June 29, 1937. M. G. CROSBY 2,085,008

PHASE AND AMPLITUDE MODULATED WAVE RECEIVING MEANS

Filed Nov. 2, 1935 4 Sheets-Sheet 1

Fig. 1

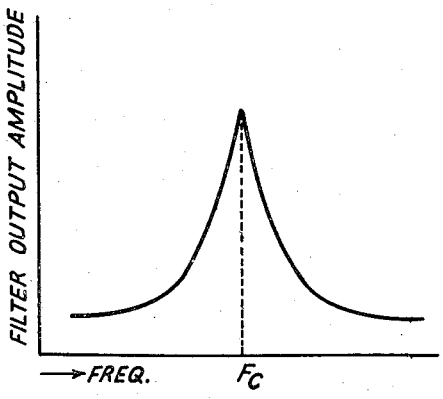


Fig. 2

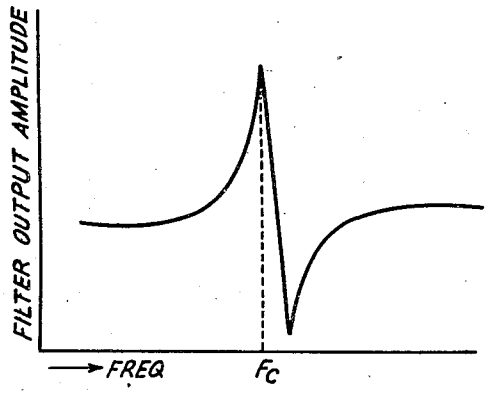


Fig. 3

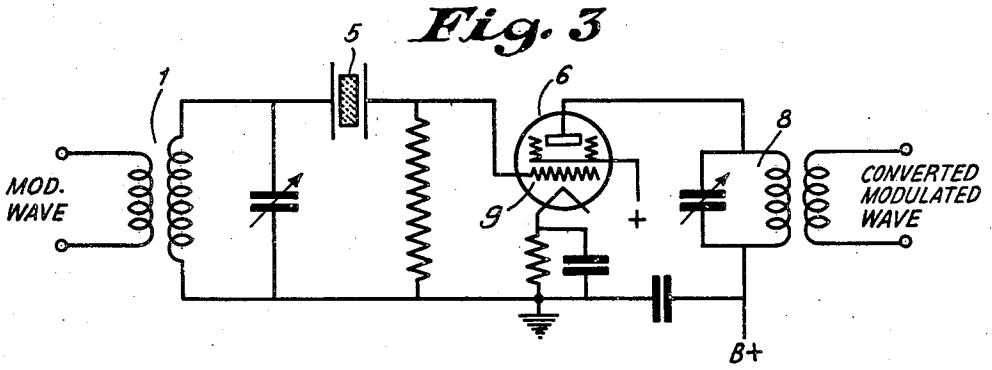


Fig. 4

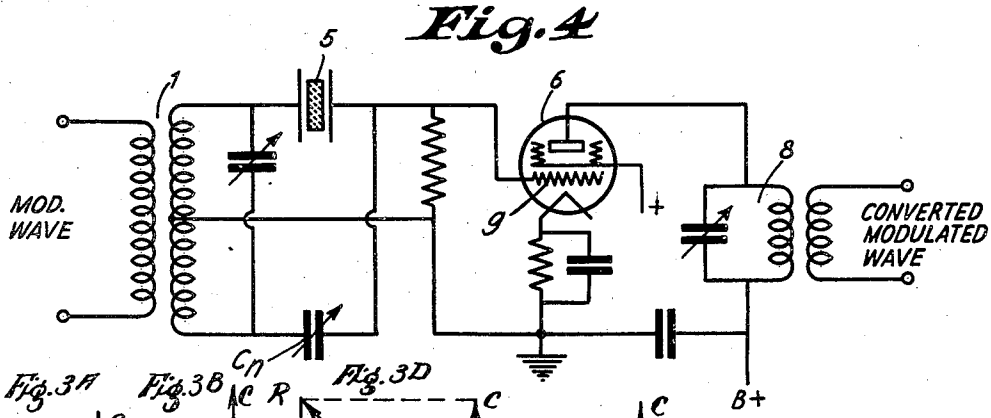
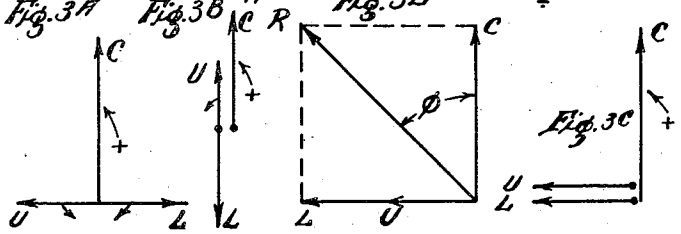


Fig. 3A Fig. 3B Fig. 3D



INVENTOR
MURRAY G. CROSBY
BY H. G. Crosby
ATTORNEY

June 29, 1937. M. G. CROSBY 2,085,008

PHASE AND AMPLITUDE MODULATED WAVE RECEIVING MEANS

Filed Nov. 2, 1935. 4 Sheets-Sheet 2

Fig. 5

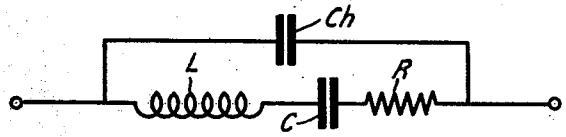


Fig. 6

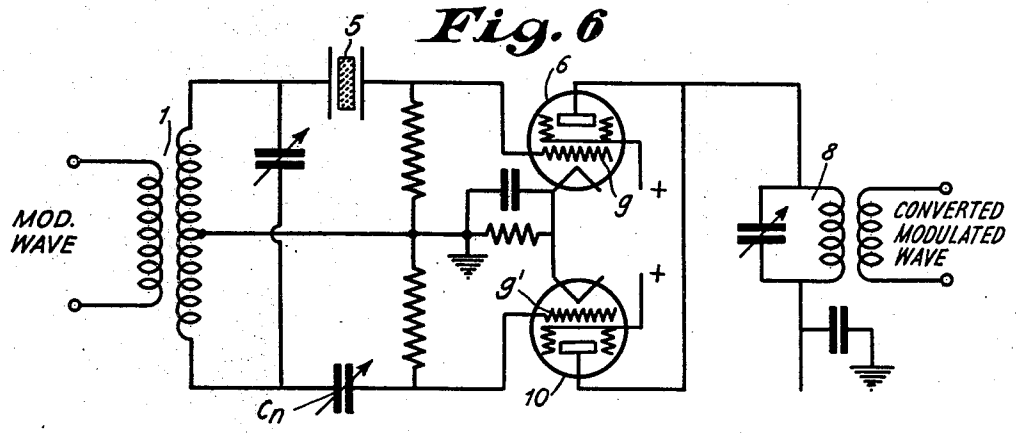
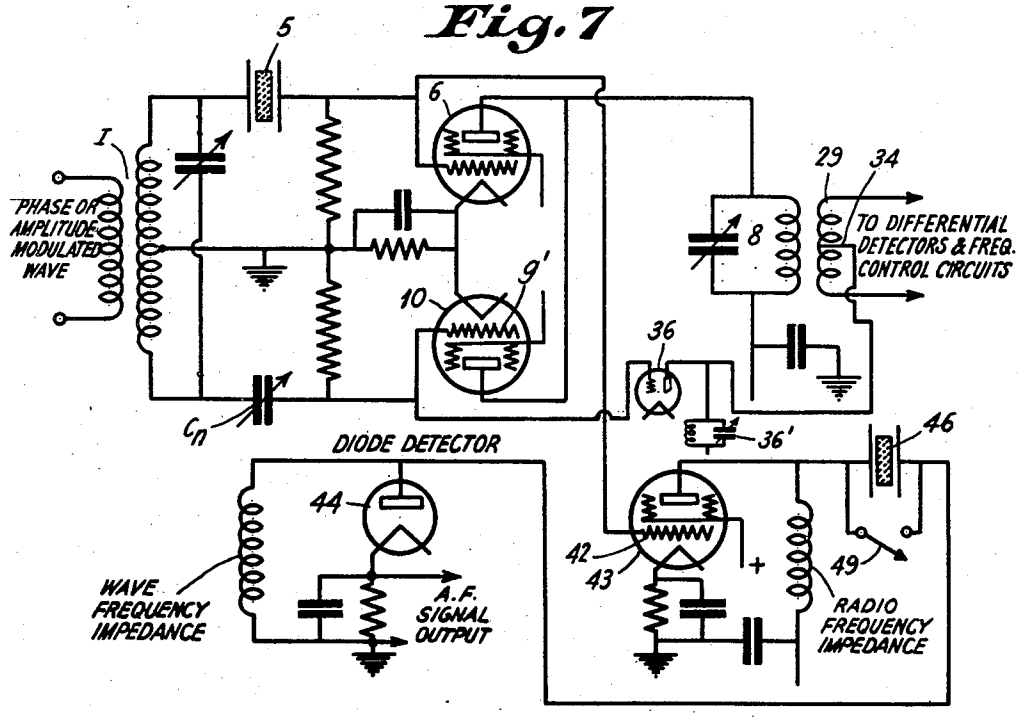


Fig. 7



INVENTOR
MURRAY G. CROSBY
BY H. S. Hoover
ATTORNEY

June 29, 1937. M. G. CROSBY 2,085,008

PHASE AND AMPLITUDE MODULATED WAVE RECEIVING MEANS

Filed Nov. 2, 1935 4 Sheets-Sheet 3

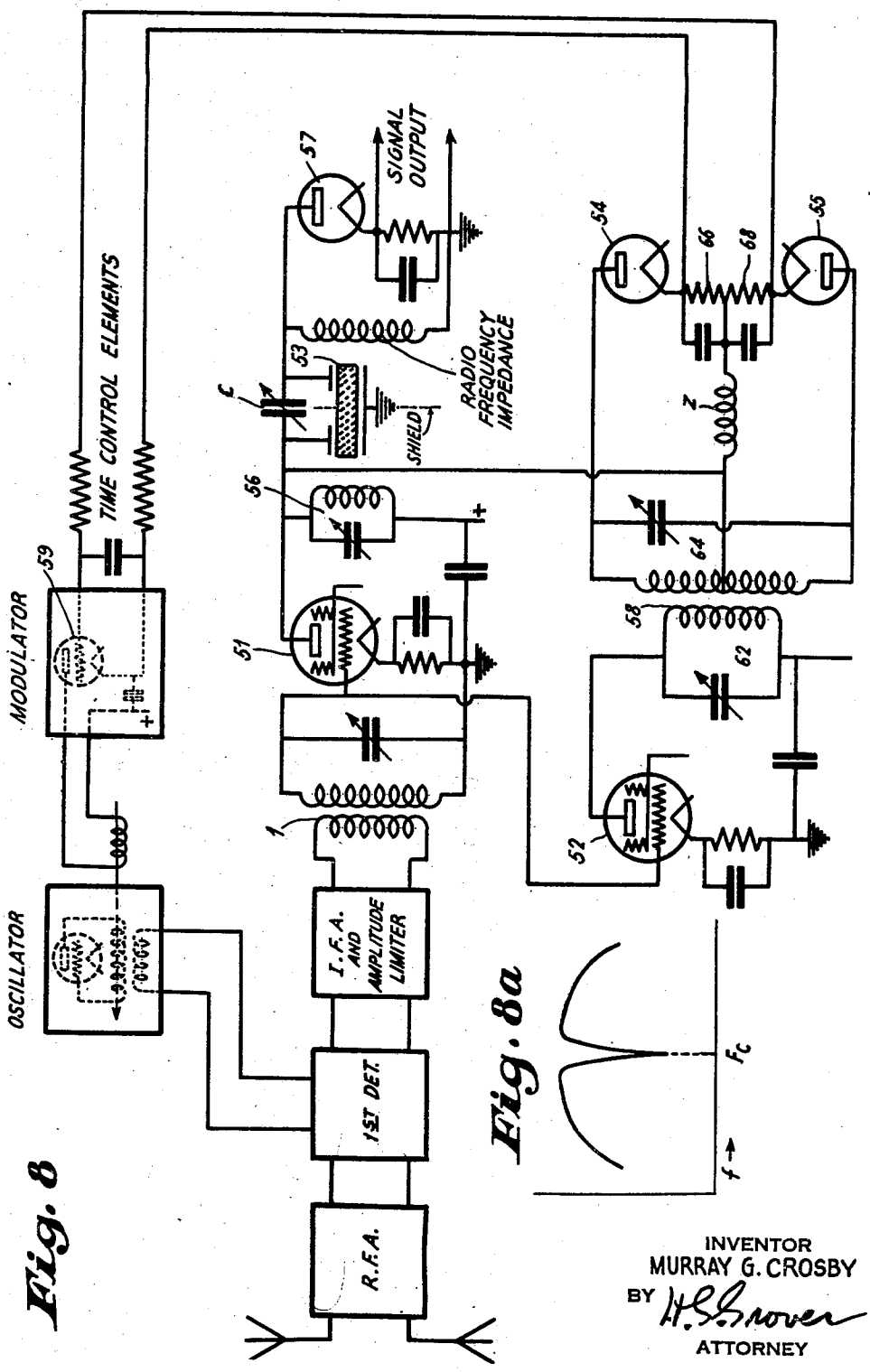


Fig. 8

Fig. 8a

INVENTOR
MURRAY G. CROSBY
BY H. G. Grover
ATTORNEY

June 29, 1937. M. G. CROSBY 2,085,008

PHASE AND AMPLITUDE MODULATED WAVE RECEIVING MEANS

Filed Nov. 2, 1935 4 Sheets-Sheet 4

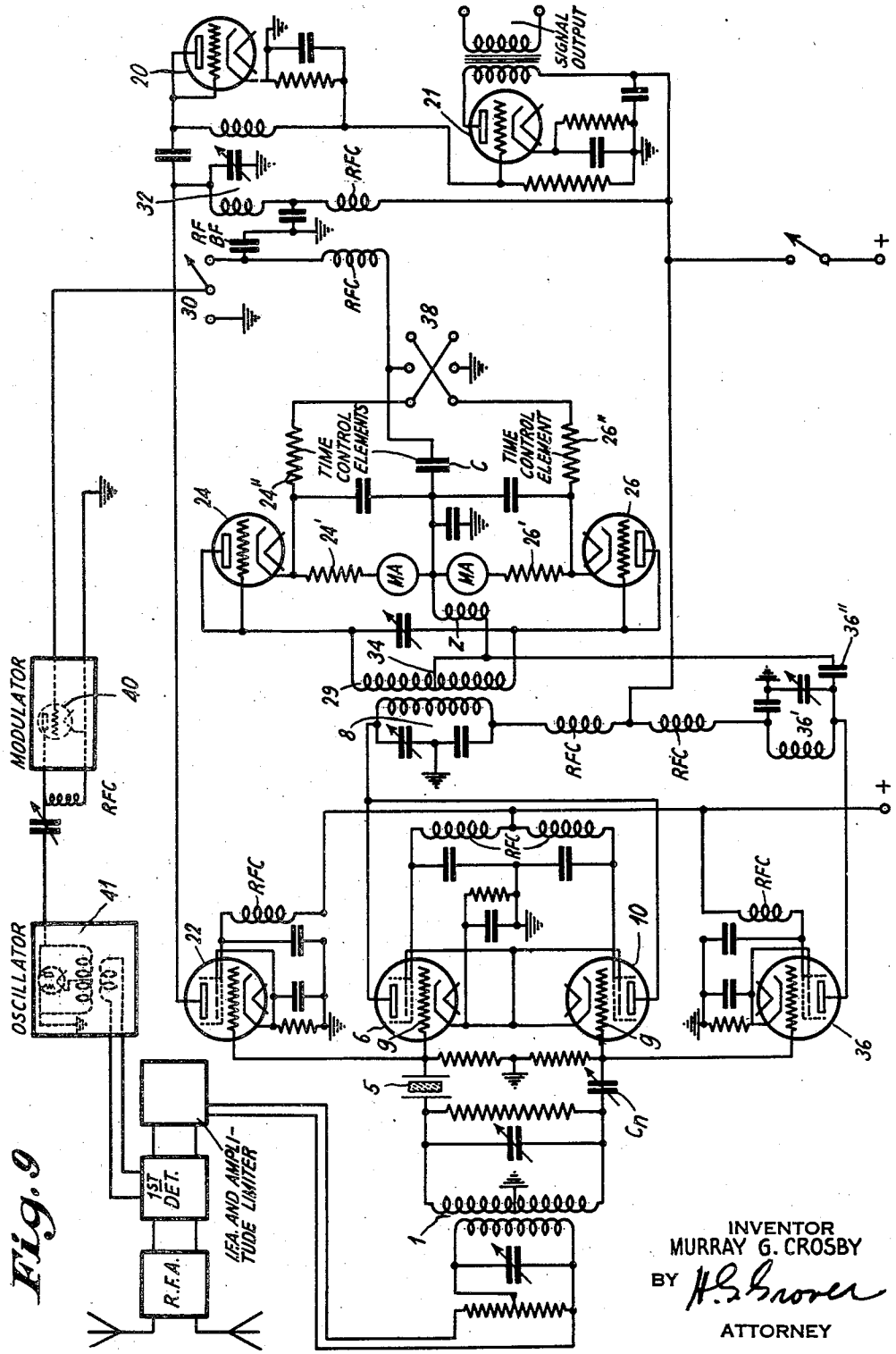


Fig. 9

Patented June 29, 1937 2,085,008

UNITED STATES PATENT OFFICE

2,085,008

PHASE AND AMPLITUDE MODULATED WAVE RECEIVING MEANS

Murray G. Crosby, Riverhead, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application November 2, 1935, Serial No. 47,933

21 Claims. (Cl. 250—20)

This application concerns wave receiving and demodulating means and in particular a novel and efficient though simple device for receiving, amplifying, demodulating and utilizing waves modulated in phase or in amplitude.

A feature of the present invention is the use of an off-neutralized or unneutralized crystal filter or filter of equivalent characteristics in a circuit through which waves modulated in phase are passed and converted into waves which have characteristics which partake of the characteristics of amplitude modulated waves.

An additional feature of the present invention is the use of an off-neutralized or unneutralized crystal filter in a manner described in the immediately preceding paragraph in combination with means for deriving filtered and unfiltered carrier wave energy and combining the same to produce resultant energy which may be utilized to automatically control the tune of one or more circuits in the receiver supplying the wave energy to be converted.

A further novel feature of the present invention is the use of two circuits connected in cascade to demodulate an amplitude modulated wave in a novel manner. The demodulation action here is accompanied by exaltation of the carrier energy and depression of the sideband energy.

Many other novel features present in my receiver will appear from the following detailed description thereof. In describing my invention, reference will be made to the attached drawings, wherein:

Figures 1, 2, and 8*a* are curves utilized through the specification in explaining the characteristic of the crystal filters involved in the present invention;

Figure 3 is a circuit diagram showing the essential features including an unneutralized crystal in the converting circuit arranged in accordance with the present invention;

Figures 3A, 3B, 3C, 3D illustrate by vectors, the manner in which a phase modulated wave comprising a carrier and sidebands impressed on an unneutralized crystal circuit as shown in Figure 3 is converted by said circuit into wave energy modulated in amplitude to correspond with the phase modulations on the impressed energy;

Figure 4 is a circuit somewhat similar to the circuit of Figure 3. However, in Figure 4. the crystal is neutralized. Figure 4 serves to illustrate the novel features of the present invention;

Figure 5 is a diagrammatic circuit including the fundamental elements of an unneutralized filter circuit as involved in the present invention;

Figure 6 is a modification of the arrangements of Figures 3 and 4. In Figure 6, neutralizing energy is supplied by way of a coupling tube;

Figure 7 is a diagrammatic showing of a circuit wherein two crystals are connected in cascade in a manner to demodulate waves modulated in amplitude;

Figure 8 illustrates diagrammatically a circuit arrangement in which filtered and unfiltered energy is supplied for automatic control purposes and in which an untuned or off-tuned crystal converts energy modulated in phase into energy modulated in amplitude; while

Figure 9 illustrates somewhat completely the essential features of a phase modulation receiver arranged in accordance with my present invention and including means for converting phase modulated waves into amplitude modulated waves in addition to means for producing differential potentials for controlling the tune of one of the stages in the wave receiving and amplifying means.

As stated above, this application concerns a phase modulation receiver wherein the phase modulated energy of high or intermediate frequency is passed through a crystal filter and detected in the manner of amplitude modulation detection. I have found that a simple unneutralized filter has the inherent characteristic whereby it shifts the phase of the sidebands ninety degrees with respect to the carrier. Consequently, the simplest crystal filter circuit provides a means for converting phase modulation to amplitude modulation and vice versa. A carrier exalted amplitude modulation receiver may also be effected by utilizing two crystal filters in cascade so that the phase of the sidebands will be shifted one hundred and eighty degrees with respect to the carrier; hence, the amplitude modulation will remain amplitude modulation, but the carrier will be exalted.

In the prior art of phase modulation reception wherein crystal filters are employed, the crystal filter was used as a means to remove the modulation or sidebands from the modulated energy. This filtered energy then took the place of a local carrier, synchronized with that of the transmitting station, so that the phase deviations could be converted to amplitude deviations for detection by combining the phase modulated energy with the filtered energy. Such a receiver is described in my United States Applns. Ser. No. 588,309, filed Jan. 23, 1932 and Ser. No. 616,803, filed June 13, 1932. The type of crystal filter used in such receivers is one which will

produce a symmetrical characteristic such as is shown in Fig. 1. This characteristic may be produced by means of the shielded type crystal filter, as described in my U. S. Appln. Ser. No. 616,803, or by means of a neutralized crystal circuit as shown in Fig. 4. In this circuit, the voltage of radio or intermediate frequency that is fed to the grid *g* of the tube through the capacity of the holder of crystal 5 is neutralized by a voltage of opposite phase fed through a condenser C*n*, having the same capacity as the crystal holder. Energy characteristic of the wave supplied to *f* appears in the output circuit 8 and may be supplied to any utilization circuit.

In the receiver of the present disclosure, the filtered energy (i. e. that passed by the crystal 5) is not recombined with unfiltered energy (i. e. that passed by C*n*), as in Fig. 4, for detection, but is fed directly to the detector after passing through an unneutralized crystal filter of the type shown in Fig. 3. In Fig. 3, the modulated wave is supplied to the primary of transformer *f* and from the secondary of transformer *f* to the unneutralized crystal 5 and thence to the grid *g* of tube 6. An amplitude modulation detector may be coupled to 8. It has been found that the phase characteristic of this type of filter (Fig. 3) is ideally suited for the conversion of phase modulation to amplitude modulation and that when phase modulated energy is passed through a circuit, as shown in Fig. 3, energy having amplitude modulation characteristics appears in 8. In the neutralized crystal filter characteristic of Fig. 1 (obtained by Fig. 4), it is easy to see that the carrier wave would be unshifted in phase relative to the sidebands, since it is tuned to resonance with the crystal. Above the resonant frequency, the phase of the crystal output would be leading and below the crystal frequency the phase would be lagging. Thus, the upper sidebands would be shifted ninety degrees in one direction, the lower sidebands ninety degrees in the other direction, and the carrier would be relatively unshifted. Consequently, the required shift of the carrier wave with respect to the sidebands, wherein both sets of sidebands must be shifted in the same direction, to convert from phase modulation to amplitude modulation, would not be effected. The result described in the second preceding sentence may be obtained by passing the phase modulated energy through the circuit of Fig. 4. However, when the unneutralized crystal filter circuit of Fig. 3 is used, producing a characteristic as shown in Fig. 2, the phase of the carrier frequency, or the maximum output point, is unshifted, but both the upper sidebands and lower sidebands are shifted ninety degrees in the same direction since the energy at frequencies on either side of the resonant frequency would have a leading phase. That this is true can be seen by a consideration of the equivalent circuit of a crystal filter as shown in Fig. 5. L, C, and R represent the effective inductance, capacity and resistance of the crystal and C*h* represents the capacity of the crystal holder. At the resonant frequency of the crystal its reactance is tuned out so that the crystal acts like a pure resistance and does not produce a phase shift. On the low frequency side of resonance, the capacities C and C*h* become predominating so that the phase of the crystal output would be leading. On the high frequency side of resonance, the circuit composed of L, C and R becomes a high impedance and capacity *Ch* becomes predominating. Thus, on both sides of resonance a capacity predominates and the phase of the crystal output is leading. The attached Fig. 3A and Fig. 3B show the sideband and carrier relationships for amplitude and phase modulation respectively. Vector C represents the carrier frequency which is taken as the reference frequency. Vectors U and L represent the upper and lower side frequencies respectively. The counter-clockwise direction is taken as the positive direction as indicated by the arrow and plus sign. Since the carrier frequency is taken as the reference frequency, the upper side frequency rotates counterclockwise with respect to the carrier frequency since the upper side frequency is higher in frequency. The lower side frequency rotates in the clockwise direction since it is of a frequency lower than that of the carrier. In the case of the amplitude modulation vector diagram of Fig. 3A, the particular instant portrayed by the diagram is that instant of the modulating cycle at which the instantaneous amplitude passes through zero so that the upper and lower side frequencies cancel each other and do not add or detract from the carrier. 90 degrees later on the modulating cycle the side frequencies would have rotated to a position such that their phase was the same as that of the carrier and they would add to the carrier to form a nodal point on the modulation envelope.

In the case of the phase modulated wave portrayed by the carrier and side frequencies of Fig. 3B, the inherent property of phase modulation is such as to form a phase relation between the carrier and side frequencies that can only allow a phase shift of the resultant wave. Thus in the particular instant portrayed by Fig. 3B the upper and lower side frequencies cancel each other and the phase of the resultant is the same as that of the carrier. At an instant 90 degrees later on the modulating wave the side frequencies will be as shown in Fig. 3C. Hence the side frequencies will add and combine with the carrier to produce a resultant, R, shifted in phase by the amount ϕ as shown in Fig. 3D.

From the above it can be seen that the function of the side frequencies in amplitude modulation is to vary the amplitude, while in phase modulation it is to vary the phase. (In the vector diagrams for phase modulation only the first and strongest side frequencies were considered for purposes of simplification. A more rigorous treatment would consider the higher order side frequencies of phase modulation. The effect of the consideration of the higher order side frequencies would be to remove the slight amplitude modulation that would seem to accompany the phase modulation as portrayed by Fig. 3B and 3D). A further description of the difference between amplitude and phase modulation may be found in the December, 1931 issue of The Proceedings of the Institute of Radio Engineers in an article entitled "Amplitude, phase and frequency modulation", by Hans Roder.

When the phase modulated wave, with carrier and side frequency phase relations as portrayed by Fig. 3B is passed through a symmetrical filter with a characteristic as shown in Fig. 1, the effect is to advance the phase of the upper side frequency which is on the capacitive side of resonance and to retard the phase of the lower side frequency which is on the inductive side of resonance. With a highly selective filter such

as a crystal filter, each side frequency would be shifted 90 degrees in opposite directions so that the vector diagram of the output of the neutralized or symmetrical crystal filter would appear as shown in Fig. 3C. Hence the effect of such a crystal filter would be the same as the effect of retarding the phase of the modulating wave 90 degrees. Consequently the wave is still phase modulated and the only change is a shift of the phase of the modulation "envelope".

When an unneutralized crystal filter, such as that of Fig. 3, having a characteristic as shown in Fig. 2, is used to filter the phase modulated energy of the vector diagram shown in Fig. 3B, the crystal filter operates to shift the phase of the side frequencies in the same direction. This is true since the unneutralized crystal filter is capacitive on both sides of resonance so that both upper and lower side frequencies are advanced 90 degrees. This changes the vector diagram as shown in Fig. 3B to one identical to that shown in Fig. 3A. Consequently the phase modulated wave has been converted to an amplitude modulated wave by altering the phase relation of the carrier and side frequencies in such a manner as to allow the side frequencies to vary the amplitude of the resultant instead of the phase.

In the circuit of Fig. 3, the phase modulated wave is fed to transformer 1. Crystal filter 5 filters the phase modulated energy and shifts the phase of the side frequencies to convert the modulation from a phase modulation to an amplitude modulation. Hence tube 6 amplifies amplitude modulated energy and this amplitude modulated energy appears in transformer 8 from which it may be drawn for subsequent detection and utilization. It is this inherent property which gives the crystal its property of converting phase modulation into amplitude modulation. The sidebands are shifted ninety degrees with respect to the carrier frequency to correct for the inherent property of phase modulation wherein it is equivalent to an amplitude modulation with the carrier phase shifted ninety degrees. As can be seen from the characteristic of Fig. 2, the amplitude of the carrier is strong compared to the sidebands so that a carrier exaltation effect is also obtained. The amount of this carrier exaltation effect may be varied by varying the dimensions of the crystal so as to vary the capacity of the holder required.

In a practical receiver, an arrangement must be provided to hold the receiver in tune with the crystal filter since the selectivity of the crystal filter is very high compared with the degrees of frequency stability obtainable. In order to obtain energy for automatic frequency control detectors, it is desirable to have available a crystal filter of the same frequency as that of the converting filter described above in connection with Figs. 2, 3, and 5, but one which will produce a symmetrical characteristic such as is shown in Fig. 1. A more desirable arrangement would be one in which the same crystal is used to obtain both the symmetrical (Fig. 1) and the unsymmetrical (Fig. 2) characteristics so that difficulties in grinding the crystals to the same frequency would be removed. Such a circuit is shown in Figs. 6 and 9 of the drawings. These circuits differ from the circuit of Fig. 4, in that neutralization is accomplished through a coupling tube. Thus, in the neutralized circuits of Figs. 6 and 9, in order to neutralize through coupling tubes, the energy from the neutralizing condenser C*n*, instead of being fed to the other terminal of the holder of crystal 5, and thence to the grid of the tube as in Fig. 4, is fed to the control grid *g'* of another coupling tube 10, and then combined in the plate circuits 8 of the tubes. This leaves unneutralized crystal filter energy, (of a characteristic as shown in Fig. 2), from which the modulations may be rendered by any amplitude modulated wave demodulator, available on the grid *g* of tube 6 and unfiltered energy on the grid *g'* of tube 10. The neutralized filtered energy, of a characteristic as shown in Fig. 1, is obtained from the common plate circuit 8 of the coupling tubes.

In the circuit of Fig. 9, signal modulated wave energy is supplied to transformer 1 from the output of a heterodyne receiver arranged as shown. The unneutralized crystal filtered energy from 5 is fed to diode amplitude modulation detector 20 via radio frequency coupling tube 22. The anode circuit of 22 is tuned to the intermediate frequency of the wave by a tuning element 32. The detected energy is fed from 20 to an audio amplifier 21, the output of which may be utilized. The other two tubes 24 and 26 are the automatic frequency control diode differential detectors. The neutralized crystal filter energy is fed to these detectors from the tuned circuit 8 coupled to the winding 29 connecting the detectors in push-pull relation. The winding 29 forms the secondary of a transformer. The primary winding of this transformer couples the anodes of coupling tubes 6 and 10 in parallel. The circuits just described impresses neutralized crystal filtered energy on the input electrodes of the diode detectors 24 and 26 in phase opposition. The unfiltered energy is amplified in 36 and fed in phase quadrature relative to the filtered energy to the midtap 34 of the push-pull transformer secondary 29, and thence in like phase to the input electrodes of diode detectors 24 and 26. The tuned impedance coupling 36' may be adjusted to produce the necessary phase quadrature relation between the in-phase unfiltered energy and the out-of-phase neutralized filtered energy on the input electrodes of 24 and 26. The automatic frequency control energy is taken from the differential diode resistors 24' and 26' and fed through the time control resistances 24'', 26'' and condenser C and reversing switch 38 and switch 30 to the grid of the modulator tube 40 which controls the frequency of the grounded grid high-frequency oscillator, shown diagrammatically at 41, of the superheterodyne receiver. The purpose of the switch 38 is to allow the automatic frequency control circuit to be shut off so that the receiver may be tuned manually. When it is desired to tune in a signal the switch 38 is moved to the left so as to ground the grid of the tube 40 and to cut off the automatic frequency control energy supplied to 41. The high frequency oscillator 41 is then tuned by hand until the signal is properly tuned after which the switch 38 is thrown to the right. The automatic frequency control circuits then hold the oscillator tuned to the point where it was tuned manually and follows the frequency drifting of the signal or of the high frequency oscillator. A somewhat similar means for producing differential currents for frequency control purposes has been shown in my U. S. Appln. Ser. No. 616,803, filed June 13, 1932. A somewhat similar oscillator con-

trol circuit has been shown in Crosby's U. S. Appln. Ser. No. 16,591, filed April 16, 1935. This energy could as well be used to control the second oscillator frequency of a double I. F. superheterodyne. The reversing switch 38 provides means for applying the control voltages to the modulator tube 40 in the proper sense. For the sake of clearness and brevity, the filaments and their heating circuits have been omitted in this description.

The circuit of Fig. 7 shows an arrangement whereby the principles of this disclosure may be applied to the reception of amplitude modulation accompanied with carrier wave exaltation. The first crystal, 5, as to its unneutralized output, converts the incoming amplitude modulation to phase modulation by shifting the sidebands relative to the carrier in the same direction (see Fig. 2), and also introduces some carrier exaltation of sideband depression. This converted filtered energy is then passed from the output of 5 to the control grid 42 of coupling tube 43 and thence to a second crystal filter, 46. This second crystal filter converts the phase modulated energy received from the first crystal filter back into amplitude modulated energy, by shifting both sidebands ninety degrees in the same direction, so that amplitude modulation detection may be accomplished. A further carrier exaltation is also effected in this second crystal filter 46. Tube 44 is a diode detector coupled to 46 to detect the amplitude modulation. The neutralized filter energy (Fig. 1) is taken from the common plate circuit 8 of tubes 6 and 10 and fed to automatic frequency control detectors, not shown, in the same manner as in the circuit of Fig. 9. Unfiltered energy may be fed from circuit 1 by way of a coupling tube in 36 to a point 34 on the winding 29 coupled with 8. Phasing of the unfiltered energy may be accomplished at 36'. The frequency control circuit may be as in Fig. 9.

Switch 48 in Fig. 7 provides a means for shorting out the second crystal 46 to convert the receiver back to a phase modulation receiver.

The circuit of Fig. 8 shows a phase modulation receiver utilizing the principles of this disclosure wherein the shielded type of crystal filter is employed. The phase modulated intermediate frequency energy is fed from 1 to the control grid and cathode of tube 52 and to coupling tube 51 and from the anode of 51 to the tuned circuit 56 connected with said anode. This tuned circuit 56 has the input electrodes of the shielded crystal filter 53 across it and the tuned circuit 56 is normally tuned so as to tune out the capacity of the crystal holder. This tuning will allow the crystal to produce a dip point in the resonance curve of the tuned circuit so that the combined resonant characteristic is as shown in Fig. 8a of the drawings wherein Fc is the mean or carrier wave frequency. On either side of this dip point, the phase of the voltage across the tuned circuit and crystal will change very rapidly due to the high selectivity of the crystal. Thus, filtered energy, the phase of which changes very rapidly with frequency and the amplitude of which increases very rapidly as the resonance point of the crystal is deviated from, is available for the automatic frequency control diode detectors 54 and 55. Such a crystal filter produces an ideal characteristic for automatic frequency control purposes, since the farther off tune the signal is, the greater the energy is which is available to correct the tuning. This filtered energy is combined with the unfiltered energy from coupling tube 52 by feeding it to the midtap of push-pull input transformer 58, the primary winding of which is connected to the anode of 52. The automatic frequency control energy is taken from the resistors of diode detectors 54 and 55 and passed to the modulator tube 59 which controls the frequency of the first or second superheterodyne oscillator. The energy which is fed to the audio frequency amplifying diode 57 for the detection of the signal is converted from phase modulation to amplitude modulation by means of the three-electrode crystal filter, as in the prior modification. Such a crystal filter may have a shield S between its input and output electrodes, as shown, but in this circuit a capacity C is provided to destroy the shielding and convert the filter from a symmetrical characteristic filter, as shown in Fig. 1, to an unsymmetrical characteristic filter, as shown in Fig. 2, as to the energy fed to the detector 57. This capacity might be replaced by some sort of a variable shielding means also; for instance, a movable grounded plate could be slid between the two electrodes to variably shield them from each other.

In Fig. 8, the filtered energy is impressed in like phase on the diode input electrodes, while the unfiltered energy is applied in phase displaced relation on these electrodes. The proper phase quadrature relation may be produced by adjusting the tune of 62.

When only a single crystal filter is used, as for phase modulation reception, amplitude modulation comes through to a certain extent due to the single sideband action of the crystal filter. Since the sidebands on one side of the carrier are eliminated due to the dip point in the unneutralized filter characteristic, the filter acts as a single sideband filter for the lower modulation frequencies. Thus, the lower modulation frequencies of either phase or amplitude modulation will come through on the phase modulation adjustment.

The principles utilized in this disclosure are not limited to the use of crystal filters. Thus, any mechanical filter or artificial line type of circuit may be used. The fundamental requisite is that the phase be shifted either capacitive on both sides of the resonant frequency or inductive on both sides of the resonant frequency. The required effect is the shift of the carrier in phase with respect to the sidebands or vice versa. The fundamental circuit of Fig. 5 has other "equivalent" circuits which will perform the same function.

What is claimed is:

1. In a system for demodulating wave energy a characteristic of which has been modulated in accordance with intelligence, an alternating current circuit tuned to the carrier frequency of the wave to be demodulated, a reactive circuit for shifting the phase of the sidebands of said wave energy in the same direction relative to the carrier wave, connected to said alternating current circuit, and a thermionic tube having its cathode and a control electrode coupled to said reactive circuit.

2. In a system for demodulating a wave the phase of which has been modulated in accordance with intelligence, an alternating current circuit tuned to the frequency of the wave to be demodulated, an unneutralized piezo-electric crystal connected to said circuit, and a thermionic tube

having a cathode coupled to said circuit and a control electrode coupled to said crystal.

3. In a system for demodulating a wave the phase of which has been modulated in accordance with intelligence, an alternating current circuit tuned to the frequency of the wave to be demodulated, a mechanical device for shifting the phase of the sidebands of said wave energy in the same direction connected at one terminal with said circuit, a thermionic tube having a control electrode coupled to another terminal of said device, and a coupling between said circuit and the anode of said tube.

4. In a demodulator system for demodulating a wave the phase of which has been modulated in accordance with intelligence, wave amplifying means, a source of local oscillations of variable frequency, demodulating means coupled to said wave amplifying means and said source of oscillations, an alternating current circuit coupled to said demodulating means, a mechanical device in said last circuit for shifting the phase of the sidebands of the energy in said last circuit in the same direction sense on both sides of its resonant characteristic, a thermionic tube having its control grid connected to said mechanical device and its anode connected to a utilization circuit, a pair of converter tubes, a circuit connecting the input electrodes of said converter tubes to said circuit and to said device, a pair of differential detectors, a transformer secondary winding connecting said detectors in phase opposition, said transformer having a primary winding connected to the anodes of said converter tubes in parallel, an additional tube having its control grid coupled to said alternating current circuit and its anode coupled to a point on said secondary winding, a modulator tube having its anode coupled to said source of oscillations of variable frequency, and a coupling between the control grid of said modulator tube and the output of said differential detectors.

5. In a wave filtering system an impedance, a thermionic tube having a control grid and an anode, a piezo-electric crystal, an electrode adjacent said crystal coupling said crystal to a point on said impedance, a second electrode adjacent said crystal coupling said crystal to the control grid of said tube, an output circuit connected with the anode of said tube, and means for neutralizing the inherent capacity of said electrodes comprising a coupling tube having an input electrode connected to said impedance and having an output electrode connected to the anode of said first named tube.

6. In a system for demodulating a wave the phase of which is modulated in accordance with signals, a circuit tuned to the frequency of the wave to be demodulated, said circuit including a reactance on which said wave may be impressed, a piezo-electric crystal having two electrodes one of which is coupled to said tuned circuit, a tube having a control grid, a cathode and an anode, a connection between the other electrode of said crystal and the control grid of said tube, a connection between the cathode of said tube and said tuned circuit, and an output circuit coupled to the anode of said tube.

7. In a system for demodulating a wave the phase of which is modulated in accordance with signals, a circuit tuned to the frequency of the wave to be demodulated, said circuit including a reactance on which said wave would be impressed, a piezo-electric crystal having two electrodes one of which is coupled to said tuned circuit, a plurality of thermionic tubes each having a control grid, an anode and a cathode, a connection between the control grid of one of said tubes and the other electrodes of said crystal, a connection between the cathodes of both of said tubes and a point on said inductance, a connection between the control grid of the other of said tubes and said tuned circuit, and an output circuit connecting the anodes of said tubes in parallel.

8. In a system for demodulating phase modulated wave energy comprising a carrier and sidebands, a tunable circuit on which said wave energy may be impressed, an alternating current circuit, tuned to the frequency of the wave energy to be demodulated, coupled to said tunable circuit, a resonant circuit for shifting the phase of the sidebands of said wave energy in the same direction relative to the wave on both sides of its resonant characteristic, said resonant circuit being coupled at its input to said alternating current circuit, a thermionic tube having its cathode and a control electrode coupled to said resonant circuit, a utilization circuit coupled to the output of said thermionic tube, a pair of differential detector tubes, means for applying energy in a predetermined sense from the output of said resonant circuit to like electrodes in said differential detectors, means for applying energy from said alternating current circuit in the same sense to said like electrodes, additional means for applying energy from said alternating current circuit to like electrodes in said differential detector tubes, and a control circuit coupling the output of said electrodes to said tunable circuit.

9. In means for receiving and demodulating phase modulated wave energy comprising a carrier and sideband energy, and for maintaining said receiving means tuned to the frequency of the wave energy, wave absorbing and amplifying means including a tunable circuit, a filter circuit the characteristic of which is reactive in the same sense as to the frequency of the wave energy applied thereto on both sides of its resonance point, said filter circuit having an input coupled to the output of said amplifying means, means coupled to the output of said filter circuit for utilizing said wave energy, a control circuit having an input, and an output coupled to said tunable circuit in said wave receiving and amplifying means, a first path for applying energy from the output of said filter to the input of said control circuit, a second path between said alternating current circuit and the input of said control circuit to alter the characteristic of said filter circuit so that as to the energy passed to said control circuit the characteristic of said filter circuit and path is symmetrical on both sides of the resonant point, and a third path between said alternating current circuit and the input of said control circuit.

10. In means for receiving and demodulating phase modulated wave energy comprising a carrier and sideband energy, and for maintaining said receiving means tuned to the frequency of the wave energy, the combination of a tunable circuit on which said wave energy may be impressed, a filter circuit the characteristic of which is reactive in the same sense as to said sideband energy and non-reactive as to the carrier energy, said filter circuit having an input coupled to said tunable circuit, means coupled to the output of said filter circuit for utilizing the wave energy at the output of said filter, a control circuit hav-

ing an input and an output coupled to said tunable circuit, means for applying energy from the output of said filter to the input of said control circuit, a second means for applying energy from the said tunable circuit to the input of said control circuit, and a third means for impressing energy from the output of said tunable circuit on the input of said control means.

11. In a signalling system, a filter circuit the characteristic of which is reactive in the same sense on both sides of the frequency to which the filter is resonant as to the frequencies of a band of frequencies of a width of the order of a modulation frequency spectrum, means for applying modulated wave energy of a mean frequency substantially equal to said resonant frequency to said filter circuit, and a utilization circuit connected to said filter circuit.

12. In a converting system a filter circuit having an input and an output, the characteristic of said filter circuit being capacitive 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, means for applying phase modulated wave energy to the input of said filter circuit, said phase modulated wave energy being converted by said filter circuit to corresponding amplitude modulated wave energy and a utilization circuit connected to the output of said filter circuit.

13. In means for receiving and demodulating phase modulated wave energy comprising a carrier and sideband energy, and for maintaining said receiving means tuned to the frequency of the wave energy, the combination of a tunable circuit on which said wave energy may be impressed, a filter circuit the characteristic of which is reactive in the same sense as to said sideband energy and non-reactive as to the carrier energy, said filter circuit having an input coupled to said tunable circuit, means coupled to the output of said filter circuit for utilizing the wave energy at the output of said filter, a control circuit having an input and having an output coupled to said tunable circuit, means for applying energy from the output of said filter circuit to the input of said control circuit and means for applying energy from said tunable circuit to the input of said control circuit.

14. In a system for receiving and demodulating phase modulated carrier wave energy comprising a carrier and two sidebands and for maintaining said receiving means tuned to the mean frequency of said wave energy, the combination of a tunable circuit on which said wave energy may be impressed, said tunable circuit including a tuning reactance, a piezo-electrical crystal having two electrodes, means coupling one of said electrodes to said tunable circuit to impress on said crystal modulated carrier energy the carrier of which is of a frequency substantially equal to the natural frequency of said crystal, a utilization circuit including wave demodulating means coupled to the other electrode of said crystal, a frequency control circuit having an input and having an output coupled to the tuning reactance in said tunable circuit, a coupling between the said tunable circuit and the input of said control circuit and reactive means connected in shunt to the electrodes of said piezo-electric crystal to neutralize the reactance betweeen said electrodes and means for impressing the energy passed by said piezo-electric crystal and neutralizing reactance on the input of said control circuit.

15. In a wave energy filtering system, an impedance on which said wave energy may be impressed, an electron discharge device having a control grid and an anode, a piezo-electric crystal in a holder having two electrodes, means connecting one of said electrodes to one end of said impedance and the other electrode to the control grid of said discharge device, an output circuit connected with the anode of said device, means for neutralizing the capacity of the holder of said crystal comprising a coupling tube having an electrode connected to said impedance and having an output electrode connected to the anode of said electron discharge device and to said output circuit, a utilization circuit coupled to a portion of said output circuit common to said tube and device, and a second utilization circuit connected to the electrode of said holder which is connected to the control grid of said device.

16. In a wave energy filtering system, a reactance on which said wave energy may be impressed, an electron discharge device having a control grid, a cathode, and an anode, a piezo-electric crystal in a holder having two electrodes, means connecting one of said electrodes to a point on said reactance, means connecting the other of said electrodes to the control grid of said discharge device, a connection between said reactance and the cathode of said device, an output circuit connected with the anode of said device, means for neutralizing the capacity of the holder of said crystal comprising a coupling tube having an input electrode connected to a point on said reactance and having an output electrode connected to the anode of said first device and to said output circuit, a utilization circuit coupled to the output circuit of said tube and device, and a second utilization circuit connected to the electrode of said holder which is connected to the control grid of said device.

17. In a receiving system, a tunable circuit having tuning means, a control circuit having an output connected to said tuning means in said tunable circuit, said control circuit having an input, a pair of diode rectifier tubes each having input and output electrodes, a direct current circuit including an impedance connected between the input and output electrodes of each of said diode rectifier tubes, means for coupling the input electrodes of said diode rectifiers in phase opposition to said tunable circuit, means for coupling the input electrodes of said diode rectifiers in phase to said tunable circuit, and means for connecting said impedances together and connecting them to the input of said control circuit.

18. In a receiving system, a tunable circuit having tuning means, a control circuit having an output connected to said tuning means in said tunable circuit, said control circuit having an input, a pair of diode rectifier tubes each having input and output electrodes, a direct current circuit including an impedance connected between the input and output electrodes of each of said diode rectifier tubes, means including a neutralized piezo-electric crystal filter coupling the input electrodes of said diode rectifier tubes in phase opposition to said tunable circuit, means including an un-neutralized portion of said aforesaid filter, coupling the input electrodes of said rectifiers in phase to said tunable circuit, and means coupling said impedances together and connecting them to the input of said control circuit.

19. In a wave filtering system, an impedance, an electron discharge tube having a control grid and an anode, a piezo-electric crystal, electrodes

coupling said crystal between a point on said impedance and the control grid of said tube, an output circuit including a second impedance connected with the anode of said tube, and means for neutralizing the inherent capacity of said electrodes comprising a coupling tube having an input electrode connected to a different point on said first named impedance and having an output electrode coupled to said second named impedance.

20. In a wave filtering system, an impedance, a pair of electron discharge systems comprising input electrodes including control grids, and output electrodes, an output circuit connected with said output electrodes, a piezo-electric crystal, conductive elements cooperating with said crystal for connecting said crystal between one of said control grids and said impedance, and means for neutralizing the inherent capacity between said conductive elements cooperating with said crystal comprising a neutralizing condenser connecting a second point on said impedance to another control grid.

21. In a wave filtering system, an impedance, a pair of electron discharge systems comprising input electrodes including control grids, and output electrodes, an output impedance connected with said output electrodes, a coupling circuit including a piezo-electric crystal, an electrode adjacent said crystal coupling said crystal to a point on said impedance, a second electrode adjacent said crystal coupling said crystal to one of said control grids, and means for neutralizing the inherent capacity between said crystal electrodes comprising a second coupling circuit including a neutralizing capacity coupling a second point on said impedance to another of said control grids.

MURRAY G. CROSBY.