance of the crystal may operate it is necessary that the quantity

$$2j\frac{\lambda}{L}(\eta_1 + j\alpha_1)\alpha_2$$

should have a modulus which is not negligible with relation to the unit, as α_2 is of the order of magnitude of 1/100, and therefore the modulus of the quantity

$$2j\frac{\lambda}{L}(\eta_1 + j\alpha_1)$$

is of the order of magnitude of 100 and, consequently, in the second parenthesis of the denominator it is possible to neglect the unit in front of this quantity.

The fourth simplified form will be:

$$(19) \quad \frac{V}{U} = \frac{g}{\omega_1^2 L^2} \frac{ab(a+b) - aZ_3^2 - bZ_2^2}{2j\frac{\lambda}{L}(\eta_1 + j\alpha_1) \left[1 + 2j\frac{\lambda}{L}\alpha_2(\eta_1 + j\alpha_1)\right]}$$

But in the numerator it will be remembered that in the binomial $a+b$ where $j\omega M$ is negligible in respect of $j\omega\lambda$ accordingly:

$$(20) \quad \frac{V}{U} = \frac{g}{\omega_1^2 L^2} \frac{a(b^2 - Z_3^2) - bZ_2^2}{2j\frac{\lambda}{L}(\eta_1 + j\alpha_1) \left[1 + 2j\frac{\lambda}{L}\alpha_2(\eta_1 + j\alpha_1)\right]}$$

$$= \frac{-jg}{2\omega_1 L \omega_1 \lambda} \frac{j\omega M \left[2j\omega\lambda - \frac{j}{\omega}\right] \left[\frac{j}{\gamma\omega}\right] - j\omega\lambda(R_1 + j\omega L_1)^2}{(\eta_1 + j\alpha_1) \left[\left(1 - 2\frac{\lambda}{L}\alpha_1\alpha_2\right) + 2j\frac{\lambda}{L}\alpha_2\eta_1\right]}$$

But as C is considerable with regard to γ :

$$(21) \quad \frac{j}{\gamma\omega_2} \div 2j\omega_2\lambda$$

therefore,

$$2j\omega\lambda - \frac{j}{\gamma\omega} = 2j\omega_2\lambda\alpha_2$$

On the other hand, in the numerator the quantity R_1 may be neglected with regard to ωL_1 and it finally becomes:

$$(22) \quad \frac{V}{U} = \frac{-jg}{2\omega_1 L \omega_1 \lambda} \frac{j\omega M 4j\omega_2\lambda\alpha_2 j\omega\lambda + j\omega\lambda^2 \omega L^2}{(\eta_1 + j\alpha_1) \left[\left(1 - 2\frac{\lambda}{L}\alpha_1\alpha_2\right) + 2j\frac{\lambda}{L}\alpha_2\eta_1\right]}$$

$$(23) \quad \frac{V}{U} = \frac{g\omega_1 L}{2} \frac{1 - \frac{4\lambda M}{L^2}\alpha_2}{(\eta_1 + j\alpha_1) \left[\left(1 - 2\frac{\lambda}{L}\alpha_1\alpha_2\right) + 2j\frac{\lambda}{L}\alpha_2\eta_1\right]}$$

in amplitude, and there is obtained

$$(24) \quad \frac{V}{U} = \frac{g\omega_1 L}{2} \frac{1 - \frac{4\lambda M}{L^2}\alpha_2}{\sqrt{(\eta_1^2 + \alpha_1^2) \left[\left(1 - 2\frac{\lambda}{L}\alpha_1\alpha_2\right)^2 + \frac{4\lambda^2}{2}\alpha_2^2\eta_1^2\right]}}$$

λ , M and L will be chosen in such a way that the infinite attenuation occurs for a value fixed by the distance in frequency as from the resonance

of the quartz crystal, this quantity being called

$$(25) \quad (1) \quad \frac{4\lambda M}{L^2} = \frac{1}{\alpha_2''}$$

is obtained, accordingly a first numerical relation is found here between the four fundamental quantities λ , M and L and η_1 which define the filter.

The expression becomes:

$$(26) \quad \frac{V}{U} = \frac{g\omega L}{2} \frac{1 - \frac{\alpha_2}{\alpha_2''}}{\sqrt{(\eta_1^2 + \alpha_1^2) \left[\left(1 - \frac{2\lambda}{L}\alpha_1\alpha_2\right)^2 + \frac{4\lambda^2}{L^2}\alpha_2^2\eta_1^2\right]}}$$

The curve which gives

$$\frac{V}{U}$$

as a function of the frequency shows the maxima in the neighbourhood of the values which correspond to the resonances of the circuit $\alpha_1=0$ or of crystal $\alpha_2=0$. The size of the band is obtained, that is to say, the numerical value of the quantity α_0 , a value which takes α_1 , for example for $\alpha_2=0$, that is to say at the resonance of the quartz crystal. It will be seen on the other hand at the moment of the circuit resonance when $\alpha_1=0$, $\alpha_2=-\alpha_0$.

Taking the amplitudes as being equal at this moment the following relationship may be deduced:

$$(27) \quad \eta_1 \sqrt{1 + \frac{4\lambda^2}{L^2}\alpha_0^2\eta_1^2} = \frac{1 + \frac{\alpha_0}{\alpha_2''}}{\sqrt{\eta_1^2 + \alpha_0^2}}$$

hence:

$$(28) \quad (2) \quad \frac{2\lambda}{L} = \frac{2}{\alpha_0\eta_1} \sqrt{\left(1 + \frac{\alpha_0^2}{\eta_1^2}\right) \left(1 + \frac{\alpha_0}{\alpha_2''}\right)^2 - 1}$$

A second relation between these fundamental quantities which define the filter is, therefore, obtained. It is equally possible to obtain two supplementary relations which entirely determine the four orders of magnitude by writing that the amplitude is still equal at two other points of the band; unfortunately, in this case equations of too high a degree are obtained which cannot, therefore, be solved algebraically.

In these circumstances in order completely to determine the different elements of the circuit in Figure 6 the invention provides for their calculation by a successive approximation which is always possible. In other words, having arrived at this point in calculation values of L and η_1 are arbitrarily fixed which correspond to an ordinary mean frequency coil and the curves of the ratio between the potentials V/U and the filter attenuation may be plotted. Under these conditions, as a rule they show maxima and minima which are very marked and, consequently, the values will not be correct. Accordingly, the value of η_1 will be changed in order to see in what direction this difference between the maxima and

minima develops and then it is possible to always be able to determine an adequate value of η_1 fairly quickly.

In actual practice it is obvious that the values of L and of η_1 will be directly selected which are capable of giving the satisfactory characteristics almost immediately, that is to say, that it will be remembered when making the first choice of values that the coefficient of overcharge of a circuit of this kind should be very low.

In order to make this method of determining a filter according to the invention clearer a numerical example is given below, but the first approximations are not given in order not to complicate the description. Only the values of L and η_1 are given which have been obtained in order to effect a satisfactory filter in practice for a superheterodyne set whose mean frequency is 472 cycles. Figures 9 and 10 give respectively curves for the ratio of potential

$$\frac{V}{U}$$

as a function of the relative differences in the frequency in thousandths, and the calculated attenuation of the filter in decibels in the pass band as a function of the frequency. These curves are calculated for the values:

(29)

$$\eta_1 = 3.10^2, Q = 33.3; \frac{2\lambda}{L} = 1, 17 \cdot 10^4; \lambda = 10 \text{ henries}$$

$$L = 1.7 \text{ millihenries}; \frac{q\omega L}{2} = 12.5; M = 18 \cdot 10^{-6}$$

It will be seen that the curves are relatively good, but if the attenuation curve of the Figure 10 is compared with the experimental attenuation curve in Figure 7 which has been drawn for a circuit realized with the given values in the numerical example, it will be seen that this latter curve is even better. This result is natural, since the calculation does not allow for the coefficients of real coupling and these are in fact better in practice than might be assumed from the calculation.

It will, in fact, be seen that the invention supplies methods for the embodiment of a mean frequency filter, which presents clear cuts for a band width which is relatively large, and a reduced attenuation which is substantially constant throughout the width of the transmission band of the filter.

It is clear that the invention is not limited to the examples of the embodiments shown and described, but may be subjected to numerous modifications and adaptations without going beyond its scope. It is, for example, clear that the method of the realisation of the piezo-electric transformers indicated with regard to Figures 1 and 2 is only given by way of example, and that any type of piezo-electric transformer which may be thought of is capable of being employed in coupling devices as per the invention. It is, further clear that the invention is not limited to coupling circuits for radio-broadcasting superheterodyne receiver sets, using a mean frequency of 472 kilocycles per second, and that this numerical value has only been given by way of example as also the details of the radio circuit stages under consideration. Other modi-

fications and applications will be evident to the expert.

I claim:

1. A band-pass filter having input and output terminals and comprising a pair of inductively coupled anti-resonant circuits and a pair of piezo-electric transformers each having input and output terminals, said transformer input terminals being connected in parallel with each other and in series with one of said circuits to the input terminals of said filter and said transformer output terminals being connected in parallel with each other and in series with the other of said circuits to the output terminals of said filter.

2. A band-pass filter having input and output terminals and comprising a pair of similar inductively coupled anti-resonant circuits and a pair of piezo-electric transformers each having input and output terminals, said transformer input terminals being connected in parallel with each other and in series with one of said circuits to the input terminals of said filter and said transformer output terminals being connected in parallel with each other and in series with the other of said circuits to the output terminals of said filter and one of said transformers having a resonance frequency lower than the lower resonance frequency of said circuits and the other of said transformers having a resonance frequency higher than the higher resonance frequency of said circuits.

3. A band-pass filter having input and output terminals and comprising a pair of similar inductively coupled anti-resonant circuits, a pair of piezo-electric transformers each having input and output terminals, said transformer input terminals being connected in parallel with each other in the same phase sense and in series with one of said circuits to the input terminals of said filter and said transformer output terminals being connected in parallel with each other in an opposite phase sense with respect to each other and in series with the other of said circuits to the output terminals of said filter and one of said transformers having a resonance frequency lower than the lower resonance frequency of said circuits and the other of said transformers having a resonance frequency higher than the higher resonance frequency of said circuits, and a pair of impedances adapted to conduct direct current, one of said impedances being connected in parallel with the transformer input terminals and the other of said impedances being connected in parallel with the transformer output terminals.

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