Nov. 2, 1937. C. W. HANSELL 2,097,458

FILTER

Original Filed Sept. 24, 1931

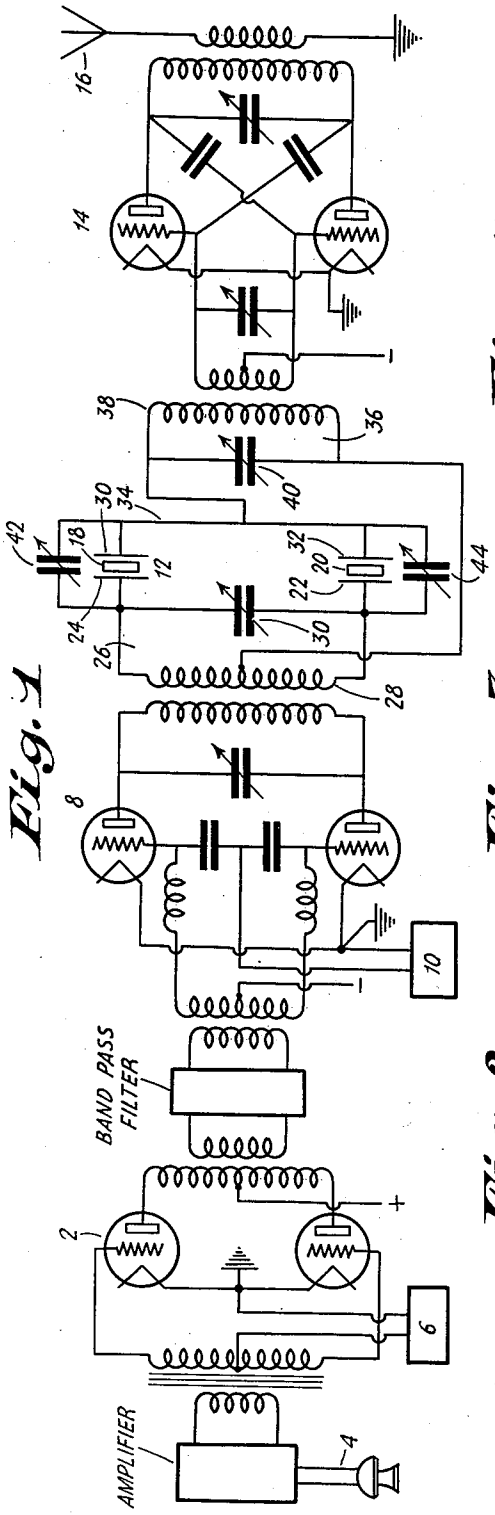


Fig. 1

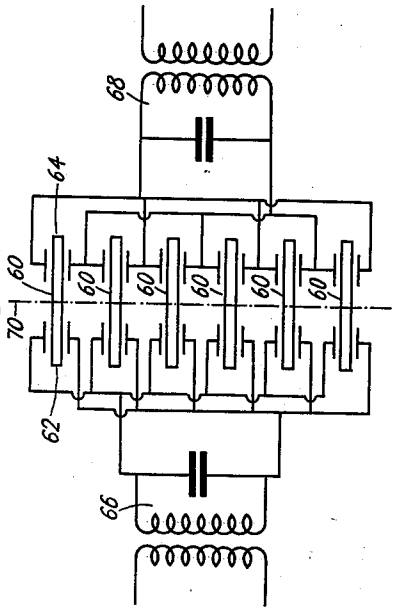


Fig. 4

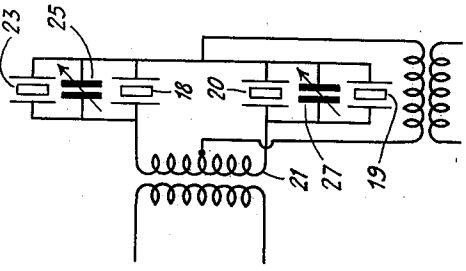


Fig. 3

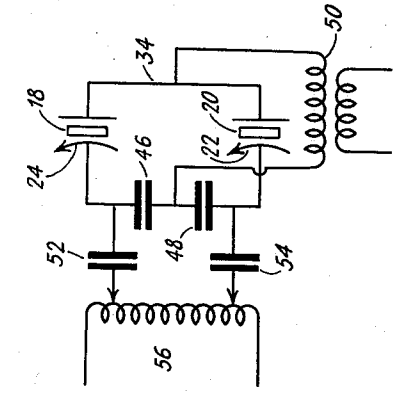


Fig. 2

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FILTER

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Original application September 24, 1931, Serial No. 564,770. Divided and this application April 4, 1935, Serial No. 14,559

10 Claims. (Cl. 178—44)

This invention relates to a filtering system and is especially directed to filters utilizing resonant means or elements such as piezo-electric crystals.

This application is a division of my copending application Serial No. 564,770, filed September 24, 1931 and patented May 14, 1935 as U. S. Patent No. 2,001,387.

It has been proposed to use a piezo-electric crystal as a filter, but it has been found under certain circumstances that such a filter, especially when neutralized in accordance with my invention described in my copending application Serial Number 203,901, filed July 7, 1927 and patented June 18, 1935 as U. S. Patent No. 2,005,083, does not pass a sufficiently wide band of frequencies. I found that the simple paralleling of crystals having overlapping resonance curves for obtaining a band pass filter, does not present all that is to be desired, for at frequencies midway between the resonance points of the two crystals it will be found that one crystal acts as an effective inductance and the other an effective capacity. Consequently, the pair of crystals act as an anti-resonant circuit preventing a transfer of energy at a desired energy passing frequency.

To overcome these defects is the principal object of my present invention and to do so I reverse the polarity of voltages applied to, in general, resonant elements or systems such as crystals with overlapping resonance curves, so that the currents through the elements or crystals will no longer oppose but will add for all frequencies between their resonance frequencies. At the same time, for frequencies lying on the same side of their resonance curves but well up on the resonance curve of one element or crystal there is little cancellation of the passed currents for the reason that the current through one of the crystals or elements is much larger than the others. Beyond the desired pass band the crystal currents of course cancel more completely and the suppression of undesired frequencies is accomplished.

A further object of my present invention is to provide, in combination with a side band telephony system, an improved crystal or other resonant element filter as just briefly described. In this manner, for single side band telephony, a lesser number of modulation stages is needed, for the reason that the filter will operate satisfactorily with much smaller percentage differences in the frequency of the side bands than heretofore found possible.

Another object of my present invention is to provide, in combination with a radio receiver, an improved crystal filter which will permit improved frequency selectivity and more efficient reception than heretofore possible.

Still another object of my present invention is to provide for the neutralization of the interelectrode capacities of the crystals used in my improved band pass filter. In this manner a much sharper band pass and more complete suppression of undesired frequencies is obtained for the filtering system. Briefly, in order to accomplish this I use the interelectrode capacity of one crystal, or that interelectrode capacity supplemented by an additional capacity to neutralize the interelectrode capacity of the other crystal and vice versa.

In order to sharpen the characteristic of ordinary filters it is a further object of my present invention to provide means, preferably a filter circuit according to my present invention in parallel with the ordinary filter circuit whereby its characteristic may be improved.

Although I have defined my invention as required by law with particularity in the appended claims, it may best be understood, both as to its structural organization and mode of operation, by referring to the accompanying drawing wherein

Figure 1 is a schematic wiring diagram of a single side band transmitter incorporating therein my improved band pass crystal filter;

Figure 2 is a diagram of a pair of series connected condensers and piezo-electric crystals employed as a filter;

Figure 3 is a diagram of parallel arranged piezo-electric crystals employed as filters;

Figure 4 is a diagram of a band pass filter applied to a receiving circuit having a plurality of interposed piezo-electric crystals employing four electrodes.

Turning to Figure 1, a relatively low-frequency carrier suppression modulator 2 is supplied with modulating potentials from a suitable source 4 and with carrier energy from a carrier source 6. Single side band energy from the carrier suppression modulator 2 is passed by a band pass filter and undesired frequencies are rejected. The operation is well known in the art and need not be repeated here. The single side band output of this modulator is fed to a second carrier suppression modulator 8 supplied with high-frequency carrier energy from a source 10.

By the use of my improved band pass filter 12, whose structure and operation will be described more fully hereinafter, a single side band is separated from the side bands appearing in the out-

put circuit of modulator 8 and this side band energy is further amplified by a power amplifier 14 of which only one stage of the several cascaded stages which may be used is shown, and thence transmitted over a suitable radiating antenna 16.

As far as I am aware, without my improved filter 12, a single side band transmitter with an output frequency higher than about 3,000 kilocycles requires at least three stages of carrier suppression modulation in order that the percentage difference between the desired side band and the suppressed carrier and other side band energies might be sufficient for obtainable filters to discriminate between them. Since my new filter circuit is much more selective than previously known band pass filters it permits one stage of modulator to take the place of two or more of the stages previously required.

My improved band pass filter comprises a plurality of resonant or oscillating elements, here in the form of piezo-electric crystals 18, 20 like electrodes 22, 24 of which are connected serially in phase opposition or in reversed polarity by means of an impedance 26 here in the form of a broadly tuned circuit comprising reactor or inductor 28 and variable reactor or capacitor 30. The other electrodes 30, 32 of the band pass filter are conductively connected by connection 34. Between connection 34 and a point of substantially zero alternating potential or a point substantially at the midpoint of alternating current circuit 26 there is connected an alternating current output circuit 36 comprising inductance 38 and variable capacity 40.

By virtue of the connections just described, input energy is applied to the crystals in reversed phase as a result of which, for the mean frequency to be passed by crystals 18, 20, ground to have overlapping resonance curves, their outputs add; whereas it is to be noted if they were simply connected in parallel, the mean frequency desired to be passed would not be passed. For some frequencies within the desired pass band which lie on the same side of the resonance curves of both crystals, there is some cancellation, but this not serious for the reason that by virtue of the resonance characteristics of the crystals in this region one crystal will be passing a large amount of current; whereas the other will be passing a relatively small amount of current. Hence, the pass band is almost as wide as the sum of the pass bands of the two individual crystals.

By virtue of the connection of the output circuit it should be clear that by suitable spacing of the electrodes of the crystals 18, 20, the transfer of energy outside the resonance bands of the crystals themselves may be prevented by making the interelectrode capacity of one crystal neutralize the interelectrode capacity of the other crystal. To facilitate this action supplementary or trimming condensers 42, 44 may be used if found desirable. These condensers, of course, supplement or add to the interelectrode capacities of the electrodes 24, 30 and 22, 32. An alternative method for obtaining an exact neutralizing adjustment is available by varying the position of the connection from one end of the output circuit to the point near the center of coil 28.

Of course, as already indicated, adjustment of the crystal electrodes alone may be sufficient to establish complete neutralization, and as means for varying the spacing and area of crystal electrodes are well known in the art, they need not be described in detail here.

The filtering circuit shown, as will occur readily to one skilled in the art, may be varied in many ways without departing from the spirit of the present invention. Thus, for example, as shown in Figure 2, the alternating current circuit 26 may be replaced by a pair of series connected condensers 46, 48, preferably of about the same size and between which and the conductive connection 34 there is connected an alternating circuit 50 here in the form of a single inductance coil. The impedance formed by condensers 46, 48 may also be connected through blocking condensers 52, 54 to some other alternating current circuit 56, and neutralization may be accomplished by varying the spacing of electrodes 24, 22 of crystals 18, 20, or by varying the relative capacities of condensers 46 and 48.

Although, in Figure 1, I have shown only two crystals by way of illustration, it should be noted that my invention includes the use of any number of crystals having successively overlapping resonance curves in my filter circuit. If more than two crystals are used, then those with successively overlapping resonance curves are connected with reversed polarity in the manner shown for the two crystals.

In designing the filter I may obtain a very narrow pass band and large ratio between the energies passed for desired and undesired frequencies by using low impedance input and output circuits for the filter. In other cases, where a broader pass band for each crystal is desired so that a large band of frequencies may be passed with a minimum number of crystals, I may use high impedance input and output circuits, though in this case the ratio of energies passed at desired and undesired frequencies is decreased.

It should be understood that the input and output ends of the filter may be reversed without changing its characteristics. In other words, it is a band pass filter for energy passing through it in either direction.

As previously stated, if a wider pass band is desired, any number of crystals with successively overlapping resonance curves may be used, provided crystals ground for adjacent frequencies are connected to opposite sides of the filter input circuit. Thus, as shown in Figure 3, if it is desired to increase the frequency band width on the side of the mean frequency passed and on the side of the mean frequency towards which the resonance curve of crystal 18 lies for the greater part, then an additional crystal 19 may be added, connected as shown to the opposite side of the input circuit 21, opposite in the sense that it is opposite the side of the inductance coil 21 to which crystal 18 is connected.

Similarly, if it is desired to increase the frequency band width in the direction of the frequencies passed by crystal 20, an additional crystal 23 having a characteristic overlapping that of crystal 20 may be added connected to the side opposite input circuit 21 to that to which crystal 20 is connected. Neutralization may be added if found desirable by adjustment of the various crystal electrodes, by the addition of supplementary trimming condensers 25, 27, or by varying the relative voltages applied to the two branches of the filter.

If desired, my invention may be carried out with crystals having more than two electrodes. Figure 4 shows one way of using crystals with four elec-

trodes. In this case no neutralization is required, particularly if the circuits are shielded.

More particularly, in Figure 4 the crystals 60 having overlapping resonance curves in accordance with what has gone hereinbefore are each provided with pairs of electrodes 62, 64 between which the crystals constitute a resonant means of electrical coupling through the piezo-electric effect and the mechanical vibration of the crystals. Capacitive feed of energy between the two circuits 66, 68 coupled by the filter including crystal element 60 is prevented by the use of suitable electrostatic shielding indicated diagrammatically at 70. From what has been said hereinbefore the operation of the system shown in Figure 4 should be obvious and therefore requires no further discussion.

In Figures 1 and 4 the tuning of the input and output circuits for the filters shown not only assist in obtaining the best impedances for use with a filter, but it also suppresses undesired frequencies. The electro-mechanical oscillators such as the piezo-electric crystals, and also resonant transmission lines, respond to a series of frequencies and exhibit resonance at frequencies approximately at harmonic relation, the tuned input and output circuits do not respond to harmonics of their fundamental frequencies, and so suppress undesired frequencies which would otherwise pass through the filter. Thus, I broadly combine tuned circuits having only one resonant frequency with circuits or mechanically oscillated equivalents of circuits which tune sharply for a series of frequencies to obtain a filter with sharp resonant discrimination but only one pass band.

As indicated hereinbefore, a still further use for my invention is to sharpen up the cut-off characteristics of the more common types of filters. This may be done by connecting one of my electro-mechanical filters in parallel with an ordinary filter. Then, if the pass band of the electro-mechanical filter lies in the imperfect cut-off region of the ordinary filter, it will extend the pass band of the ordinary filter and the cut-off characteristics of the combination will be that of the electro-mechanical filter, which is very sharp, while the width of pass band will be substantially that of the ordinary filter.

In the crystal filter of Figure 4, I may obtain the desired results by varying the sizes of the crystal electrodes or by varying the coupling to either input or output electrodes, or both. In fact, any method for varying the effectiveness of the individual vibrators, including the application of damping, may be used whereby the combination of filters gives the desired characteristic.

In my claims where I speak of connecting the filter circuit elements "cophasally" or "in phase opposition", it is to be understood that I refer to the phase conditions which would correspond to resonance of the elements. Since the elements will not be resonant for the same frequencies and their currents change phase as the frequency is changed, it must be understood that I have used the expressions "cophasally" and "in phase opposition" for want of more expressive language.

Having thus described my invention, what I claim is:

1. A crystal filter comprising a plurality of crystals having overlapping resonance curves, means connecting an electrode of each of the crystals directly together, and means connecting other electrodes of the crystals in phase opposition, and a high-frequency utilization circuit connected between said direct connecting means and between said phase opposition connecting means.

2. A crystal filter comprising a pair of piezo-electric crystals having overlapping resonance curves, a reactor connecting an electrode of each of the crystals in phase opposition, means conductively connecting other electrodes of the crystals together, an input circuit coupled to said reactor and an output circuit connected between the midpoint of said reactor and said conductive connection.

3. A piezo-electric crystal filter comprising a pair of piezo-electric crystals having overlapping resonance curves, an impedance connected between electrodes of said crystals, a conductive connection connecting together other electrodes of said crystals, an input circuit coupled to said impedance, an output circuit connected between the midpoint of said impedance and said conductive connection, the interelectrode capacity of said crystals being variable whereby the interelectrode capacity of one crystal may be adjusted to neutralize the interelectrode capacity of the other crystal.

4. A piezo-electric crystal filter comprising an input source of current supply having a plurality of different desired resonant frequencies, a pair of piezo-electric crystals, said crystals having symmetrically displaced overlapping resonant currents of similar characteristics as said desired resonant frequencies, an inductance coil connected serially between a pair of electrodes of said crystals, a conductive connection connecting other electrodes of said crystals together conductively, an alternating current circuit coupled to said inductance coil, an alternating current circuit connected to the midpoint of said coil and to said conductive connection, means for varying the capacity between electrodes of one of said crystals, and means for varying the capacity between electrodes of said other crystal.

5. A piezo-electric crystal filter comprising an input source of current supply having a plurality of different desired resonant frequencies, a pair of piezo-electric crystals having overlapping resonance curves of similar characteristics as said resonant frequencies, an impedance connection connected between like electrodes of said crystals, a low impedance connection connecting the other electrodes of said crystals effectively directly together, and an alternating current circuit connected between the substantially the midpoint of said impedance connection, said midpoint connection effectively directly connecting together the electrodes of said crystals to an output inductance of said filter.

6. A transmitting system comprising a carrier suppression modulating system, a band pass piezo-electric filter coupled to the output circuit of said carrier suppression system, and a power amplifier coupled to the output circuit of said band pass filter, said filter comprising a pair of piezo-electric crystals having a pair of electrodes connected in phase opposition for applied alternating currents, said crystals having overlapping resonance curves, an output circuit connected to the other electrodes of said crystals and to substantially the midpoint of the connection connecting said electrodes in phase opposition, and means for neutralizing the interelectrode capacities of said crystals.

7. A piezo-electric crystal filter comprising a

plurality of piezo-electric crystals having overlapping resonance curves, each of said crystals having a plurality of pairs of electrodes, means for connecting like pairs of electrodes in parallel, means for connecting the other pairs of electrodes of adjacent resonant frequencies, in reversed polarity, circuits connected to said connection means, and shielding means for preventing coupling of said circuits other than that through the crystals.

8. A crystal filter comprising a pair of piezo-electric crystals having overlapping resonance curves, a reactor connecting an electrode of each of the crystals in phase opposition with respect to an electrode of one of the other crystals, means conductively connecting the other electrodes of the crystals together, an input circuit coupled to said reactor, and an output circuit connected between the midpoint of said reactor and said conductive connection.

9. A crystal filter comprising a pair of piezo-electric crystals having overlapping resonance curves, a first reactor connecting an electrode of each of the crystals in phase opposition with respect to an electrode of one of the other crystals, a second reactor connecting the other electrodes of the crystals together, and to a point on said first reactor, an input circuit coupled to one of said reactors, and an output circuit coupled to the other of said reactors.

10. A crystal filter comprising a plurality of crystals having overlapping resonance curves, a first reactor connecting an electrode of each of the crystals in phase opposition with respect to an electrode of one of the other crystals, a second reactor connecting the other electrodes of the crystals together and to a point on said first reactor, an input circuit coupled to one of said reactors, and an output circuit coupled to the other of said reactors.

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