

May 2, 1939.

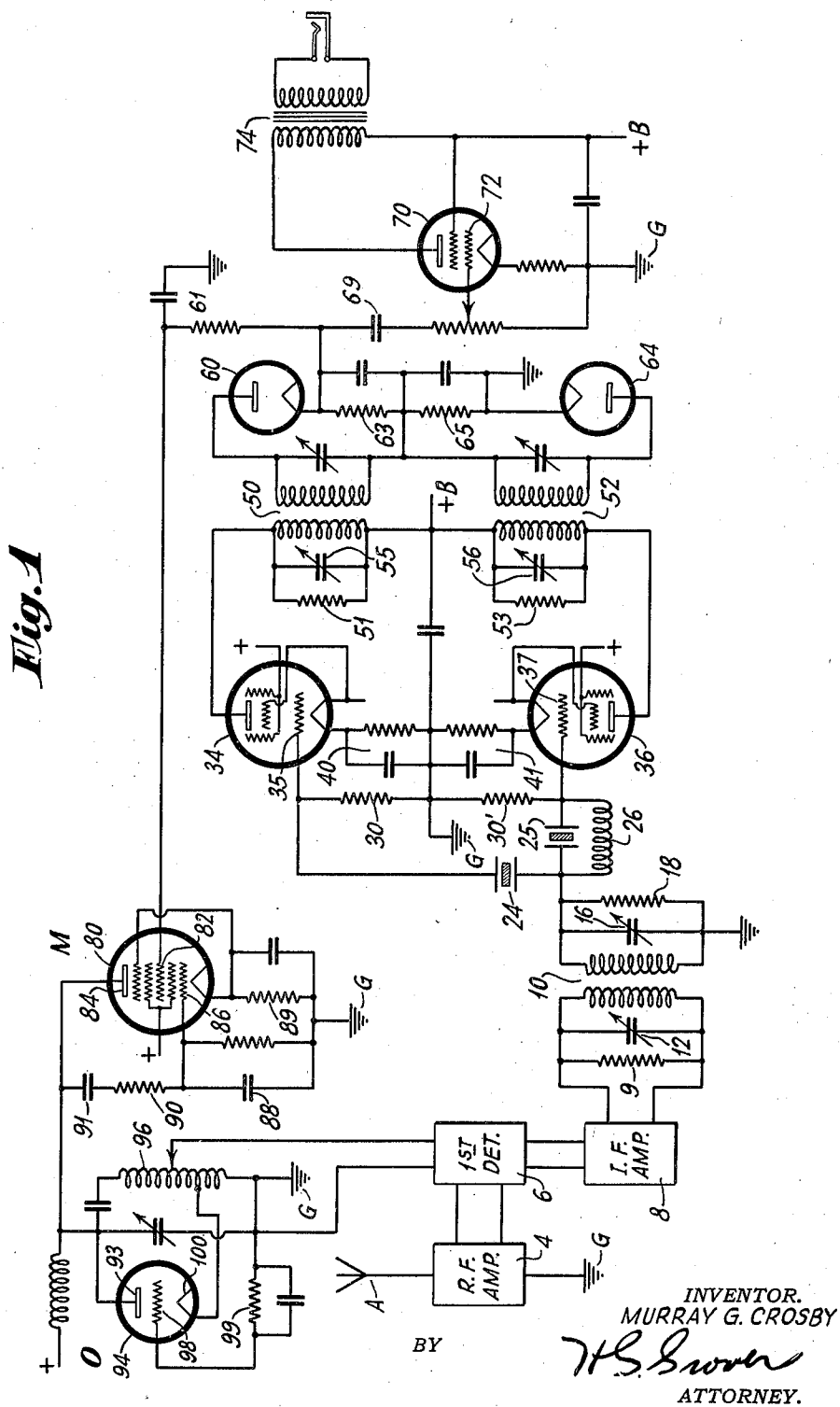
M. G. CROSBY

2,156,376

SERIES CRYSTAL PHASE MODULATION RECEIVER

Filed Dec. 8, 1937

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 2a

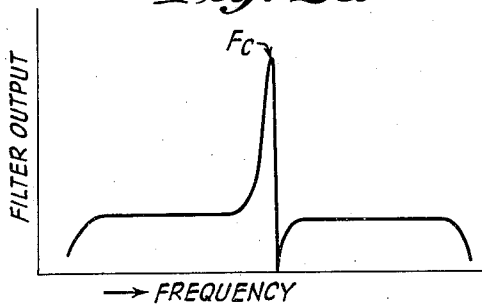


Fig. 2e

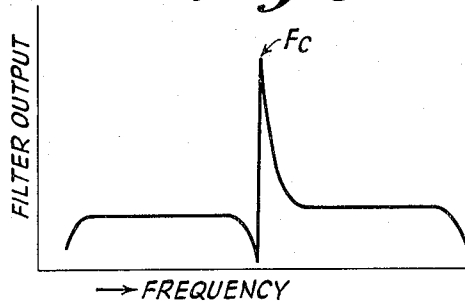


Fig. 2b

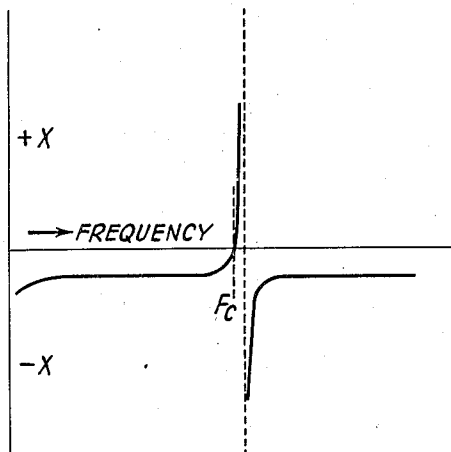


Fig. 2f

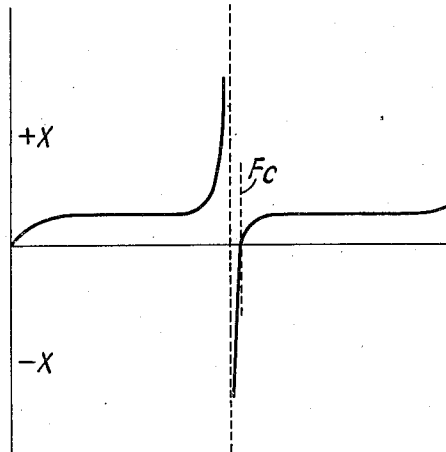


Fig. 2c

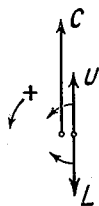


Fig. 2d

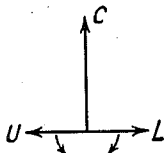


Fig. 2g

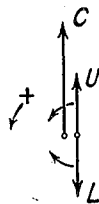
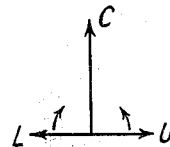


Fig. 2h



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2,156,376

SERIES CRYSTAL PHASE MODULATION
RECEIVERMurray G. Crosby, Riverhead, N. Y., assignor to
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Application December 8, 1937, Serial No. 178,655

8 Claims. (Cl. 250—20)

This application concerns a phase modulation receiver of the crystal filter converting type, in which two separate crystals are used to obtain the required over- and under-neutralized filter characteristics with demodulating means of the back-to-back type coupled with the output of the filters. The characteristic of the filters comprising the under- and over-neutralized crystals is such that when phase modulated wave energy is passed by the filters, it is converted to waves of amplitude modulation and the filter outputs are so arranged and coupled to the back-to-back demodulators that the modulation envelopes resulting from the conversion have a 180° relation so that the detector system coupled to the filters detects the amplitude modulations, resulting from the conversion, to render the signal. Undesired amplitude modulations reaching the filters have similar effects on the output thereof and are, due to the back-to-back effect in the demodulators, cancelled or substantially cancelled by differential action.

In my United States application Serial #167,344, filed October 5, 1937, I have described a receiver of the general type involved here. The present receiver, however, includes various improvements and novel features not included in the said prior application. One difference between the receiver of the prior application and the receiver of the present application resides in the manner of connecting the crystal filters. In the prior application, energy is fed from an impedance or reactance to the crystal through a resistor and the output of the filter comprises the drop across the crystal. In the receiver of the present application, the crystals in their holders are connected in series circuits so that at the resonant frequency of the crystal a maximum amount of wave energy is passed thereby, while at the anti-resonant frequency of the piezo-electric crystal a minimum amount of energy is passed. The anti-resonant frequency characteristic of the crystal is due to the holder capacity and the inductive effect of the crystal per se. With the crystals connected in series as in this application, a more efficient transfer of energy from the input reactance or impedance to the filter outputs is obtained due to the fact that there is no loss in the resistor which has been used heretofore for feeding the crystals in the shunt connection. I have also found that the series connection as used in the present invention gives a greater exaltation of the carrier with respect to the side bands. This is of material ad-

vantage in reducing the distortion due to fading of the character during transmission.

In describing my invention, reference will be made to the attached drawings wherein:

Figure 1 illustrates the essential elements of phase modulated wave energy receiving, amplifying and converting means with automatic frequency control means, all arranged in accordance with the present invention. Certain of the elements of the receiver are shown diagrammatically by rectangles since these elements per se form no part of the present invention. The filter circuits for converting phase modulations on the wave energy to characteristic amplitude modulations are illustrated in detail, although in the sake of simplicity, even these circuits do not include all known refinements which applicant might use in a practical application.

Figures 2a to 2h inclusive, are resonant curves, reactance curves, and wave component vector diagrams used in illustrating the operation of the converting circuit.

Referring to the drawings, Figure 1 shows a somewhat complete receiver employing the principles involved here. In this receiver, wave energy to be demodulated is intercepted by an aerial system A and supplied by A to a radio frequency amplifier 5 wherein the energy is selected and amplified as desired. Energy from the output of 4 is supplied to a first detector 6 also coupled to a local oscillator O of the controllable type. Oscillations from O beat with the wave energy in 6 to produce intermediate frequency energy supplied to intermediate frequency amplifier 8. The output of 8 supplies potentials to the primary winding of a transformer 10, the secondary winding of which has one terminal connected to ground and the other terminal connected to electrodes or holders of piezo-electric crystals 24 and 25. The primary and secondary windings of 10 are tuned to substantially the mean frequency of the intermediate frequency energy by condensers 12 and 16, respectively. In order to pass substantially uniformly all of the frequencies involved, the primary and secondary windings are shunted by damping resistors 9 and 18, respectively. An electrode of crystal 24 is connected to the control grid 35 of a coupling and amplifying tube 34, while an electrode of piezo-electric crystal 25 is coupled to the control grid 37 of a coupling and amplifying tube 36. The crystal 25 has its two holders or electrodes shunted by an inductive reactance 26, the purpose of which will appear in detail hereinafter. Grid leak resistors 30 and 30' are connected between the control grids 35

and 37, respectively, and ground G, while self-biasing resistors shunted by by-passing condensers 40 and 41 are connected between the cathodes of the tubes 34 and 36, respectively, and ground.

The anode-electrode of 34 is connected with the primary winding of a coupling bandpass transformer 50, while the anode of 36 is coupled to the primary winding of a bandpass transformer 52. The bandpass transformer 50 may be tuned to the desired frequency by tuning condenser 55 and may be damped by damping resistor 51 to give it the desired bandpass characteristic. In like manner and for the same purpose, the primary winding of transformer 52 may be tuned by condenser 56 and damped by resistor 53. The secondary windings of 52 and 59 are connected in series between the anodes of diode rectifier 60 and 64. The cathodes of diode rectifiers 60 and 64 are connected together by resistors 63 and 65, the resistors being shunted by by-passing condensers as shown. The cathode end of the resistor 65 is connected to ground so that potentials at the cathode end of 63 vary with respect to ground in accordance with the combined outputs of 60 and 64, which in turn are excited by the energy passed by 50 and 52. The latter energy is, due to causes which will be described hereinafter, amplitude modulated energy resulting from the conversion of the phase modulations in the crystal filters. Moreover, the amplitude modulations have opposed envelopes. The resulting amplitude modulations are impressed by condenser 69 on the input electrode 72 of an audio frequency amplifier 70, the anode of which is coupled to a transformer 74 having a secondary which may supply the amplified modulation potentials to any utilization circuit. Potentials from the resistors 63 and 65 are also supplied by way of a time constant control circuit 61 to the control grid 82 of a modulator tube which controls the frequency of the oscillator O supplying oscillations to the first detector for beating purposes.

The modulator M comprises a reactance tube 80 having an anode 84 coupled to the anode 93 of the oscillator 94. The anode to cathode impedance of modulator tube 80 is in shunt to the reactance 96 in the oscillation generating circuit 94 so that it controls the frequency of the oscillation generated. The anode 84 of tube 80 also is connected by way of a blocking condenser 91 to its grid 86 through phase shifting resistor 90 and condenser 88. Resistor 89, which is properly by-passed by a condenser, furnishes self-bias for tube 80. The grid 86 of tube 80 is coupled to the connections between 90 and 88. Oscillator tube 94 has its grid 98, anode 93, and cathode 100 coupled in a frequency determining and stabilizing circuit 96 which circuit is coupled by leads to the first detector 6. This reactance circuit and oscillator are as described in my copending application Serial #167,344 filed October 5, 1937.

The value of resistance 90 is high as compared to the reactance of condenser 88 for the frequency used, that is, generated in O, so that the current through this circuit is largely resistive and is in phase with the voltage. However, the voltage drop across 88 leads the current by 90° and the phase quadrature relation between the radio frequency potentials on 84 and 86 necessary for the reactive effect is obtained. The reactance of tube 80 shunts the frequency determining circuit 96 and consequently the reactance tube controls to some extent the frequency of the

oscillations produced in 96 and tube 94. This reactive effect, which may be considered inductive or capacitive, is, in turn, controlled by the potential supplied from the time control circuit 61 to the grid 82 of reactance tube 80. The potential supplied to 82 is a function of the mean frequency of the intermediate frequency energy supplied by 50 and 52 changing when the intermediate frequency energy drifts in either direction from the selected mean frequency. Such drift may be caused by the change in frequency of the received wave or the frequency of the oscillator O, or both, and results in a change in potential developed in 63 and 65, a change of the potential of 82 and a correcting change in the reactance reflected by the reactance tube 80 into the circuit 96 or a part thereof. Since the plate 84 is connected to the plate 93 and the grid 86 is excited by voltage displaced in phase relation to that of the circuit 96, the plate current in 80 is likewise out of phase with the voltage of 96 and the control tube 80 looks like a reactance to the circuit 96.

The operation of my receiver and in particular of the converting circuits including the crystals 24 and 25, will be more clearly understood by reference to Figures 2a to 2h, inclusive, of the drawings. Crystals 24 and 25 are ground to the same frequency, but crystal 25 has an inductance 26 in shunt with the electrodes so that this crystal holder will have an inductive instead of a capacitive effect. The holder reactance of crystal 24 is left capacitive. Since one of the crystals is shunted by capacity only and the other is shunted by inductance, the required over- and under-neutralized characteristics will be obtained due to the fact that an inductance in shunt with the crystal is equivalent to an over-neutralization. Thus, the capacitive crystal holder, e. g., 24, will effect an under-neutralized characteristic and the inductive holder, e. g., 25, will effect an over-neutralized characteristic.

The reactance characteristic of crystal 24, which is capacitive, is as shown in Figure 2b. The voltage from transformer 10 is fed directly to this circuit and the drop across the crystal is inductive or capacitive, depending on the frequency of the wave supplied by 10, and, in accordance with the curve of Figure 2b. It can be seen that in the region where the side bands are disposed, the crystal is capacitive on both sides of the carrier frequency except for a small interval near the carrier frequency. Due to this fact, the phase of the side bands is shifted 90° with respect to the carrier as shown in Figures 2c and 2d. Figure 2c represents the phase modulated wave supplied from 10 to be converted, while Figure 2d represents the wave to which the phase modulated wave has been converted and has the characteristics of an amplitude modulated wave. Note that the arrows denoting rotation of the side bands in Figure 2d show that they rotate in a direction such as to approach cancellation of the carrier which corresponds to a minimum point on the amplitude envelope of the resultant wave. The amplitude characteristic of this filter, including crystal 24, has been shown at Figure 2a.

Crystal 25, which is shunted by the inductance 26, has a reactance frequency characteristic as shown in Figure 2f. In this figure, the filter is inductive on both sides of the carrier except for a small portion of the frequencies adjacent the carrier. Due to this reactive effect, the phase of the side bands is 90° lagging instead of leading as was the case with crystal 24. Consequently,

the phase modulated wave of Figure 2g is converted to the amplitude modulated wave of Figure 2h. Note that in the amplitude modulated wave of Figure 2h, the side bands are approaching the condition of aiding the carrier which corresponds to a maximum point on the amplitude envelope of the resultant wave.

The amplitude characteristics of the filter 25 are as shown in Figure 2e. From an examination of Figures 2d and 2h, due to the manner in which the side bands combine with the carrier, it can be seen that the phases of the amplitude modulation envelopes resulting from the conversion by the two filters is 180° out of phase. Consequently, the detection of this amplitude modulation and combination by the series connection of the diodes 60 and 64 and diode resistors 63 and 65 combines the phase modulation outputs additively. The resulting potentials of modulation frequency are amplified in 70 and utilized in 74, while the resulting potentials due to slow changes or drifts in the mean frequency act through 61 to correct the oscillator frequency.

Amplitude modulation, both noise and signal, which is present on the wave being received by this receiver either is not detected or is balanced out before appearing at the receiver output terminals. The side bands of amplitude modulation, after being shifted in phase by the filters, are converted to phase modulation which is not detectable on the amplitude detectors. In the frequency range close to the carrier where the side bands are not shifted, or for the amplitude modulation which is present due to the fact that the filters may not completely convert the amplitude modulation into phase modulation, the push-pull connection of the diode detectors is such as to cause the amplitude modulation output from one detector to cancel that from the other. Even-harmonic detector distortion appearing in the output of each detector due to the detection of the desired modulation, is also cancelled or compensated in the output.

I claim:

1. In a system for converting phase modulations on wave energy to corresponding amplitude modulations, a filter circuit which is capacitive on both sides of the frequency to which it is resonant as to a frequency spectrum of the order of a modulation frequency band, a second filter circuit which is inductive on both sides of the frequency to which the filter circuit is resonant as to a frequency spectrum of the order of a modulation frequency band, an impedance on which phase modulated wave energy may be impressed, pairs of output terminals, and means connecting said impedance and each of said filters in a series circuit including a different pair of said output terminals.

2. In a filter system for converting phase modulations on wave energy to characteristic amplitude modulations, pairs of output terminals, a crystal in a holder in an under-neutralized filter circuit resonant substantially at the mean frequency of the phase modulated wave energy to be converted, a second crystal in a second holder shunted by an inductance to form an over-neutralized filter circuit substantially resonant at the mean frequency of the wave energy to be converted, means for impressing phase modulated wave energy on said filter circuits, and means for connecting each of said filter circuits in a series circuit with a different pair of said output terminals.

3. In a system for filtering modulated wave energy, a reactance, two pairs of output terminals including a common electrode, a connection between a point on said reactance and the common electrode of said pairs of terminals, a piezo-electric crystal connecting another point on said reactance to the remaining terminal of one of said pairs of terminals, a second piezo-electric crystal connecting a point on said reactance to the remaining terminal of the other of said pairs of terminals, and an inductive reactance in shunt to one of said piezo-electric crystals.

4. In a system for converting phase modulations on wave energy to corresponding amplitude modulations, a reactance, means for impressing phase modulated wave energy on said reactance, a pair of electron discharge devices each having input electrodes and having output electrodes coupled to a utilization circuit, a connection between an input electrode in each of said devices and a point on said reactance, separate piezo-electric crystals connecting another point on said reactance to an input electrode of each of said devices, and a reactance in shunt to one of said crystals.

5. In a system for converting phase modulated wave energy into corresponding amplitude modulated wave energy and demodulating the same, a reactance, pairs of output terminals, a connection between a point on said reactance and a terminal of each of said pairs of terminals, a piezo-electric crystal connecting another point on said reactance to the remaining terminal of one of said pairs of terminals, a second piezo-electric crystal connecting another point on said reactance to the remaining terminal of the other of said pairs of terminals, an inductive reactance in shunt to one of said piezo-electric crystals, and a rectifier system having input electrodes coupled in push-pull relation to said pairs of terminals and output electrodes connected to a utilization circuit.

6. In a system for converting phase modulations and wave energy to corresponding amplitude modulations and demodulating the same, a reactance, means for impressing phase modulated wave energy on said reactance, a pair of electron discharge devices each having input electrodes and having output electrodes, a connection between the input electrode in each of said tubes and a point on said reactance, separate piezo-electric crystals connecting other points on said reactance to an input electrode of each of said tubes, a reactance in shunt to one of said crystals, and a detector system having input electrodes coupled in push-pull relation to the output electrodes of said devices and output electrodes coupled to a utilization circuit.

7. In a system for converting phase modulated wave energy to characteristic amplitude modulated wave energies with envelopes of opposed phase to substantially eliminate or cancel undesired amplitude modulations on said wave energy, a reactance excited by said wave energy, a rectifier system having input electrodes and a common output circuit, a pair of piezo-electric crystals in holders, a pair of electron discharge coupling tubes each having input and output electrodes, means connecting the output electrodes of said tube to the input electrodes of said rectifier system, a circuit including one of said crystals connecting the input electrodes of said tube in series with said reactance, a circuit including the other of said crystals connecting the input electrodes of the other of said tubes in series with

said reactance, and a second reactance in shunt to one of said crystals.

8. In a filter system for converting phase modulations on wave energy to characteristic amplitude modulations, pairs of output terminals, a crystal in a holder in a filter circuit, said crystal having dimensions such that it is resonant substantially at the mean frequency of the phase modulated wave energy to be converted, a second crystal in a second holder in a filter circuit, said

second crystal having dimensions such that it is resonant substantially at the mean frequency of the wave energy to be converted, means for over-neutralizing one of said crystals, means for impressing phase modulated wave energy on said filter circuit and means for connecting each of said filter circuits to a pair of said output terminals.

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