April 21, 1942. W. VAN B. ROBERTS 2,280,605

PIEZO-ELECTRIC CRYSTAL FILTER CIRCUIT

Filed Jan. 7, 1939

Fig. 1

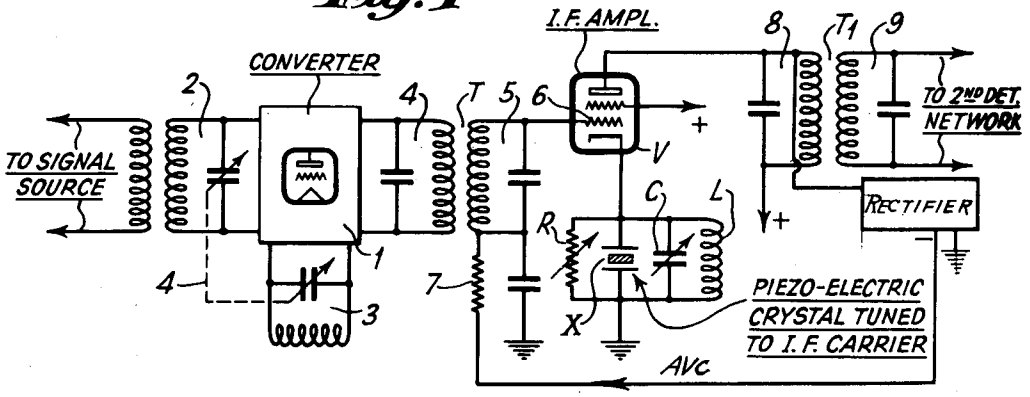


Fig. 2

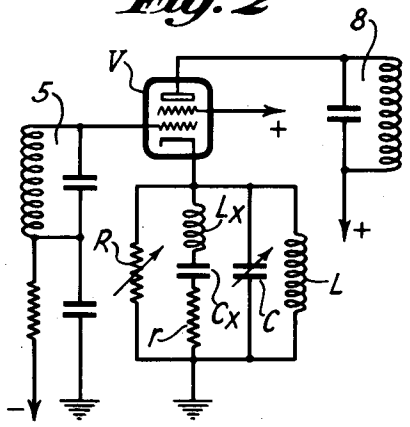


Fig. 3

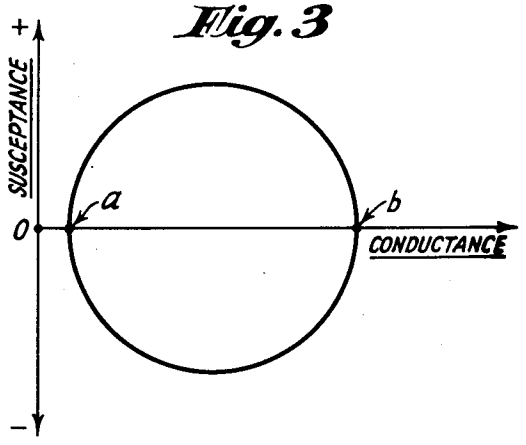


Fig. 4

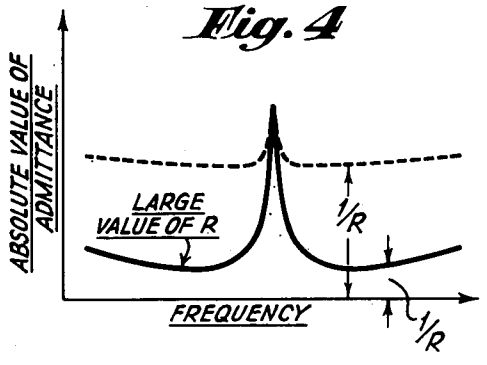
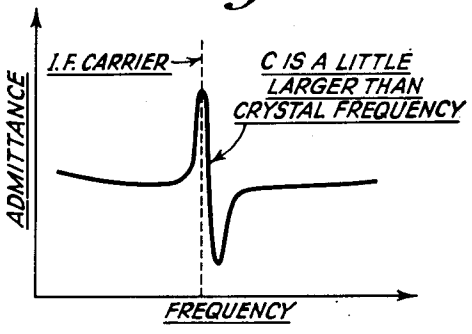


Fig. 5



INVENTOR.
WALTER VAN B. ROBERTS

BY H. S. Brown

ATTORNEY.

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PIEZOELECTRIC CRYSTAL FILTER CIRCUIT

Walter van B. Roberts, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 7, 1939, Serial No. 249,751

2 Claims. (Cl. 179—171)

My present invention relates to signal translating systems, and more particularly to systems including, in combination, an amplifying circuit, a sharply resonant system connected to cause degenerative feedback in said circuit, and means for controlling the degeneration at frequencies other than the resonant frequency of said resonant system.

The main object of the invention is to provide an amplifying system having normal gain at a single frequency and a lesser gain at other frequencies, said other frequencies including frequencies closely adjacent to said single frequency.

Another important object of my invention is to provide an amplifier whose gain is substantially uniform over a range of frequencies except for an extremely narrow range of frequencies located within or adjacent said first range, the gain in said narrow range rising to a value having a predetermined ratio to said uniform value.

Still another object of the invention is to provide a signal translating system having a peak value of gain at one frequency and a minimum value of gain at a closely adjacent frequency, the gain at other frequencies being of a substantially uniform value of predetermined adjustable relation to said peak value over a range of frequencies that is wide relative to the range of frequencies at which the gain is substantially greater than said uniform value.

One important use for such an amplifying system, as described in this application, is in connection with the intermediate frequency (I. F.) amplifier of a superheterodyne receiver for the purpose of exaggerating the amplification of the carrier frequency while maintaining uniform the amplification of the side band frequencies. Such exaggeration is useful for reducing the distortion that often accompanies fading of the signals as a result of the carrier fading down more than the side frequencies, a phenomenon termed "selective fading" and that results in the same type of distortion as produced by over-modulation. Other uses for such an exaggerated carrier will be apparent in connection with manual sharp tuning by reference to indicator devices known under the trade-mark "Magic Eye"; with automatic sharp tuning devices operating on carrier response; and, also, in connection with muting devices and so on.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically a circuit organization whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows an amplifier circuit arrangement according to the invention,

Fig. 2 shows the equivalent circuit of the frequency-selecting elements of Fig. 1,

Fig. 3 is a diagram showing the variation with frequency of the admittance of portions of the network shown in Fig. 2.

Fig. 4 shows the variation of the admittance of the circuit of Fig. 2 with normal adjustment, and

Fig. 5 shows the variation of the admittance of the circuit of Fig. 2 with another adjustment.

Before describing the behaviour of the circuit of Fig. 1 it should be noted that the network located between ground and the cathode of tube V produces a degenerative feedback of a magnitude determined by the impedance of the network. It is well known that the gain of the stage is reduced by this feedback so that the variation of gain of the stage depends on the way this impedance varies. For this reason it is preferable to study the behaviour of the degenerative network before attempting to describe the complete operation of the invention. In the cathode circuit of tube V in Fig. 1 there is shown a condenser C and coil L connected in parallel. While not customarily indicated on the drawing, it will be understood that these elements are not in practice entirely devoid of resistance. However, it can be shown that their parallel impedance is the same as that of a resistance-less condenser in parallel with a resistance-less coil, and, also, in parallel with a pure resistance. Furthermore, if the actual coil and condenser are reasonably "low-loss" the equivalent loss-free elements will be of nearly the same values, while the equivalent shunt resistance will be of very high value and all of the equivalent elements will be substantially constant over a considerable range of frequencies. The equivalent shunt resistance may thus be considered as part of the adjustable resistance element R in the cathode circuit of tube V of Fig. 1. As to the crystal X itself, its impedance is well known to be exactly the same as that of a series circuit including resistance, capacity and inductance, said series circuit being shunted by a small capacity. In Fig. 2 the series circuit of the crystal is r, L_x, C_x

while the shunt capacity is considered as a part of the adjustable condenser C. Thus, finally, the I. F. amplifier network of Fig. 1 is replaced by the equivalent network of Fig. 2 which is of a form more readily adapted to analysis.

Refer, now, to Fig. 3 which is a complex plane representation of the variation with frequency of the admittance of portions of the network of Fig. 2. In Fig. 3 the origin is at point 0 and "Conductance" values are plotted along the real axis while "Susceptance" is plotted upwards. It may be readily shown that the circle represents the admittance of the elements R, r, L_x and C_x as the frequency varies from zero to infinity. At zero frequency the admittance is a pure conductance $1/R$, and is represented by the point a on the circle. As the frequency is increased the admittance value moves clockwise around the circle until at the frequency at which L_x and C_x resonate the admittance is again a pure conductance $1/r$ plus $1/R$ and is represented by point b. It will be noted that the diameter of the circle is $1/r$ regardless of the value chosen for R. As the frequency is further increased to infinity the admittance value continues clockwise around the circle back toward the point a. So far there has been considered only the admittance of the resistance and series resonant portions of the network. As to elements C and L since these are loss-free, their admittances are at all frequencies pure susceptances and hence are always located on the vertical axis. As frequency increases from zero to infinity the sum of these two susceptances travels up the vertical axis from minus infinity to plus infinity. The total admittance of the network of Fig. 2 is obtained at any frequency by adding the admittance represented by the appropriate point on the circle to the susceptance represented by the corresponding point on the vertical axis. The total impedance of the network is then the reciprocal of the result.

Let us suppose that C is so adjusted that the anti-resonant frequency of L and C is the same as the series-resonant frequency of L_x and C_x. In this case the susceptance of the LC combination vanishes at the same frequency at which the admittance of the rest of the network becomes a pure conductance represented by point b. Furthermore, if any ordinary sized coil and condenser are used at L and C the admittance of these two elements will be found to remain relatively very small throughout the narrow range of frequencies in which the admittance of the other elements traverses nearly the whole circumference of the circle. Hence, the admittance of the entire network has an absolute value that varies with frequency somewhat as shown in Fig. 4, in which the solid curve corresponds to a large value of R while the dotted curve is obtained from a smaller value of R. By making the value of R small enough the relative exaggeration of the admittance at the crystal frequency can be reduced as much as desired.

Consider next the effect of adjusting C so that the combination LC is not resonant at the crystal frequency. In this case the total admittance has a peak substantially as before but at other frequencies falls to a value determined by both R and the admittance of the LC combination except at one frequency where the susceptance of the crystal branch is equal and opposite to that of the LC combination. At this latter frequency the total admittance drops to substantially $1/R$. Fig. 5 shows qualitatively the effect of making C a little larger than the resonant value. A similar curve but with the dip on the other side of the crystal frequency is obtained by making C a little too small. Again the relative magnitudes of the departures from the mean value can be reduced by reducing R. The type of response curve shown in Fig. 5 is sometimes useful when a single frequency closely adjacent a desired carrier is to be rejected. The frequency at which this rejection occurs is controlled by the setting of C.

Returning, now, to Fig. 1 there is shown in schematic manner a superheterodyne receiver system comprising a converter 1 whose variably tuned signal input circuit 2 may be coupled to any desired signal source. For example, the usual signal collector may be employed, and the signals can be amplified in one or more amplifiers prior to impression of the signal energy on circuit 1. The numeral 3 denotes the usual adjustably tuned local oscillator tank circuit which is tuned over a frequency range differing from the signal range by the I. F. value. A common tuner 4, well known to those skilled in the art, is employed to adjust the tuning reactances of circuits 2 and 3. The output circuit 4 is fixedly resonated to the desired I. F., while the input circuit 5 of I. F. amplifier V is tuned to the same I. F. value.

Amplifier V may be of any desired type; its cathode is grounded through the piezo-electric crystal element X. The latter is shunted by the adjustable resistor R; the anti-resonant combination L—C shunts the crystal X as well. Normal negative bias is applied to signal grid 6 from any desired negative bias source through the resistor 7. If AVC bias is used at this point, the phenomena heretofore described become complicated by the fact that in the case of strong signals, which result in a large AVC voltage, the mutual conductance of tube V is greatly reduced. This in turn greatly reduces the relative magnitude of the effects of the degenerative feedback. This fact may be usefully employed to provide a carrier-emphasizing action only on weak signals such as are particularly benefitted by such action. The AVC bias may be dreived from the I. F. signals in any desired and well known manner; for example, a rectifier can be coupled to the output of circuit 8 or 9, and the direct current voltage output of the rectifier can be applied as the bias for grid 6. The amplifier plate circuit includes the resonant network 8 tuned to the I. F., and the circuit 9 may be coupled thereto to transfer the I. F. energy to a second detector. Of course, if desired, the I. F. circuit 9 can be coupled to additional I. F. amplifiers prior to demodulation of the I. F. energy. Any type of audio amplifier and reproducer can be used subsequent to the demodulator.

The amplifier V is a typical amplifier of intermediate frequency energy except for the inclusion of the degenerative network in the cathode circuit. Transformers T and T_1 are bandpass transformers. The gain of the stage is the more reduced from normal the higher the impedance of the cathode network. Hence, the gain is greater the larger the admittance of this network. Therefore, the curves of Figs. 4 and 5 also represent the stage gain in the vicinity of crystal resonance. Frequencies outside of the band passed by the transformers T, however, are attenuated by these transformers regardless of the state of degeneration so that the slight rise of the curves of Figs. 4 and 5 as the frequency departs widely from the carrier frequency has very little effect on the over-all selectivity characteristic of the amplifier stage.

To recapitulate the performance of the system:

(1) With C tuned to I. F. resonance, and R very small, the gain is substantially normal; as R is increased the side frequency gain is decreased while the carrier frequency gain is reduced only to a slight extent depending on the equivalent series resistance of the crystal. Thus the carrier may be exaggerated to any desired extent while the gain throughout the side band frequencies is substantially uniform.

(2) With C suitably detuned not only is the carrier emphasized, but a frequency determined by the amount of detuning is suppressed. In this case, also, the amount of emphasis and suppression is determined by the adjustment of R.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In an amplifier of modulated carrier waves, a tube having at least a cathode, control electrode and output electrode, a modulated carrier output circuit coupled to the output electrode of said tube, a network for producing exaggeration of the carrier with respect to the modulation side band frequency components, said network comprising a parallel resonant cicuit, tuned to the carrier frequency of applied carrier waves, arranged in the space current path of said tube between said cathode and a point of invariable potential, said resonant circuit being of substantially low resistance, a piezo-electric crystal connected in shunt with said resonant circuit and tuned to said carrier frequency, a purely resistive element, connected between said cathode and said point, arranged in shunt with each of said crystal and resonant circuit, a resonant modulated carrier input circuit connected between said control electrode and said point whereby voltages of said modulation side band frequency components developed across said exaggeration network are applied in substantially uniform manner upon said control electrode in degenerative sense thereby to provide at said output circuit a substantially uniform decrease of said components' amplitudes with respect to the carrier frequency and means for adjusting the resistance of said resistive element to such a large value that said uniform degeneration of said components is greatly increased thereby greatly to increase the relative exaggeration of said carrier amplitude while maintaining said components at a substantially uniform decreased amplitude.

2. In the intermediate frequency amplifier of a superheterodyne receiver, a tube having an input circuit and an output circuit each tuned to the operating intermediate frequency value, means for compensating for the effect of selective fading wherein the carrier fades relative to its modulation side band frequency components, said compensating means comprising a piezo-electric crystal, tuned to said intermediate frequency, connected in the tube space current path between the tube cathode and a point of invariable potential, a parallel resonant circuit, substantially free of resistance and tuned to said intermediate frequency, in shunt with said crystal, voltages of solely said modulation side band components and of substantially uniform amplitude being developed across said cystal and resonant circuit, said input circuit being connected between the tube control grid and said point whereby said voltages are degeneratively applied to the control grid, a separate resistor, in shunt with each of said crystal and resonant circuit, providing the resistance for said compensation means, and means for adjusting the resistive magnitude of said resistor to increase the resistance of said compensation means to an extent such that said degenerative voltages are increased sufficiently to provide such relative exaggeration of the carrier frequency as to produce said compensation.

WALTER VAN B. ROBERTS.