

June 18, 1940.

M. G. CROSBY

2,204,574

THREE ELECTRODE CRYSTAL PHASE MODULATION RECEIVER

Filed Jan. 22, 1938

3 Sheets-Sheet 1

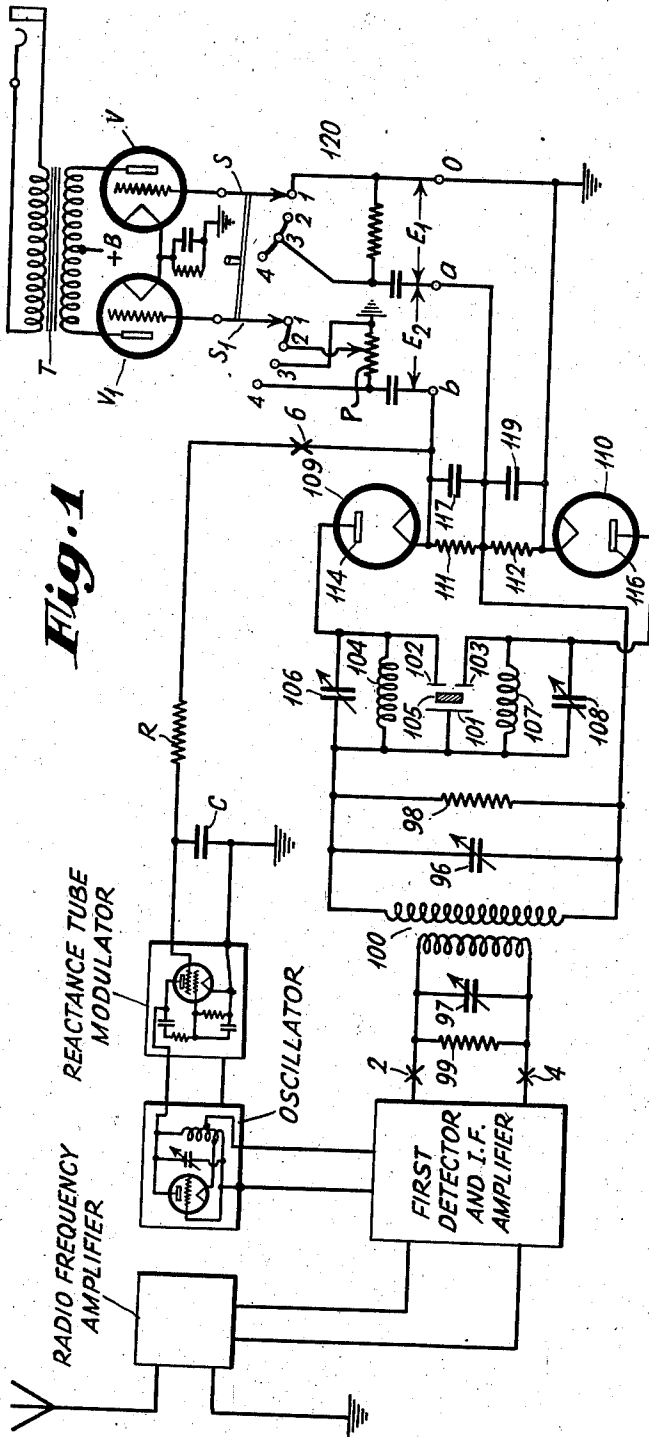


Fig. 1

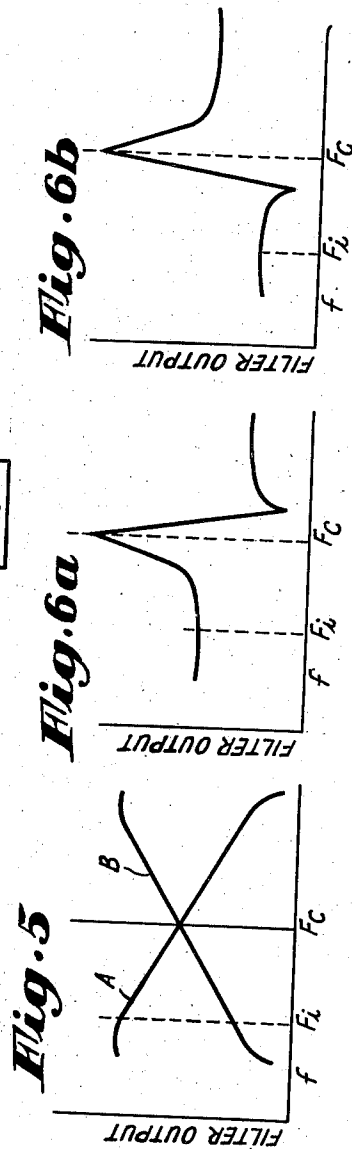


Fig. 6b

Fig. 6a

Fig. 5

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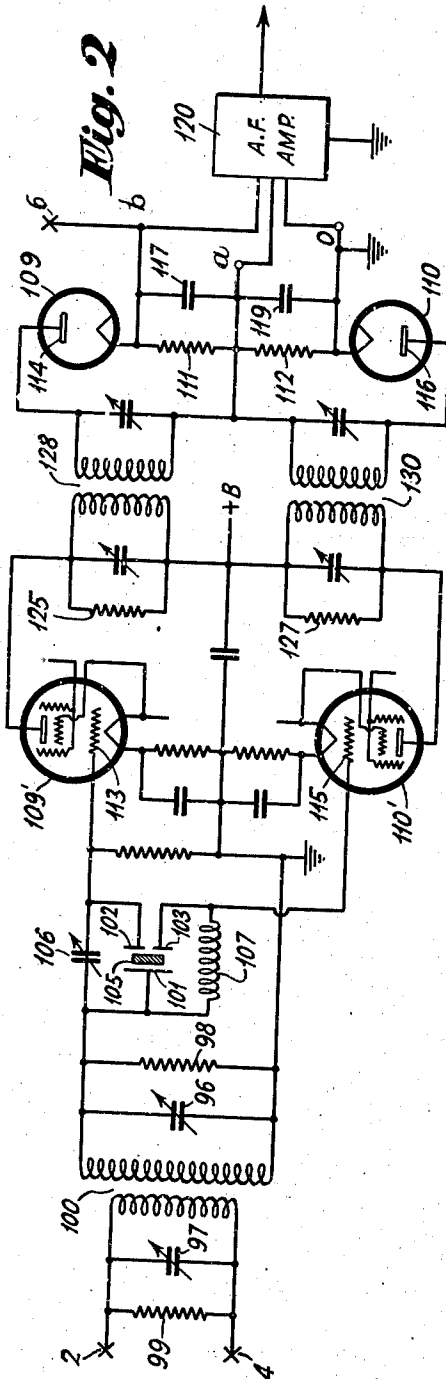
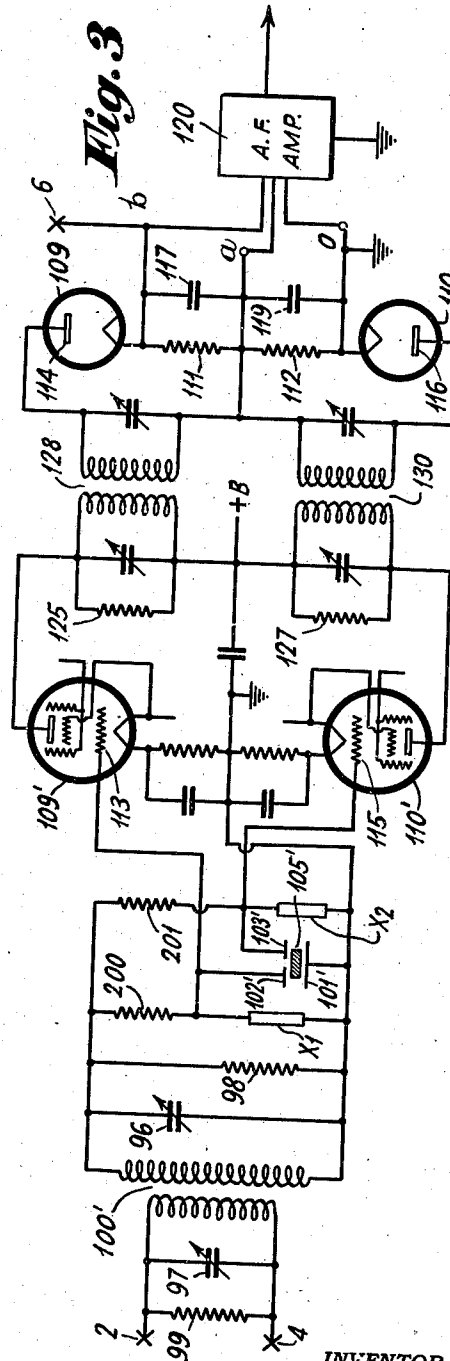
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

Fig. 4a

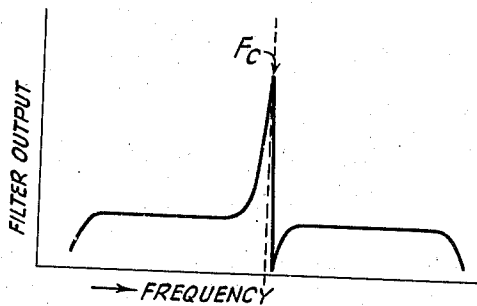


Fig. 4e

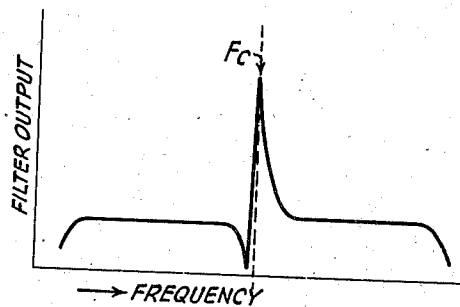


Fig. 4b

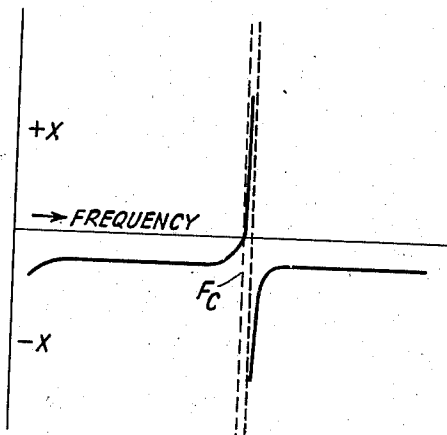


Fig. 4f

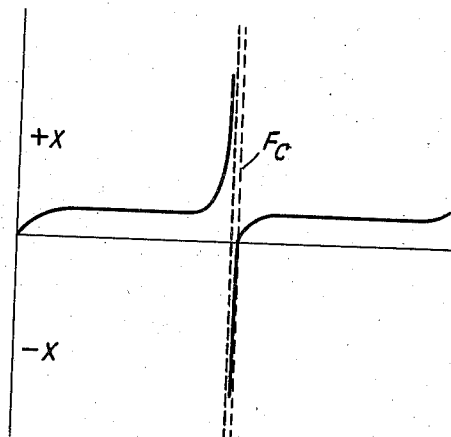


Fig. 4c

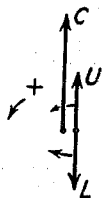


Fig. 4d

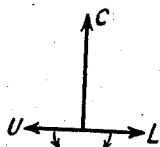


Fig. 4g

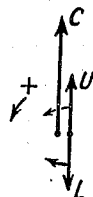
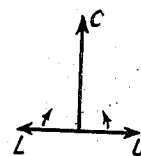


Fig. 4h



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UNITED STATES PATENT OFFICE

2,204,574

THREE ELECTRODE CRYSTAL PHASE
MODULATION RECEIVERMurray G. Crosby, Riverhead, N. Y., assignor to
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Delaware

Application January 22, 1938, Serial No. 186,273

23 Claims. (Cl. 250-29)

This disclosure concerns phase modulation receivers of the type which utilize over- and under-neutralized crystal filter characteristics to form a back-to-back phase modulation detector. A three-electrode crystal holder is used, but instead of employing a neutralizing circuit to over- and under-neutralize the holder capacities, shunt tuned-circuits or reactances are connected across the holder so as to tune with the holder capacity and thereby over- or under-compensate for its effect. The filters so formed convert phase modulations in wave energy into corresponding amplitude.

The receivers of this disclosure utilize a combination of the principles described in my Patent #2,085,008 dated June 29, 1937, and United States applications Serial #165,056 filed September 22, 1937, now Patent #2,156,374 dated May 2, 1939; Serial #167,344 filed October 5, 1937, now Patent #2,156,375 dated May 2, 1939; Serial #195,041 filed March 10, 1938; Serial #178,655 filed December 8, 1937, now Patent #2,156,376 dated May 2, 1939; Serial #242,469 filed November 26, 1938. The present circuits have an advantage in simplicity in that a push-pull transformer is not required to obtain neutralizing voltage.

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

Figures 1, 2, and 3 each show the essential elements of converting circuits arranged in accordance with my invention. Figure 1 also shows a novel amplifying system to be used with the converting circuit and detectors to permit the reception of phase or frequency or amplitude modulated waves in the circuit without revising its connections;

Figures 4a to 4h are filter impedance characteristic reactance curves and vector diagrams of modulated wave components, all illustrating the operation of my system; while

Figures 5, 6a, and 6b are filter characteristic curves used to explain the operation of all of the receivers and in particular of the receivers when using therewith a novel signal amplifier as shown in Figure 1 following the differential connected detectors.

The circuit of Figure 1 shows the pertinent parts of the discriminator circuit for converting phase modulation into amplitude modulation and for obtaining automatic frequency control voltage. Intermediate frequency energy from a superheterodyne receiver is fed to the primary winding of tuned transformer 100. This transformer is properly damped by resistances 99 and 98 and adjusted by condensers 97 and 96 to form

a band-pass filter. The crystal 105 is held in a crystal holder having a single input terminal 101 and two output terminals 102 and 103. The input terminal is connected to the high potential side of the tuned transformer 100 and the two output terminals are connected to the plates 114 and 116 of diodes 109 and 110. Tuned circuits 104, 106, and 107, 108 are connected between the common input terminal and the two output terminals. The resonant frequencies of these tuned circuits are adjusted to be a little above and a little below the resonant frequency of the crystal 105. This slight off-tuning produces an inductive reactance in one case and a capacitive reactance in the other case. Hence the effect will be the same as though a capacity were across one of the sets of crystal terminals and an inductance across the other set. This arrangement causes the formation of two crystal filters having over- and under-neutralized characteristics respectively. Thus, tuned circuit 104, 106 might be tuned capacitive to present an under-neutralized characteristic such as shown at Figure 4a between transformer 100 and diode 109, and tuned circuit 107, 108 might be tuned inductive to present an over-neutralized filter characteristic such as shown at Figure 4e between transformer 100 and diode 110. These two characteristics convert the phase modulation into amplitude modulations with 180° phase relation between the amplitude envelopes. Consequently, the push-pull connection of diode resistors 111 and 112 will add or aid the phase modulations and oppose and substantially cancel amplitude modulations present on the original phase modulated wave. By virtue of the fact that one of the filter characteristics has a rejection point at a frequency lower than the carrier frequency and the other filter has a rejection point at a frequency higher than the carrier frequency, when the mean frequency of the wave energy shifts slowly a differential voltage is available across resistors 111 and 112 shunters by bypass condensers 117 and 119 to control the grid of a reactance tube modulator which tunes a frequency-changing heterodyne oscillator in the circuits prior to transformer 100. The time control circuit RC prevents this frequency control circuit from responding to signal modulations on the wave. The detected phase modulation appearing across resistors 111 and 112 is fed to an audio frequency amplifier 120 for subsequent utilization. The audio frequency amplifier may be a simple tube amplifier where phase modulation only is to be received. In case phase or amplitude modulated waves are to be received

the amplifier shown in Figure 1 and described in detail hereinafter may be used.

In the circuit of Figure 2 in order to simplify the description the radio frequency amplifier heterodyne receiver and automatic frequency control circuits have been omitted. These circuits may be of any type such as shown in Figure 1. The circuits of Figure 1 may be added to the circuits of Figure 2 as indicated in the drawings by connecting the elements not shown to points 2, 4, and 6.

In the circuit of Figure 2 the same principles are applied except that single reactances 106 and 107 take the place of the tuned circuits of the prior figure connected across the crystal holder terminals and diode-driver amplifier tubes 109' and 110' having their grids 113, 115 and cathodes connected to the crystal output electrodes are excited by the filtered energy and are used to feed the two filtered energies to the diodes 109 and 110. Tuned bandpass transformers 128 and 130, having their primaries shunted by damping resistances 125 and 127 couple the anodes and cathodes of the driver tubes 109' and 110' to the diode plates 114 and 116. The terminals of the diode output impedances 111 and 112 may be connected to the input electrodes of any audio frequency amplifier tube supplying a utilization means or directly to a utilization means. If desired, the impedances 111 and 112 may be connected to an amplifier as illustrated in Figure 1. The rectangle 120 of the figure represents the simple amplifier mentioned above and also represents an amplifier as illustrated in Figure 1. The operation of this circuit in other respects is the same as that of Figure 1.

In the circuit of Figure 3 a discriminator is shown which utilizes a shunt connected crystal in the manner of the discriminators described in my application #167,344 filed October 5, 1937, now Patent #2,156,375 dated May 2, 1939. Intermediate frequency energy is fed to tuned transformer 100' and through isolating resistors 200 and 201 to the two terminals of the crystal holder 102' and 103'. The common terminal 101' of the crystal holder is connected to the low side of the tuned transformer. Reactances X_1 and X_2 would be either an inductance and a capacity or two tuned circuits. These reactances are adjusted so that one forms a capacitive action across the crystal holder and the other an inductive action. The output of the two filters is taken from terminals 102' and 103' and fed to the grids 113 and 115 of diode-driver tubes 109' and 110' such as are used in Figure 2. The other features of this circuit are the same as those of Figure 1 and Figure 2.

In the operation of the receiver of Figures 1, 2, and 3 two filter characteristics are produced to be fed to the two diode detectors 109 and 110. The energies fed from the crystal output terminals 102 and 103 to amplifier and coupling tubes 109' and 110' of Figures 2 and 3, or directly to diode rectifiers 109 and 110 of Figure 1, are over- or under-neutralized crystal energy and have characteristics as shown in Figures 4a and 4e. This energy appears in transformers 128 and 130 of Figures 2 and 3 and on the diode electrodes of Figure 1. The characteristic of the energy present on the input electrodes of 109 of Figure 1 and in, say, transformer 128 of Figures 2 and 3, is as shown in Figure 4a being derived from a filter of the under-neutralized type such as is obtained by under-neutralizing the holder electrodes 101 and 102 by means of 106 of Figure 2 or the re-

actance at X_1 of Figure 3 or 104 and 106 of Figure 1. This is obtained by adjusting the said elements of the respective figures so that the reactance across the crystal holder is capacitive for the case of the series connected crystals of Figures 1 and 2 and inductive for the case of the shunt connected crystals of Figure 3. The characteristic of the energy, say in transformer 130 of Figures 2 and 3, or on the electrodes of diode 110 of Figure 1 is as shown in Figure 4e, this energy being passed by filters which are over-neutralized by adjusting the elements 107 and 108 of Figure 1 or 107 of Figure 2 so that the crystal holder has an inductive reactance at substantially the carrier frequency, and adjusting the reactance X_2 of Figure 3 so that the crystal holder has a capacitive reactance. In the case of the shunt connected crystal, the under-neutralized characteristic is given by Figure 4e and its reactance characteristic is given by Figure 4b. That is, in the case of the shunt connected filter the low impedance point on the reactance curve (where the line crosses the X axis) coincides with the rejection point on the output characteristic. Also, the high impedance point on the reactance curve coincides with the carrier frequency. This is opposite to the case of the series connected filter in which the under-neutralized characteristic is given by Figure 4a, its reactance curve is given by 4b, the zero reactance curve coincides with the carrier frequency, and the maximum impedance point coincides with the rejection point.

The reason for this difference between the shunt- and series-connected filters is the fact that with the series connection the crystal allows more or less energy to flow according to its impedance, while with the shunt connection, since the drop across the crystal is utilized, the output voltage is proportional to the crystal impedance.

In the case of Figure 4b a negative reactance is present on both sides of the carrier frequency, that is, the circuit would be capacitive on both sides of the carrier except for the very short interval near the carrier frequency. Since the reactance is capacitive in the frequency region in which the side bands are disposed and is resistive at the carrier frequency, the phase of the side bands will be shifted 90° with respect to the carrier. In Figure 4c the carrier and side bands of a phase modulated wave are shown. The carrier is marked C, the upper side band U and the lower side band L. The positive direction of rotation is taken as counter-clockwise and 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 1 has been neglected due to their small amplitude and for simplicity of explanation. When the phase modulated wave of Figure 4c is passed to the crystal having the characteristic of Figure 4a and the reactance characteristic of Figure 4b the side bands are shifted 90° with respect to the carrier so that the side band relation shown in Figure 4d is effected. With the relation of Figure 4d between the carrier and side bands, the wave is an amplitude modulated wave and is suitable for detection in diode 109 or for amplification in 109' and detection in diode 109. There would also be an attenuation of the side bands which is not shown in Figure 4d. This conversion of the phase modulated wave as of 4c to an amplitude modulated wave as of 4d takes place in 101, 102, 103, and 105, and the converted

energy appears on the diode cathode or grid of the diode driver tube 109.

The energy present in 101, 103, 107, and 108 of Figure 1 and of the same elements and transformers 130 of Figures 2 and 3 is passed by and is a characteristic of energy in a filter having an over-neutralized characteristic and having an input-output characteristic as shown in Figure 4e, and having a reactance characteristic as shown in Figure 4f. Thus, the reactance of this last filter is positive or inductive on both sides of the carrier frequency except for a short interval near the carrier frequency. Consequently, the side bands are shifted 90° in phase by this filter also but in an opposite direction to the shift produced by filters having the characteristics shown in Figure 4a. Hence, the phase modulated wave as shown in Figure 4g is converted to the amplitude modulated wave as shown in Figure 4h. From an examination of Figure 4d and Figure 4h, it can be seen that the side bands are approaching cancellation of the carrier in Figure 4d and are approaching aiding the carrier in Figure 4h. Thus, the envelope of the amplitude modulations produced by the two filters having characteristics as shown above are 180° apart and their detected output must be combined in a push-pull or series combination to reproduce the converted modulations. This combination is effected in the diode circuits of all of the figures by grounding the cathode of one of the diodes, say 110, and making the cathode of the other diode, say 109, the high potential side of the output circuit.

Unwanted amplitude modulations on the wave received, which are not converted to phase modulations by the action of the filters as described herein and in my United States Patent #2,085,008 dated June 29, 1937, have the same or substantially the same effect on the energies passed by both filters and consequently due to the phase displaced combination of the detected energies cancel each other more or less completely. The unwanted amplitude modulations which are converted to characteristic phase modulations have no effect on the diode detectors.

As stated above, the phase modulations on the wave are, in the filter circuits, converted to corresponding amplitude modulations of opposed envelopes and rectified in the diodes 109 and 110 so that a difference potential appears across the resistances 111 and 112 characteristic of the signal which may be utilized in any manner. An additional feature of this application is the provision of a novel differential diode combining amplifier which amplifies variations in potential in the differential detectors characteristic of the phase modulations on the wave and also characteristic of the amplitude modulations on wave energy passed through the conversion circuit, thereby adapting the receiver to the reception of amplitude modulated wave energy.

More specifically, this application also concerns an amplifier for combining the outputs of differentially connected diodes such as 109 and 110 of Figures 1, 2, and 3 in a manner such that either the differential output or a parallel combination of the outputs may be utilized without disturbing the connections of the diode resistors. Thus, the amplifier is applicable to phase and frequency modulated wave receivers and amplitude modulated wave receivers. This amplifier also has additional uses and features which will appear from the description thereof which will now be given.

In frequency and phase modulation receivers in which a frequency or phase discriminator feeds diode detectors, the diode detectors must be connected differentially so that automatic frequency control may be taken from the combination of the diode voltages. This differential connection is effected as shown in Figures 1, 2, and 3 by grounding the cathode of one of the diode detectors, such as for example, tube 110, and making the cathode of the other diode detector, such as for example, tube 109, a high potential point. This effectively reverses the voltage across one diode resistor with respect to that on the other so that the two diode voltages oppose and the only output that is obtained is that due to the difference between the two diode voltages. This differential output is desired for the automatic frequency controlling potentials, supplied in this particular system to RC, and is also desired for the frequency and phase modulation output. However, when it is desired to receive amplitude modulation on the same receivers, a parallel connection of the diode resistors is necessary for proper operation although the differential connection is necessary if automatic frequency control voltage is obtained from the same diode resistors.

By the use of the audio amplifier of Figure 1 and proper adjustment of the degree of off-neutralization of the crystal filters the present receivers may be tuned to receive either phase or amplitude modulation. I have found that by adjusting the crystal filters so that one has a very small amount of negative reactance across the holder and the other a very small amount of positive reactance, a single sideband effect is obtained as shown in Figures 6a and 6b. With the crystals almost neutralized in this way the output on the side of the carrier frequency which does not have the rejection point is higher than the output on the side having the rejection point. Consequently, one of the filters exalts the carrier and selects the lower sideband and the other exalts the carrier and selects the upper sideband. Hence, in accordance with the principles described in my United States Patent #2,114,335, dated April 19, 1938, these two filter outputs may be detected and combined differentially to receive phase modulation and in parallel to receive amplitude modulation. However, in the circuits of Figures 1, 2, and 3, the detectors are connected differentially in order that automatic frequency control energy may be obtained from them. Hence, the novel combining amplifier of Figure 1 is required.

With the amplifier such as is about to be described here, a means is provided which allows the amplitude modulation output to be obtained from the differentially connected diodes. While the same differential connections are supplying the automatic frequency control voltages used in these receivers, it will be understood that this new amplifier circuit is to be used with any phase or frequency or amplitude modulated wave receiver wherein differential output effect is utilized when phase or frequency modulation is being received and for frequency control purposes.

The circuit of Figure 1 shows the combining amplifier connected to the differentially connected diodes at points *o-a-b*. Diodes 109 and 110 are differentially connected with the diode resistor 112 of diode 110 grounded at the cathode connection and with the diode resistor 111 of diode 109 made high potential at the cathode connection. This combines the voltages E_1 and E_2 which appear across the diode resistors so that they are

subtracted from each other and the resultant is $E_1 - E_2$. This subtractive resultant is that which is desired for automatic frequency control and for frequency or phase modulation wave detection.

- 5 When it is desired to receive amplitude modulation, the desired resultant is $E_1 + E_2$. In order to obtain such a resultant, the combining system consisting of switches S and S_1 , tubes V and V_1 and transformer T are used. Switches S and S_1 are ganged together so that when switch S is on point #1 switch S_1 will be on its point #1 also and when switch S is on point #2 switch S_1 is also on point #2, etc. Potentiometer P divides the voltage from point "b" to a value substantially equal to $(E_1 - E_2)/2$. Tubes V and V_1 amplify the voltages on the arms of switches S and S_1 , respectively, and combine them in push-pull in transformer T. This push-pull connection causes the voltage fed to tube V to be subtracted from that fed to tube V_1 .

20 With the switches on point 1, no voltage is fed to tube V and the voltage, $(E_1 - E_2)/2$ is fed to tube V_1 . The output voltage is then equal to the voltage fed to tube V_1 , or $(E_1 - E_2)/2$ which is the resultant desired for phase or frequency modulation detection when the two diodes are fed by phase or frequency modulation discriminator circuits which impart amplitude modulation envelopes of opposite phase to the two diodes. (The gain of the tubes V and V_1 has been disregarded for simplicity.)

30 With the switches on point 2, the voltage E_1 is applied to tube V and the voltage $(E_1 - E_2)/2$ to tube V_1 . The resultant appearing in transformer T would then be equal to E_1 minus $(E_1 - E_2)/2$ or $(E_1 + E_2)/2$. This resultant is the sum of the two diode voltages instead of the difference and is that desired for amplitude modulation output when the diode detectors are fed amplitude modulated waves by phase or frequency modulation discriminator circuits.

40 The other two positions on the switches, positions 3 and 4, are for obtaining the outputs of each diode separately. With the arm on point 3, tube V_1 is shut off and tube V amplifies E_1 which appears in the output transformer. With the arms on point 4, tube V receives the voltage E_1 and tube V_1 receives the voltage $E_1 - E_2$. When these two inputs are combined subtractively in the push-pull output transformer, the resultant is $E_1 - (E_1 - E_2)$ or E_2 . These single outputs are used for testing purposes on the frequency and phase modulation receivers or are used for reducing interference. These single outputs aid in balancing the two filter characteristics and also allow the choice of the filter which gives the least interference. In other words, interference may be reduced by choosing the discriminator which gives minimum output for the frequency at which the interference occurs. For instance, suppose the two diodes 109 and 110 are fed by the sloping filters having characteristics as shown at A and B of Figure 5 in a frequency modulation receiver. If the interference has the frequency F_1 , a reduced interference output may be obtained by choosing that diode which is fed by discriminator filter having characteristic B which has a minimum output at the frequency F_1 . Another instance would be that of Figures 6a and 6b in which the discriminator characteristics of a phase modulation receiver, which may also receive amplitude modulated waves, are shown. Since either amplitude or phase modulation may be received on a single filter, when an interference occurs, say at the frequency F_1 , the detector

which is being fed by a filter circuit or discriminator having the characteristic shown in Figure 6b, is chosen and that fed by the filter or discriminator having the characteristic shown in Figure 6a switched off. The single sideband effect of the discriminator circuit therefore reduces the effect of the interference.

I claim:

1. In a system for converting phase modulation on wave energy into corresponding amplitude modulations, an impedance on which said phase modulated wave energy may be impressed, a pair of diode detectors having input electrodes and having output electrodes connected in series, an under-neutralized crystal filter circuit and an over-neutralized crystal filter circuit comprising a single piezo-electric crystal having one input electrode connected to said impedance, and a pair of output electrodes connected to the input electrodes of said detectors, and a connection between a second point on said impedance and said detector input electrodes.

2. In a system for converting phase modulations on wave energy to corresponding amplitude modulations on wave energy, an impedance energized by said phase modulated wave energy, a piezo-electric crystal having a plurality of electrodes, a first filter circuit including a pair of said piezo-electric electrodes coupled to said impedance to be fed by wave energy therefrom, a second filter circuit including a pair of the electrodes of said piezo-electric crystal coupled to said impedance to be fed by wave energy therefrom, a detector coupled to each of said filter circuits, and means for under-neutralizing the capacity between a pair of said electrodes and over-neutralizing the capacity between another pair of said electrodes.

3. In a system for converting phase modulations on wave energy to corresponding amplitude modulations on wave energy, an impedance energized by said phase modulated wave energy, a piezo-electric crystal having a plurality of electrodes, a first filter circuit including a pair of said piezo-electric electrodes connected in series with said impedance to be fed by wave energy therefrom, a second filter circuit including a pair of the electrodes of said piezo-electric crystal connected in series with said impedance to be fed by wave energy therefrom, a detector having input electrodes coupled to each of said filter circuits, and means for under-neutralizing the capacity between a pair of said electrodes and over-neutralizing the capacity between another pair of said electrodes.

4. In a system for converting phase modulations on wave energy to corresponding amplitude modulations and demodulating the same, an impedance energized by said phase modulated wave energy, a detector system having input electrodes, a piezo-electric crystal having a plurality of electrodes, a filter circuit including a pair of said piezo-electric electrodes coupling the input electrodes of said detector system to said impedance, a second filter including a pair of the electrodes of said piezo-electric crystal coupling other input electrodes of said detector system to said impedance, and means for under-neutralizing the capacity between a pair of said electrodes and over-neutralizing capacity between another pair of said electrodes.

5. In a system for converting phase modulations on wave energy to corresponding amplitude modulations and demodulating the same, an impedance energized by said phase modulated wave

energy, a detector system having input electrodes, a piezo-electric crystal having a plurality of electrodes, a filter circuit including a pair of said piezo-electric electrodes and a resistance coupling the input electrodes of said detector system in shunt to said impedance, a second filter including a resistance and a pair of the electrodes of said piezo-electric crystal coupling other input electrodes of said detector system in shunt to said impedance, and means for under-neutralizing the capacity between a pair of said electrodes and over-neutralizing the capacity between another pair of said electrodes.

6. In a phase modulation receiver, a reactance on which phase modulated wave energy may be impressed, a piezo-electric crystal having an electrode connected to a point on said reactance said crystal having an additional pair of electrodes, a pair of electron discharge devices each having a control electrode, a cathode, and an anode, a connection between the cathodes of said tubes and another point on said impedance, connections between said pair of crystal electrodes and the control grids of said tubes, reactances of different character connected in shunt to the electrodes of said crystal, a pair of diode rectifiers each having input and output electrodes, a band pass transformer coupling the input electrodes of one of said diode rectifiers to the output electrodes of one of said tubes, a second band pass transformer connecting the input electrodes of the other of said diode rectifiers to the output electrodes of the other of said tubes, and a utilization circuit coupled to the output electrodes of said diode rectifiers.

7. In a modulated wave demodulating and indicating system the combination of a plurality of filter circuits having similar but opposed output characteristics such that certain frequencies within the band passed thereby are exalted and others substantially rejected, rectifying means having inputs coupled to said filter circuits and having outputs coupled by impedances differentially responsive to rectified energy, and means for amplifying the potentials in the separate differential impedances or the sum of the potentials in the differential impedances or the difference of the potentials in the differential impedances.

8. In a system for adapting a phase or frequency modulated wave receiver of the type wherein a pair of filter circuits of opposed characteristics supply energy to detectors having output electrodes differentially coupled by a pair of series impedances, one terminal of the series connection of which is connected to a point of substantially fixed potential, the combination of a pair of electron discharge devices each having an anode, a cathode, and a control grid, a connection between the cathodes of said devices and said point of substantially fixed potential, a connection between the anodes of said devices and an indicating circuit, an impedance connecting a relatively high potential end of each of said series resistances to said point of substantially fixed potential, a switch connected to the control grid of each of said tubes and contacts cooperating with said switches for connecting different points on said impedances to said control grids.

9. In a phase or frequency or amplitude modulated wave energy receiver, a wave energy amplifying and demodulating means of the heterodyne type including a detector cooperating with a local oscillator of controllable frequency to pro-

duce intermediate frequency energy, filter circuits of different characteristics tuned to substantially the mean frequency of the intermediate frequency resulting from beating said modulated wave energy with said local oscillations, means for impressing said intermediate frequency energy on said filter circuits, a pair of detectors having input electrodes coupled to said filter circuits and having output electrodes connected differentially by impedances, means for controlling the frequency of said local oscillator in accordance with the potentials across said impedances, and voltage dividing means connected with said impedances for supplying therefrom the sum of the potentials produced thereacross and the difference of the potentials produced thereacross.

10. In a wave energy translating system, a tunable wave responsive means with means for impressing wave energy thereon, a frequency discriminating circuit including a piezo-electric crystal having an input electrode coupled to said wave responsive means and a pair of output electrodes, reactances shunted between said input electrode and each of said output electrodes to form therewith a pair of circuits one of which is effectively capacitive and the other of which is effectively inductive with respect to the mean frequency of the wave energy impressed from said means on said crystal input electrode, rectifiers coupled with said output electrodes for producing a current component characteristic of the reaction of the instantaneous mean frequency of said wave energy impressed on said crystal input electrode and the frequency at which said circuits are normally capacitive and inductive respectively, and means for tuning said tunable wave responsive means in accordance with said current component.

11. A system as recited in claim 7 wherein each of said filter circuits have a characteristic such that the carrier frequency of said modulated wave is exalted.

12. A system as recited in claim 7 wherein each of said filter circuits have a characteristic such that one of said filters substantially rejects sideband frequencies on one side of the carrier frequency of said wave energy and the other filter substantially rejects sideband frequencies on the other side of said carrier frequency.

13. In a system for demodulating wave energy modulated in amplitude at signal frequency comprising a carrier and sideband frequencies, a circuit having a characteristic which is reactive in the same sense with respect to a band of sideband frequencies lying on both sides of the frequency to which the circuit is tuned, a circuit having a characteristic which is reactive in the same sense, but opposite to the sense of the aforesaid circuit, with respect to a band of sideband frequencies lying on both sides of the frequency to which the circuit is tuned, means for applying amplitude modulated wave energy of a mean frequency substantially equal to the frequency to which said circuits are tuned to said circuits, and detecting means coupled with said circuits.

14. In a system for demodulating wave energy modulated in amplitude at signal frequency comprising a carrier and sideband frequencies, a circuit having a characteristic which is reactive in the same sense with respect to a band of sideband frequencies lying on both sides of the frequency to which the circuit is tuned, a circuit having a characteristic which is reactive in the same sense, but opposite to the sense of the aforesaid circuit with respect to a band of side-

band frequencies lying on both sides of the frequency to which the circuit is tuned, means for applying amplitude modulated wave energy the carrier wave frequency of which is substantially equal to the frequency to which said circuits are tuned to said circuits, and detecting means coupled with said circuits.

15. In an amplifying system to be used to amplify potentials characteristic of signals produced in series connected impedances a terminal of one only of which is connected to a point of substantially fixed potential, a pair of electron discharge devices having a control grid, a cathode and an anode, an output circuit connecting the anodes and cathodes of said devices in push-pull relation, a connection between the cathodes of said devices and said point of substantially fixed potential, two resistances connected between said point of substantially fixed potential and different points on said impedances, and switching means for connecting the control grid of each of said devices to different points on one only of said resistances.

16. In a system for demodulating phase or frequency or amplitude modulated wave energy, a pair of rectifiers having input and output electrodes, filter circuits of dissimilar characteristics coupled to the input electrodes of said rectifiers, a pair of impedances connecting the output electrodes of said rectifiers in a circuit, means for impressing modulated wave energy to be modulated on said filter circuits, whereby rectified current flows in said impedances to produce therein potentials characteristic of the said rectified current, and voltage dividing means connected with said impedances for supplying therefrom potentials which represent the difference of the potentials produced by rectified current in said impedances and potentials which represent the summation of the potentials produced by rectified current in said impedances.

17. In a system for receiving amplitude modulated wave energy and demodulating the same, an impedance on which said wave energy is impressed, a pair of filter circuits each having an input coupled to said impedance and an output coupled to demodulating means, said filter circuits including a crystal having three terminals one of which is common to said filters the other two of which are each in a different one of said filter circuits, reactive means in shunt to electrodes of said crystal in said filter circuits for slightly off-neutralizing said crystal with respect to the wave energy whereby the carrier and certain side frequencies passed by each of said filter circuits are relatively exalted and other side frequencies are relatively reduced.

18. In a system for converting phase modulation on wave energy into corresponding amplitude modulations, an impedance, means for impressing phase modulated wave energy on said impedance, two pairs of output terminals, an under-neutralized crystal filter circuit, an over-neutralized crystal filter circuit, said filter circuits including a single piezo-electric crystal having one electrode connected to said impedance and having two other electrodes each connected to an output terminal of a different pair of said output terminals, a connection between a second point on said impedance and the remaining terminal of each pair of output terminals, and a utilization circuit coupled to said pairs of output terminals.

19. In a system for converting wave length modulations on wave energy into modulations

of a different type, an impedance, a plurality of output terminals, a piezo-electric crystal having a plurality of electrodes, means for impressing wave length modulated wave energy on said impedance, means coupling one of said electrodes of said crystal to said impedance, means coupling other of said crystal electrodes each to one of said output terminals to form two filter circuits between said impedance and said output terminals, and means for relatively varying the degree of neutralization of the reactance between pairs of said crystal electrodes to thereby relatively vary the characteristics of said filter circuits.

20. In a system for converting phase modulated wave energy to corresponding amplitude modulated wave energy, an impedance, a plurality of output terminals, a piezo-electric crystal having a plurality of electrodes, means for impressing modulated wave energy on said impedance, means coupling one of said electrodes of said crystal to said impedance, means coupling other of said crystal electrodes to a pair of said output terminals, means coupling a point on said impedance to another of said output terminals, and means for varying the degree of neutralization of the reactance between pairs of said crystal electrodes.

21. In a system for converting wave length modulations on wave energy into modulations of a different type, an impedance, a plurality of coupling tubes having input electrodes and having output electrodes coupled to a utilization means, means for impressing wave length modulated wave energy on said impedance, a piezo-electric crystal having a plurality of electrodes, means coupling one of said crystal electrodes to said impedance, means coupling other of said crystal electrodes to said coupling tube input electrodes, and means for varying the degree of neutralization of the reactance between pairs of said crystal electrodes.

22. In a system for converting phase modulated wave energy to corresponding amplitude modulated wave energy, means for receiving said wave energy, a tunable oscillator coupled with said last named means for beating local oscillations with said received wave energy to produce corresponding wave energy of reduced frequency, a reactance, means for impressing said wave energy of reduced frequency on said reactance, a piezo-electric crystal having an input electrode and a pair of output electrodes, means coupling said crystal input electrode to said reactance, a rectifier system having an input circuit and an output circuit including impedance, a circuit coupling one of the output electrodes of said crystal to the input circuit of said rectifier system, a circuit coupling the other of said crystal output electrodes to the input circuit of said rectifier system, a coupling between said rectifier input circuit and said reactance, variable reactances connecting said reactance to each of said crystal output electrodes, and means coupling said rectifier output circuit to said tunable oscillator to control the oscillator frequency in accordance with potentials at the output circuit of said rectifier.

23. In a system for converting phase modulated wave energy to corresponding amplitude modulated wave energy, means for receiving said wave energy, a tunable oscillator coupled with said last named means for beating local oscillations with said wave energy to produce corresponding wave energy of reduced frequency, a

reactance, means for impressing said wave energy of reduced frequency on said reactance, a piezo-electric crystal having an input electrode and a pair of output electrodes, means coupling
5 said crystal input electrode to said reactance, a rectifier system having an input and an output circuit, means coupling the output circuit of said rectifier system to a utilization circuit, a circuit including coupling means tuned to sub-
10 stantially the mean frequency of said wave energy of reduced frequency coupling one of the output electrodes of said crystal to the input circuit of said rectifier system, a circuit includ-

ing a coupling tuned to substantially the mean frequency of said wave energy of reduced frequency coupling the other of said crystal output electrodes to the input circuit of said rectifier system, a coupling between the input circuit of
5 said rectifier system and said first reactance, variable reactances coupling said first reactance to each of said crystal output electrodes, and a circuit connecting the output of said rectifier system to said tunable oscillator to control the
10 tune thereof.

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