

April 2, 1946.

M. G. CROSBY

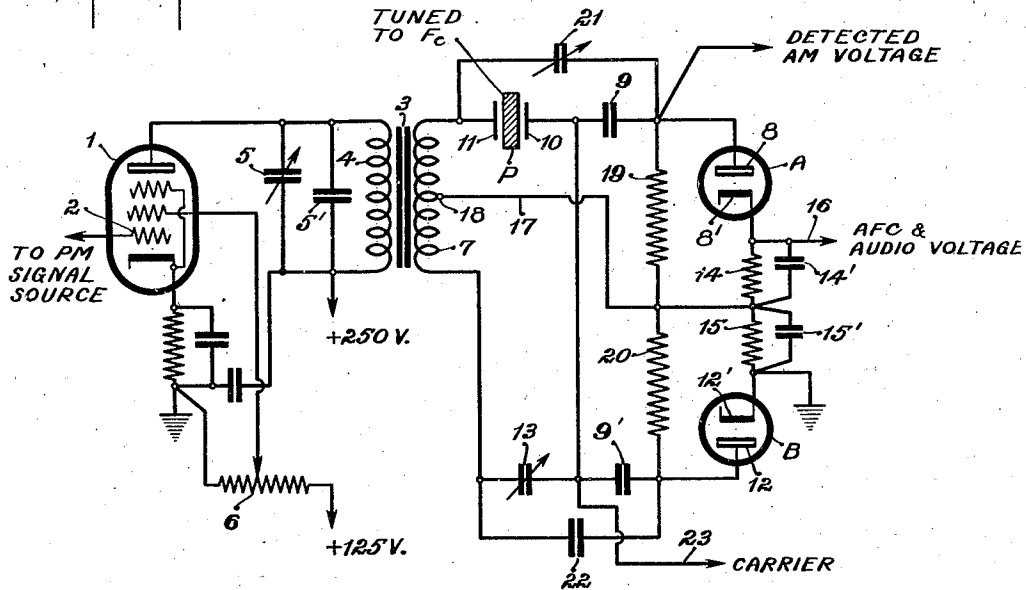
2,397,840

PHASE MODULATION DETECTOR

Filed Feb. 16, 1943

2 Sheets-Sheet 1

Fig. 1.



T i g. 2.

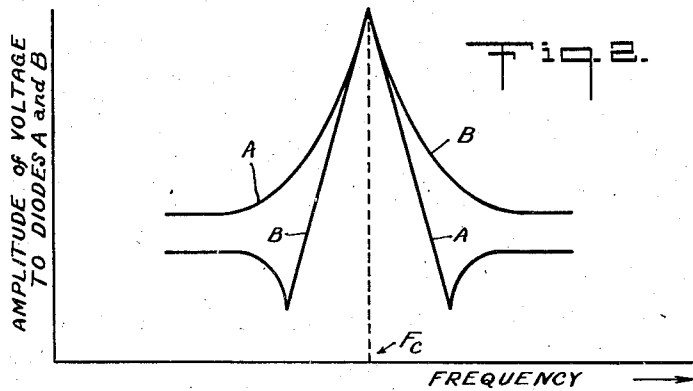


Fig. 3a.

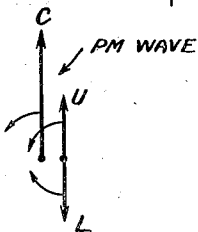


Fig. 3b.

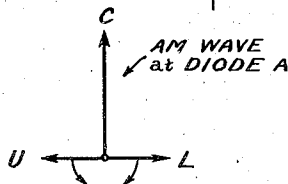
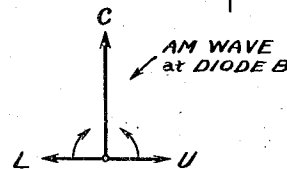


Fig. 3c.



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2 Sheets-Sheet 2

Fig. 4.

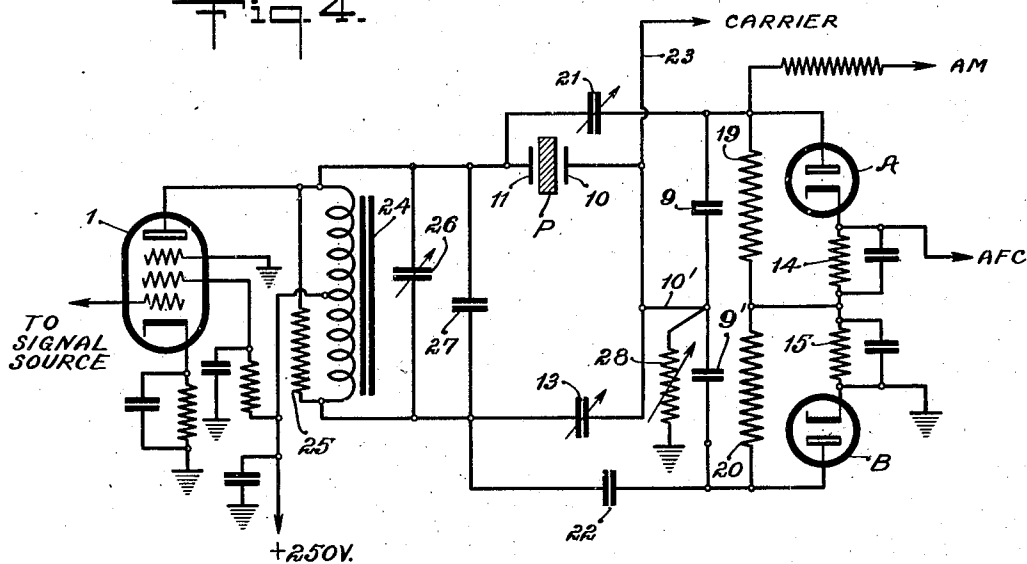
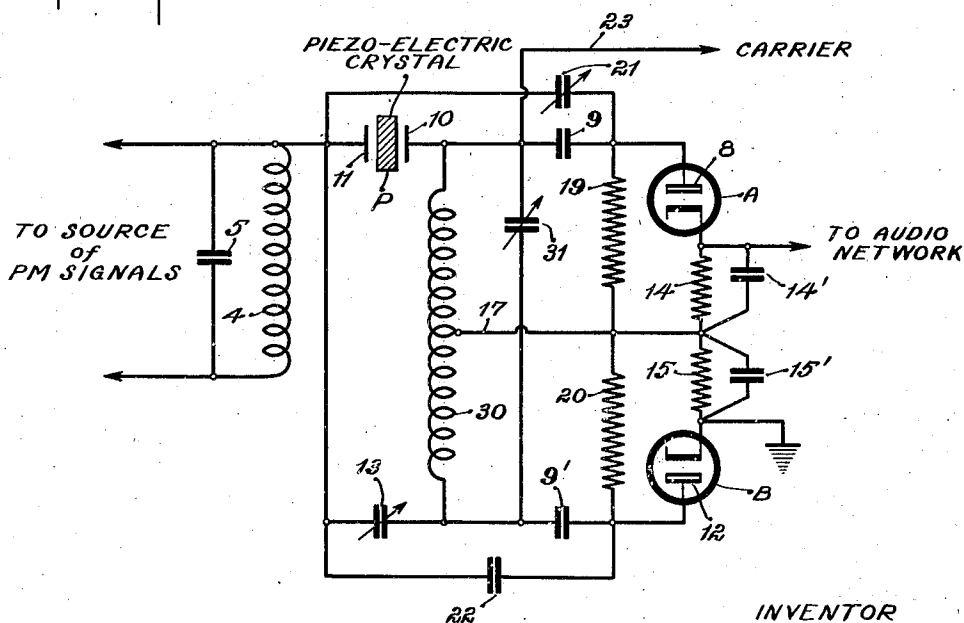


Fig. 5.



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2,397,840

PHASE MODULATION DETECTOR

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Application February 16, 1943, Serial No. 476,052

12 Claims. (Cl. 250—27)

My present invention relates to detectors, or demodulators, of phase modulated carrier wave energy (hereinafter referred to as "PM" for brevity), and more particularly to improved PM detectors employing discrimination networks of the piezo-electric crystal type.

In the past I have disclosed various PM demodulator circuits utilizing piezo-electric crystal elements for translation of the PM wave into a corresponding amplitude modulated (referred to hereinafter as "AM") carrier wave. Reference is made to my following patents for an explanation of the fundamental theory of operation of such crystal discriminator networks: U. S. Patent No. 2,085,008, granted June 29, 1937; U. S. Patent No. 2,156,374, granted May 2, 1939; U. S. Patent No. 2,156,375, granted May 2, 1939; U. S. Patent No. 2,204,575, granted June 18, 1940; U. S. Patent No. 2,204,574, granted June 18, 1940.

In the disclosure of my U. S. Patent No. 2,204,575 there has been disclosed a PM detector whose input circuit comprises a single piezo-electric crystal in a three-electrode crystal holder. Condensers were used to provide two filtered outputs from the single crystal. One of the filters has an over-neutralized characteristic, while the other filter has an under-neutralized characteristic. The effect of the filter characteristics is to cause a quadrature phase shift of the carrier relative to the upper and lower modulation sidebands. In this way a conversion from PM wave energy to AM wave energy takes place, and rectification by opposed rectifiers follows.

In prior circuits of this type over and under-neutralized crystal filter characteristics were obtained to provide a discriminator action for automatic frequency control (AFC) potentials, PM and AM detector, and filtered carrier output. In these circuits various methods were utilized to provide both an over and under-neutralized output from the same crystal. In one modification, the neutralization was accomplished in a circuit isolated from the crystal by means of coupling tubes. In another, a three-electrode crystal was employed so that two separate crystal output terminals were available for the application of over and under-neutralization, respectively. In the circuits of my present application, isolating impedances are used to separate the crystal output energy from the utilized output energy. The over and under-neutralizing energy is fed to the utilizing points to form the two different types of characteristics. This type of circuit eliminates the necessity of coupling tubes, and allows the use of the simpler two-electrode crystal holder.

Accordingly, one of the main objects of my present invention is to improve the crystal conversion circuits of my aforesaid patents, and in particular to accomplish in a much simpler fashion what has been shown previously in PM detectors of the over and under-neutralized type.

Another important object of my invention is to provide a demodulator having a pair of opposed rectifiers, an input circuit supplying PM wave energy to said rectifiers through a network comprising a piezo-electric crystal and shunt capacity for neutralizing the crystal holder capacity, and separate condensers providing under-neutralization and over-neutralization of the crystal holder capacity thereby to provide the filter characteristics which convert the PM wave energy into AM wave energy.

Another object of the invention is to provide a simplified PM detector which employs a single piezo-electric crystal, and which detector provides automatic frequency control (AFC) voltage, modulation voltage and pure carrier voltage.

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 circuit organizations whereby my invention may be carried into effect.

In the drawings:

Fig. 1 shows a circuit embodying one form of the invention,

Fig. 2 graphically illustrates the conversion action of the demodulator input circuit,

Fig. 3a shows the vector relations between the carrier and sidebands of the PM wave.

Figs. 3b and 3c illustrate the vector relations of the converted PM wave at diodes A and B respectively,

Fig. 4 illustrates a modification of the circuit of Fig. 1,

Fig. 5 shows a further modification of the circuit of Fig. 1.

Referring now to the accompanying drawings, wherein like reference characters in the different figures designate similar circuit elements, the circuit of Fig. 1 shows a demodulator of PM signals. The mean frequency of the applied PM signals is assumed to be of the order of 50 kilocycles (kc.). The tube 1, which may be a pentode tube by way of example, has its input electrode coupled to a PM signal source, such as the

intermediate frequency amplifier section of a superheterodyne receiver. This invention is not limited to the detection of PM signals whose mean frequency is located as low as 50 kc., but is generic and can readily be used for higher frequencies in the kilocycle range, or in the megacycle range. Assuming, however, that the PM signals applied to the control grid 2 of tube 1 have been reduced to an intermediate frequency (I. F.) value as low as 50 kc., the output transformer 3 can readily be made of the iron core type. In that case the primary winding 4 of the transformer 3 is tuned, as by tuning condenser 5, to the 50 kc. mean, or reduced carrier, frequency. The tube 1 is shown as having its screen electrode established at a positive voltage which is derived, as by means of potentiometer 6, from a +125 volt point of a direct current source. The plate of tube 1 may be established at +250 volts. Appropriate carrier bypass condensers are employed where required, and a fixed trimmer condenser 5' is shunted across the primary winding 4.

The amplified PM signal energy is applied to the opposed diode rectifiers A and B through a piezo-electric crystal network which functions to convert, or transform, the PM signal energy into corresponding AM energy. That is to say, the function of the network coupling the secondary winding 7 of transformer 3 to the electrodes of diodes A and B is to produce a quadrature phase shift between the carrier and modulation side bands of the applied PM signal energy. Before explaining the manner in which this is accomplished, the circuit details of the crystal network will be explained.

The anode 8 of diode A is connected to the upper end of winding 7 by a path which consists of isolating condenser 9 and the piezo-electric crystal P. The crystal P is positioned between the metal electrodes, or holder elements, 10 and 11. The construction of the crystal and holder elements is well known to those skilled in the art, and need not be described in any further detail. The crystal P is cut so as to be tuned to F_c , the mean frequency of the applied PM signal energy. This would be, in the example of this case, the 50 kc. value.

The anode 12 of diode B is connected to the opposite end of winding 7 through a path comprising isolation condenser 9' arranged in series with a condenser 13. The condenser 13 functions to neutralize the capacity between the crystal holder electrodes 10 and 11. The cathode 8' and the cathode 12' of diodes A and B respectively are connected together by series load resistors 14 and 15. The cathode end of resistor 15 is established at ground potential, while an output connection 16 is connected to the cathode end of resistor 14. Each of resistors 14 and 15 is bypassed for carrier frequency energy by respective bypass condensers 14' and 15'.

The junction of resistors 14 and 15 is connected by a lead 17 to the midpoint 18 of winding 7. The anode 8 is connected to lead 17 by a resistor 19, while the anode 12 is connected to lead 17 by a separate resistor 20. Resistors 19 and 20 function to develop detected AM signal voltage thereacross, should AM signal energy be applied to tube 1 instead of PM signal energy. In shunt across the series path P—9 there is connected a condenser 21. The latter functions to provide under-neutralization of the crystal holder capacity at the diode anode 8. Similarly, the condenser 22, in shunt with path 13—9', provides over-neutralization at the diode anode 12. The con-

densers 9 and 9' isolate the neutralized terminals of the crystal P.

As indicated in Fig. 1, modulation voltage, which is in the audio range, may be taken off from connection 16. This connection also provides AFC voltage for the regulation of the local oscillator of the receiving system, where the receiver is of the superheterodyne type. Pure carrier energy may be derived from crystal P by way of electrode 10. The carrier energy taken off from this point is free of any modulation side bands, and is energy which has a frequency value of 50 kc.

Such pure carrier energy may be then employed in another part of the receiving system to accomplish a carrier exaltation function. For example, the pure carrier energy could be fed over connection 23 to another PM demodulator coupled to the PM signal source which feeds the grid 2. In such case only AFC voltage would be taken off from connection 16, and the circuits shown in Fig. 1 would then act as a network to provide AFC voltage and pure carrier energy. The demodulator circuit to which the pure carrier energy would be fed would then be the actual demodulator of the system which provides the audio voltage output. Such a general system is disclosed, for example, in my U. S. Patent No. 2,063,588, granted December 8, 1936.

Considering now the theoretical aspects of the circuit of Fig. 1, reference is first made to Fig. 2 wherein are shown curves A and B. The curve A shows the change in amplitude of signal voltage which is fed to the diode A of Fig. 1. The curve B shows the amplitude of signal voltage which is fed to the diode B. It will be seen that both curves have a common peak at the value F_c . This latter value corresponds to the mean frequency of the applied PM signal energy. In other words, the crystal network which feeds diodes A and B accomplishes in a much simpler fashion what has been disclosed previously in the PM detectors of the over and under-neutralized types of my aforesaid patents.

Considering the functioning of the crystal circuit from another viewpoint, Figs. 3a, 3b and 3c illustrate in a purely pictorial manner how the circuit acts to provide a relative displacement of 90 degrees between the carrier and the upper and lower modulation sidebands of the incoming PM signal energy. Fig. 3a shows vectorially the phase relations which can be depicted as existing in the PM wave applied through transformer 3. The carrier is marked C, the upper modulation side band is U, and the lower modulation side band is L. The positive direction of rotation is taken as clockwise. The directions of rotation of the side bands with respect to the carrier are indicated by arrows attached to the side band vectors. Side bands of an order greater than unity have been neglected due to their small amplitude and for simplicity of explanation. When the PM wave of Fig. 3a is passed through one side of the crystal network, the side bands are shifted 90 degrees with respect to the carrier, so that the side band relation shown in Fig. 3b is effected. Let it be assumed that the rotation of Fig. 3b is that of the AM wave existing at diode anode 8 of diode A. The relation of Fig. 3b is that which may be said to exist between the carrier and side bands in an AM wave.

The opposite side of the crystal network causes the side bands to be shifted 90 degrees in phase, but in an opposite direction to the shift previously described. Hence, at the diode anode 12 there

will be produced the vector relation shown in Fig. 3c. The envelope of the amplitude modulations produced by the two filter characteristics A and B of Fig. 2 are 180 degrees apart, and their detected output must be combined in a push-pull combination to reproduce the converted modulations. Hence, the rectifiers A and B are connected in opposition, and the differential of the rectified voltage outputs developed across resistors 14 and 15 is taken off from the cathode end of resistor 14.

When the mean, or carrier, frequency drifts the relative amplitudes of the two filter outputs vary differentially. That is, as the frequency drifts lower, the output of the filter whose characteristic is represented by curve A of Fig. 2 approaches the dip point, whereas the output of the other filter reduces more gradually. This results in a differential action which produces differentially-detected energy that may be used for AFC. As is well known to those skilled in the art, the AFC voltage may act through any desired type of reactance tube devices upon the local oscillator to hold the output frequency thereof such as to maintain proper tuning of the signal. Reference is made to Fig. 1 of my aforesaid Patent 2,204,575 for a detailed disclosure of said AFC circuit. Should the signal energy applied to the receiver system be AM signal energy, then the detected AM signal voltage will be taken off from the end of resistor 19. Reference is made to the aforesaid Patent 2,204,575 for an explanation of how the AM detection occurs.

The functioning of the system of Fig. 1 may be explained from still another viewpoint. In Fig. 1 when an unmodulated carrier wave is received there are delivered to each of diode rectifiers A and B two voltages. One of the voltages is that of the filtered carrier from crystal P without phase change, and the other voltage is that of the unfiltered carrier substantially 90 degrees different in phase from the filtered carrier. The crystal output phase is zero degrees, since condensers 9 and 9' merely act as a series condenser in series with the equivalent capacity of the crystal. The substantial phase quadrature of the two voltages at each rectifier results from the fact that the unfiltered carrier wave is applied to the rectifiers by condensers 21 and 22 which are effective to effect a 90 degree phase shift. These condensers 21 and 22 are non-selective to phase or frequency variations of the unfiltered carrier, and accordingly permit all signal components to pass to rectifiers A and B. The crystal P, however, effects no phase shift, as already explained, at the carrier, but substantially removes the phase modulation of the signal thereby restoring the carrier substantially to the phase and wave form which it had before modulation at the transmitter. The crystal P is, of course, selective for frequencies off resonance. This follows from the sharp selectivity characteristic of the crystal. The filtered carrier voltage at the output electrode 10 of crystal P is applied in like polarity, or in parallel, to the anodes 8 and 12. The unfiltered carrier voltage is applied in push-pull, or opposite polarity, to the said anodes 8 and 12.

When the received carrier is phase modulated the filtered carrier remains as before.

The unfiltered phase modulated carrier energy is supplied to rectifiers A and B in phases differing from the 90 degrees, or phase quadrature, relation to an extent determined by the degree of phase modulation of the carrier. The greater

the degree of phase modulation the greater the combined voltage of the unfiltered signal and filtered carrier on one of the rectifiers, and the less the sum of such voltages on the other rectifier. The polarity of the rectified voltage at the lead 16 depends on the direction of the phase change of the received PM signals. The rectified voltages across load resistors 14 and 15 are differentially combined relative to ground.

The AFC voltage results from a relatively slow drift or shift of the applied carrier wave frequency from the crystal frequency. Hence, there will occur a change in the phase of the filtered carrier voltage applied to the anodes in like polarity. This is caused by the selectivity characteristic of crystal P. Such phase-shifted filtered carrier voltage will combine with the unfiltered signal energy at each rectifier to produce rectified voltages across resistors 14 and 15. The differential voltage at lead 16 in that case is the AFC bias, and will arise only in response to relatively slow frequency shifts of the received carrier relative to crystal frequency.

The AM signal voltage, of course, varies solely in carrier amplitude. Hence, at each rectifier there is provided the combined filtered AM carrier voltage and unfiltered AM signal voltage. The rectified AM voltage due to rectifier A appears across resistors 19 and 14. The rectified AM voltage due to rectifier B appears across resistors 20 and 15. The detected AM voltage taken off at the anode end of resistor 19 is the additive resultant of the rectified voltages across resistors 19 and 15. Variation of the carrier amplitude results in variation of this additive resultant voltage. Carrier-exaltation occurs, both for AM and PM reception, due to the action of crystal P in removing modulation components from the carrier.

In Fig. 4 there is shown a modification which differs from the circuit of Fig. 1 in that instead of transformer 3 feeding the crystal discriminator network, there is employed an auto-transformer. The circuit is otherwise quite similar to that shown in Fig. 1. The auto-transformer is designated by numeral 24. An intermediate point thereof is connected to the +250 volt source. A resistor 25 is shunted across the transformer to provide proper damping. Condenser 27 is arranged in shunt with auto-transformer 24 to provide proper tuning; for example, the transformer 24 could be tuned to a signal of 450 kc., if desired. The auxiliary trimmer condenser 26 is shunted across tuning condenser 27. The condenser 13 neutralizes the crystal holder capacity. The under-neutralization condenser 21 is connected in shunt with crystal P and isolating condenser 9, while the over-neutralization condenser 22 is connected in shunt with condenser 13 and isolating condenser 9'. The junction of crystal holder 10 and neutralizing condenser 13 is connected by a lead 10' to the junction of isolation condensers 9 and 9'. The latter junction point is connected to ground through an adjustable resistor 28. The resistor 28 functions to adjust the "Q" of the crystal P. The resistor 28 may be used in any of Figs. 1, 4 or 5. The remainder of the circuit elements are similar to those shown in Fig. 1, and have corresponding reference numerals. The pure, or filtered, carrier energy is taken from crystal P.

In Fig. 5 the crystal P has its electrodes 10 and 11 connected to the high potential sides of primary circuit 5-4 and secondary circuit 30-31. Coil 30 has one end coupled to anode 8 by con-

denser 9; the other end is coupled by condenser 9' to anode 12. The midpoint of coil 30 is connected by lead 17 to the junction of resistors 19 and 20. The holder capacity neutralizing condenser 13 is connected from electrode 11 to the end of coil 30 connected to condenser 9'. The condenser 21 is connected in shunt with crystal P and condenser 9. The condenser 22 is arranged in shunt with condensers 13 and 9' in series. The circuit 30—31 is tuned to either side of F_c to provide either positive or negative reactance so as properly to phase the crystal output energy with respect to the unfiltered PM energy. Circuit 5—4 is tuned to F_c , as is crystal P. This circuit of Fig. 5 differs from that of Fig. 1 in that neutralization of the crystal is carried out directly ahead of the secondary circuit 30—31 of the input transformer 4—30. The neutralization is accomplished by feeding backwards instead of forwards. That is to say, neutralization of the holder capacity is effected through condenser 13 from circuit 30—31.

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 discriminator circuit for a phase modulation detector, a pair of input terminals and a pair of output terminals, a piezo-electric crystal, a crystal holder consisting of an input electrode and an output electrode, said crystal being connected by said holder electrodes between one input terminal and a corresponding output terminal, a condenser in shunt with the crystal and connected between said electrodes to neutralize the crystal holder capacity, an under-neutralization condenser connected between said electrodes in shunt with the crystal, a second condenser in shunt with the neutralization condenser for providing over-neutralization, and said utilization condenser being connected between the second of the input terminals and its corresponding second output terminal.

2. In a discriminator circuit, a pair of input terminals, a pair of output terminals, a piezo-electric crystal provided with a holder, said holder consisting of an input electrode and an output electrode, said holder electrodes being respectively connected to one input terminal and a like output terminal, a holder-capacity neutralizing condenser, in shunt with the crystal between its holder electrodes, coupling the second input terminal and corresponding output terminal, an under-neutralization condenser connected between said one input terminal and like output terminal and in shunt with said crystal, an over-neutralization condenser in shunt with the neutralizing condenser and connected between said second input terminal and corresponding output terminal.

3. In a discriminator circuit, a pair of input terminals, a pair of output terminals, a piezo-electric crystal provided with a holder consisting of an input electrode and an output electrode connected respectively to one input terminal and a like output terminal, a holder-capacity neutralizing condenser, connected between said electrodes in shunt with crystal, coupling the second input terminal and corresponding output terminal, an under-neutralization condenser in shunt

with the crystal and being connected between said one input terminal and like output terminal, an under-neutralization condenser in parallel with the neutralizing condenser and being coupled between said second input terminal and corresponding output terminal, and a pair of opposed rectifiers coupled between said output terminals.

4. In a discriminator circuit, a pair of input terminals, a pair of output terminals, a piezo-electric crystal provided with a holder consisting of an input electrode and an output electrode connected respectively to one input terminal and a like output terminal, a holder-capacity neutralizing condenser, connected between said electrodes in shunt with crystal, coupling the second input terminal and corresponding output terminal, an under-neutralization condenser in shunt with the crystal and being connected between said one input terminal and like output terminal, an under-neutralization condenser in parallel with the neutralizing condenser and being coupled between said second input terminal and corresponding output terminal, a phase modulation signal input circuit coupled to said input terminals, and a balanced rectifier system coupled to the output terminals.

5. In a discriminator circuit for a phase modulation detector, a pair of input terminals and a pair of output terminals, a piezo-electric crystal provided with a holder consisting of an input electrode and an output electrode respectively connected between one input terminal and a corresponding output terminal, a condenser in shunt with the crystal and connected between said electrodes to neutralize the crystal holder capacity, an under-neutralization condenser connected between said holder electrodes in shunt with the crystal, a second condenser connected in shunt with the neutralization condenser for providing over-neutralization, and a pair of opposed rectifiers coupled between said output terminals.

6. A phase modulation signal detector comprising a primary circuit tuned to the mean frequency of applied signals, a secondary signal circuit, a piezo-electric crystal resonant to said mean frequency provided with a holder consisting of an input electrode and an output electrode respectively connected to the high potential sides of the primary and secondary circuits, a holder-capacity neutralizing condenser in shunt with said crystal and secondary circuit and connected between said input electrode and the low potential side of the secondary circuit, an under-neutralizing condenser connected between said high potential sides of the primary circuit and the secondary circuit in shunt with the crystal, and an over-neutralizing condenser in shunt with said neutralizing condenser.

7. In a discriminator circuit for a phase modulation detector, a pair of input terminals and a pair of output terminals, a piezo-electric crystal tuned to the mean frequency of applied phase modulated carrier energy, a crystal holder consisting of an input electrode and an output electrode respectively connecting the crystal between one input terminal and a corresponding output terminal, a condenser in shunt with the crystal and connected between the holder electrodes to neutralize the crystal holder capacity, an under-neutralization condenser connected between said electrodes in shunt with the crystal, a second condenser in shunt with the neutralization condenser for providing over-neutralization, said neutralization condenser being connected between

the second input terminal and its corresponding second output terminal, a first isolation condenser connected in series between said crystal holder output electrode and said corresponding first output terminal, and a second isolation condenser between said neutralization condenser and its corresponding second output terminal.

8. In a discriminator circuit, a pair of input terminals, a pair of output terminals, a piezo-electric crystal provided with an input electrode and output electrode respectively connected to one input terminal and a like output terminal, a neutralizing condenser connected between said electrodes to neutralize the capacity therebetween and coupling the second input terminal and corresponding second output terminal, an under-neutralization condenser coupling the one input terminal and like output terminal in parallel with the crystal, an over-neutralization condenser coupling the second input terminal and corresponding second output terminal in parallel with the neutralizing condenser, a pair of opposed rectifiers coupled between said output terminals, and respective isolation condensers connected in series with each said crystal output electrode and neutralizing condenser.

9. In a discriminator circuit for phase modulation signals, a pair of input terminals, a pair of output terminals, a piezo-electric crystal provided with holder input and output electrodes respectively connected to one input terminal and a like output terminal, said crystal being tuned to the mean frequency of said signals, a crystal-holder capacity neutralizing condenser coupling the second input terminal and corresponding second output terminal, an under-neutralization condenser coupling the one input terminal and like output terminal, an over-neutralization condenser coupling the second input terminal and corresponding output terminal, a phase modulation signal input circuit coupled in push-pull to said input terminals, a balanced rectifier system coupled to the output terminals, and means connected to the crystal for adjusting the "Q" thereof.

10. A discriminator network comprising a pair of input terminals and a pair of output terminals, a pair of metal electrodes, one electrode being connected to one input terminal and the second electrode being connected to a corresponding output terminal, said electrodes being adapted to receive a piezo-electric crystal, a capacitance in shunt with said electrodes to neutralize the capacity between the latter, under-neutralization capacitance connected in shunt with said electrodes, a third capacitance in shunt with the neutralization capacitance for providing over-neutralization, and said neutralization capacitance being connected in circuit with the second input terminal and its corresponding second output terminal.

11. In a wave detecting system, a resonant input circuit tuned to the frequency of applied waves a pair of output terminals, a piezo-electric filter coupled between one side of said input circuit and one of the output terminals, a connection between the filter output and the second output terminal whereby filtered wave energy is applied to said output terminals in like phase relation, a first path in shunt with said filter for applying said wave energy from said input circuit to said first output terminal in unfiltered condition, a second path between the opposite side of said input circuit and the second output terminal for applying unfiltered wave energy to the second output terminal in a phase opposite to the phase of the unfiltered wave energy at said first output terminal.

12. A phase modulation signal detector comprising a primary circuit tuned to the mean frequency of the signals, a secondary signal circuit tuned to one side of the mean frequency, a piezo-electric crystal tuned to said mean frequency, a holder for the crystal consisting of an input electrode and an output electrode respectively connected to the high potential sides of the primary and secondary tuned circuits, a crystal-holder capacity neutralizing condenser in shunt with said crystal and secondary circuit and connected between the input electrode and the low potential side of the secondary circuit, a respective isolation condenser in series with each of said crystal output electrode and neutralizing condenser, an under-neutralizing condenser connected from the high potential side of the primary circuit to the secondary circuit in shunt with the crystal and its series isolation condenser, and an over-neutralizing condenser in shunt with said crystal-holder neutralizing condenser and its series isolation condenser.

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