May 15, 1945. M. G. CROSBY 2,376,127

FREQUENCY DISCRIMINATOR

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Fig. 1.

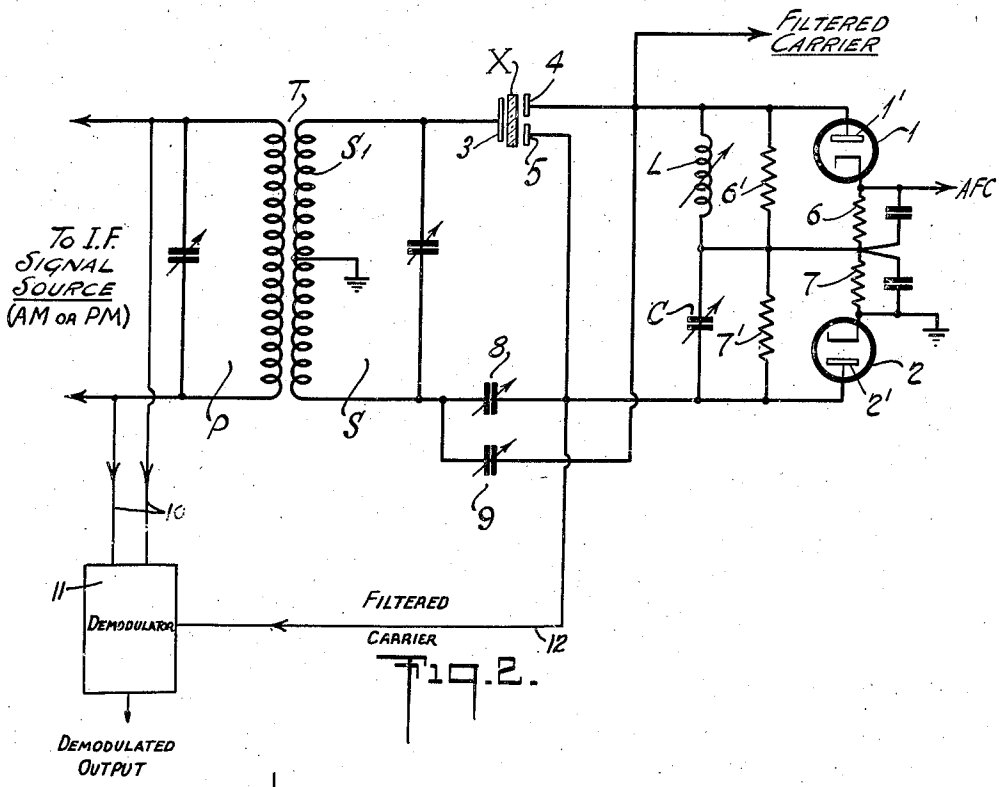
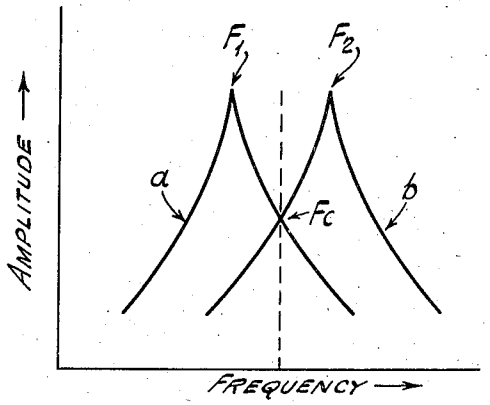


Fig. 2.



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Fig. 3.

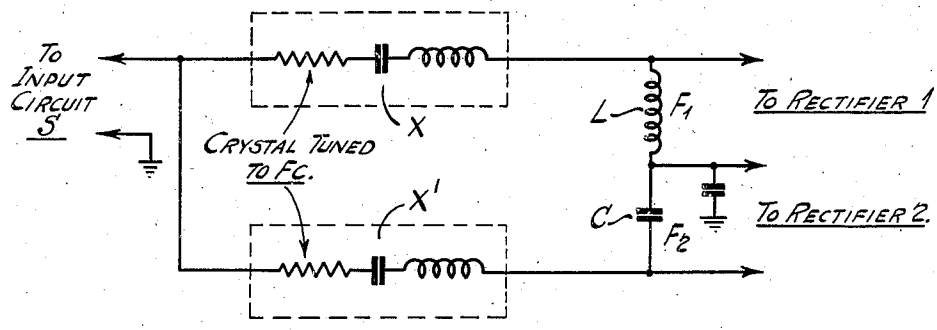
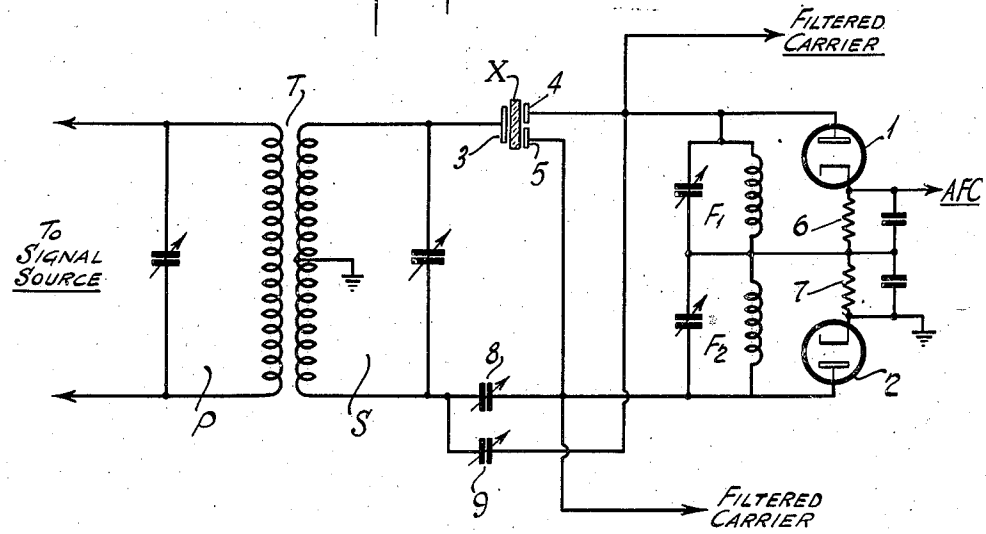


Fig. 4.



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FREQUENCY DISCRIMINATOR

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Application April 27, 1943, Serial No. 484,704

6 Claims. (Cl. 250—40)

My present invention relates generally to frequency discriminators, and more especially to piezo-electric crystal filter discriminators.

One of the main objects of my invention is to provide a frequency discriminator employing but a single piezo-electric crystal element tuned to the mean frequency of applied modulated carrier waves, and yet providing at its output terminals a pair of complementary sloping filter characteristics.

Another important object of my present invention is to provide a crystal filter network for phase modulated ("PM" hereinafter for brevity) carrier waves, or amplitude modulated ("AM" for brevity) carrier waves, for the purpose of providing filtered carrier energy to be fed to a carrier-exalted demodulator, the filter network concurrently providing a pair of complementary sloping filter characteristics for frequency discrimination.

The novel features which I believe to be characteristic of my invention are set forth with 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 drawings, in which I have indicated diagrammatically several circuits whereby my invention may be carried into effect.

In the drawings:

Fig. 1 shows an embodiment of the invention,

Fig. 2 shows the frequency discrimination characteristic,

Fig. 3 shows a simplified explanation of the circuit,

Fig. 4 illustrates a modification.

The crystal filter network of my present invention functions, as set forth above, to provide substantially pure carrier energy for carrier exaltation reception; to provide AFC (automatic frequency control) bias for the receiver local oscillator; and to provide a response to either PM or AM wave energy. In other words, the present crystal filter discriminator will function in either PM or AM receivers to provide sharp AFC action and carrier exaltation. Furthermore, the circuit provides two points at which the filtered or stripped carrier may be derived. Another feature of the invention is the fact that while using but a single crystal, yet the discriminator may be designed to have two spaced off-center frequency peaks.

These various functions are provided by the circuit depicted in Fig. 1. Here, the input transformer T has primary and secondary circuits P and S each tuned to the mean, or center, frequency F_c of applied radio signals. Let it be assumed that the receiver is of the superheterodyne type, and that there is fed to the primary circuit P intermediate frequency (I. F.) energy. Let it further be assumed that the receiver is a carrier exaltation receiver. This means that a parallel I. F. branch circuit 10 would be coupled to the network feeding P, and that the branch circuit would feed a demodulator 11. The latter would be fed with the substantially pure carrier output of the crystal X. For example, lead 12 feeds pure carrier energy to demodulator 11. Whether the signal energy is PM wave energy or AM wave energy, the same mode of operation would apply. Insofar as the AFC action is concerned, in either of PM or AM reception employing carrier exaltation, it is desirable to have a sharp AFC action so that the local oscillator is rigidly held in tune thereby to keep the modulated carrier and filtered carrier at the demodulator in strict frequency synchronism.

The secondary circuit S has its coil S_1 grounded at the midpoint thereof. The upper end of winding S_1 connects to the anode of rectifier 1, a diode, by piezo-electric crystal X. The latter is ground so as to be tuned to F_c, and is of the type having one input electrode 3 and a pair of output electrodes 4 and 5. These electrodes may be conventional holder plates, or they may be metallic coats provided on the opposite crystal faces. Electrode 4 connects to anode 1' of rectifier 1. The anode 2' of diode rectifier 2 is connected to the second output electrode 5 of the crystal. The lower end of winding S_1 feeds neutralizing voltage through adjustable condenser 8 to the electrode 5. This neutralizing voltage bucks out, or nullifies, the inter-electrode capacitance existing between electrodes 3 and 5. The condenser 9 performs the same function in connection with the capacity between electrodes 3 and 4. Since the midpoint of S_1 is grounded, the voltage fed through condensers 8 and 9 necessarily is of opposite phase to that transmitted through capacitance 3—5 and 3—4 respectively.

Adjustable coil L is arranged in series with crystal X to provide the off-center peak frequency F_1. The adjustable condenser C is arranged in series with the crystal to provide the off-center peak frequency F_2. In Fig. 2 there are graphically indicated the off-center peak frequencies F_1 and F_2, and the manner in which the two sharp resonance curves cross over at F_c. It will be understood that curve *a* of Fig. 2 is the resonance curve of crystal X in series with induct-

ance L. The curve *b* is the resonance curve of crystal X in series with condenser C. The magnitudes of L and C are so chosen as to provide a predetermined frequency spacing between F_1 and F_2. The frequencies F_1 and F_2 are equally spaced from F_c. Hence, it will be seen that there has been provided a frequency discriminator which presents at its output terminals complementary sloping filter characteristics.

The inductive reactance L feeds rectifier 1. The anode 1' is connected to the upper end of coil L. The cathode of diode 1 is connected to the lower end of the coil by load resistor 6. The direct current return path 6' connects the anode and cathode of diode 1 directly together. The capacitative reactance C feeds the diode 2. The anode 2' is connected to the lower end of condenser C, while the cathode is connected to the junction of L and C by load resistor 7. Each of load resistors 6 and 7 is bypassed by a respective I. F. bypass condenser. The load resistors are series-arranged, and the cathode end of resistor 7 is grounded. Return resistor 7' connects the anode 2' to the junction of resistors 6 and 7. The lower end of resistor 6' is, also, connected to the same junction point. Furthermore, the junction of L and C is connected to the junction of 6' and 7'. It will be seen that diode 1 derives its signal voltage from across L, while diode 2 derives its signal voltage from across C.

The AFC bias is derived from the cathode end of load resistor 6. The substantially pure or filtered carrier energy may be tapped from one of two points in the system. It may be taken from crystal output electrode 4, or it may be derived from the crystal output electrode 5. The filtered carrier energy, regardless of its point of derivation, is fed to the aforementioned demodulator for carrier-exalted detection of received signals.

The AFC bias production will be better understood by reference to Fig. 3. Here the crystal X is depicted by its equivalent circuit. By the use of two output electrodes, two equivalent crystal circuits X and X' are provided. These circuits are series resonant circuits, tuned to F_c, which have a certain value of resistance. Coil L in series with the equivalent series resonant circuit X provides a total network tuned to F_1. Condenser C in series with the series resonant circuit X' provides a network tuned to F_2. Rectifier 1 is adapted for connection across L, while rectifier 2 is shunted across C. Hence, if applied signal energy has its mean frequency equal to F_c, then there will be equal signal voltage fed across each of L and C to their respective rectifiers. The latter being in opposition, the differential rectified voltage at the upper end of resistor 6 will be zero.

Should the mean frequency of applied signal energy shift to F_1, then more signal voltage will be developed across L. This follows from the fact that X in series with L tunes to F_1. The shift of the mean frequency towards F_2 will cause more voltage to appear across C than across L. Accordingly, the AFC bias will have a polarity and magnitude dependent respectively upon the sense and extent of frequency shift of the mean frequency of applied signal energy with respect to F_c.

It will be apparent to those skilled in the art that the reactive effects produced by L and C may be produced by any type of circuits which produce equal and opposite reactive effects. For instance, tuned circuits could be substituted for L and C, and the opposite reactive effects produced by detuning the tuned circuits in opposite directions from the frequency F_c. Fig. 4 shows how this may be done. In that figure the tuned circuit tuned to F_1 replaces L, while the tuned circuit tuned to F_2 replaces C. It will be noted that the return resistors 6' and 7' may be omitted in this modification.

While I have indicated and described several systems 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 organizations 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 a frequency discriminator circuit, a signal carrier input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to a desired reference frequency equal to the frequency of said input circuit, means connecting the input electrode to one side of the input circuit, means grounding the electrical midpoint of the input circuit, means connecting one crystal output electrode to the opposite side of the input circuit, an inductive impedance in series with one output electrode of the crystal and being resonant with the latter to a frequency spaced from said reference frequency, a capacitative impedance in series with the second output electrode of the crystal and being resonant with the latter to a frequency spaced from the reference frequency in the opposite sense, and respective output connections to each of said impedances.

2. In a frequency discriminator circuit, a signal carrier input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to a desired reference frequency, means grounding the electrical midpoint of the input circuit, means connecting said input electrode and one crystal output electrode to opposite sides of the electrical midpoint, an inductive reactance in series with one output electrode of the crystal and being resonant with the latter to a frequency spaced from said reference frequency, a capacitative reactance in series with the second output electrode of the crystal and being resonant with the latter to a frequency spaced from the reference frequency in the opposite sense, respective output connections to each of said reactances, and means grounding the junction of said reactances for signal currents.

3. In a frequency discriminator circuit, a signal carrier input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to the frequency of said input circuit, means connecting the input electrode to one side of the input circuit, means grounding the electrical midpoint of the input circuit, means connecting one crystal output electrode to the opposite side of the input circuit, an inductive impedance in series with one output electrode of the crystal and being resonant with the latter to a frequency spaced from said reference frequency, a capacitative impedance in series with the second output electrode of the crystal and being resonant with the latter to a frequency spaced from the reference frequency in the opposite sense, a respective rectifier connected to each of the impedances,

and the rectifiers being connected in opposition to provide a differential rectified voltage.

4. In a frequency discriminator circuit, a signal carrier input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to the frequency of said input circuit, means connecting the input electrode to one side of the input circuit, means grounding the electrical midpoint of the input circuit, means connecting one crystal output electrode to the opposite side of the input circuit, an essentially inductive impedance in series with one output electrode of the crystal and being resonant with the latter to a frequency spaced from said reference frequency, essentially capacitative impedance in series with the second output electrode of the crystal and being resonant with the latter to a frequency spaced from the reference frequency in the opposite sense, respective output connections to each of said impedances, and means for deriving from at least one crystal output electrode filtered energy of substantially carrier frequency.

5. In combination, a signal carrier input circuit, a source of phase modulated signals coupled to the input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to a desired reference frequency, means grounding the electrical midpoint of the input circuit, means connecting said input electrode and one crystal output electrode to opposite sides of the electrical midpoint, means connecting the second output electrode to the side of the midpoint to which the one output electrode is connected, an inductive reactance in series with one output electrode of the crystal and tuning the crystal to a frequency spaced from said reference frequency, a capacitative reactance in series with the second output electrode of the crystal and being resonant with the latter to a frequency spaced from the reference frequency in the opposite sense, respective output connections to each of said reactances, means grounding the junction of said reactances for signal currents, and means for deriving substantially unmodulated signal carrier energy from at least one output electrode.

6. In a frequency discriminator circuit, a signal carrier input circuit, a piezo-electric crystal element provided with an input electrode and a pair of output electrodes, said crystal being tuned to the frequency of said input circuit, means connecting the input electrode to one side of the input circuit, means grounding the electrical midpoint of the input circuit, means connecting one crystal output electrode to the opposite side of the input circuit, a tuned circuit in a series path with the crystal, means connecting one side of said tuned circuit to one of the crystal output electrodes, said tuned circuit being resonant to a frequency spaced from said reference frequency, a second tuned circuit in a series path with the crystal, means connecting one side of said second tuned circuit to the second crystal output electrode, said second tuned circuit being resonant to a frequency spaced from the reference frequency in the opposite sense, means establishing a common ground point for the sides of said two tuned circuits not connected to said crystal output electrodes, respective output connections to each of said tuned circuits, and means for deriving from at least one crystal output electrode filtered energy of substantially carrier frequency.

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