July 9, 1940. M. G. CROSBY 2,207,691

PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

Filed Feb. 10, 1937 5 Sheets-Sheet 1

Fig. 1

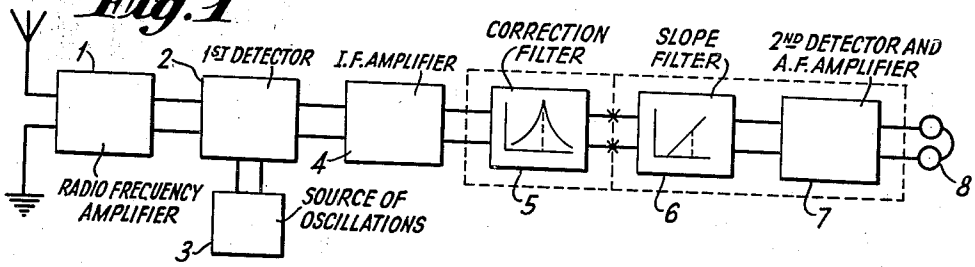
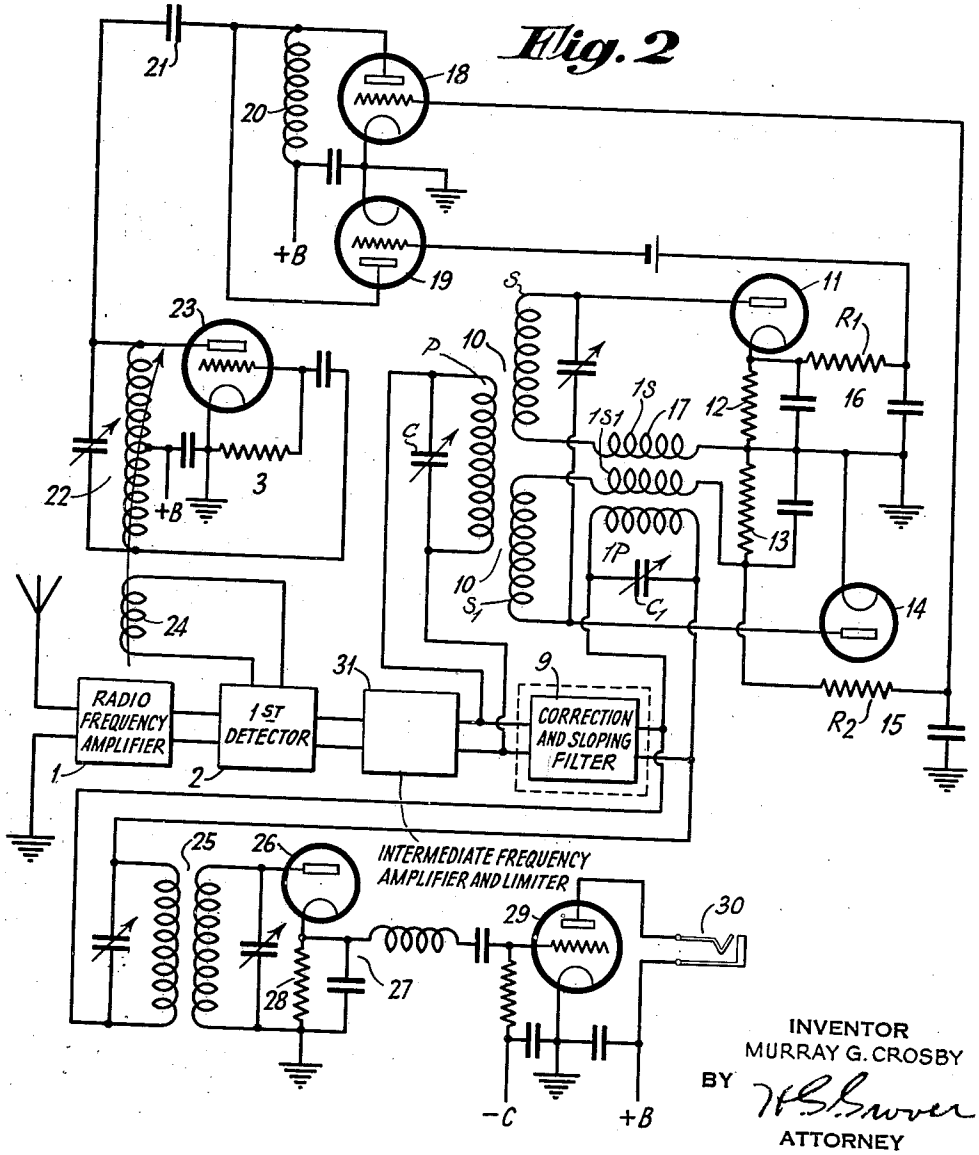


Fig. 2



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PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

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Fig. 3

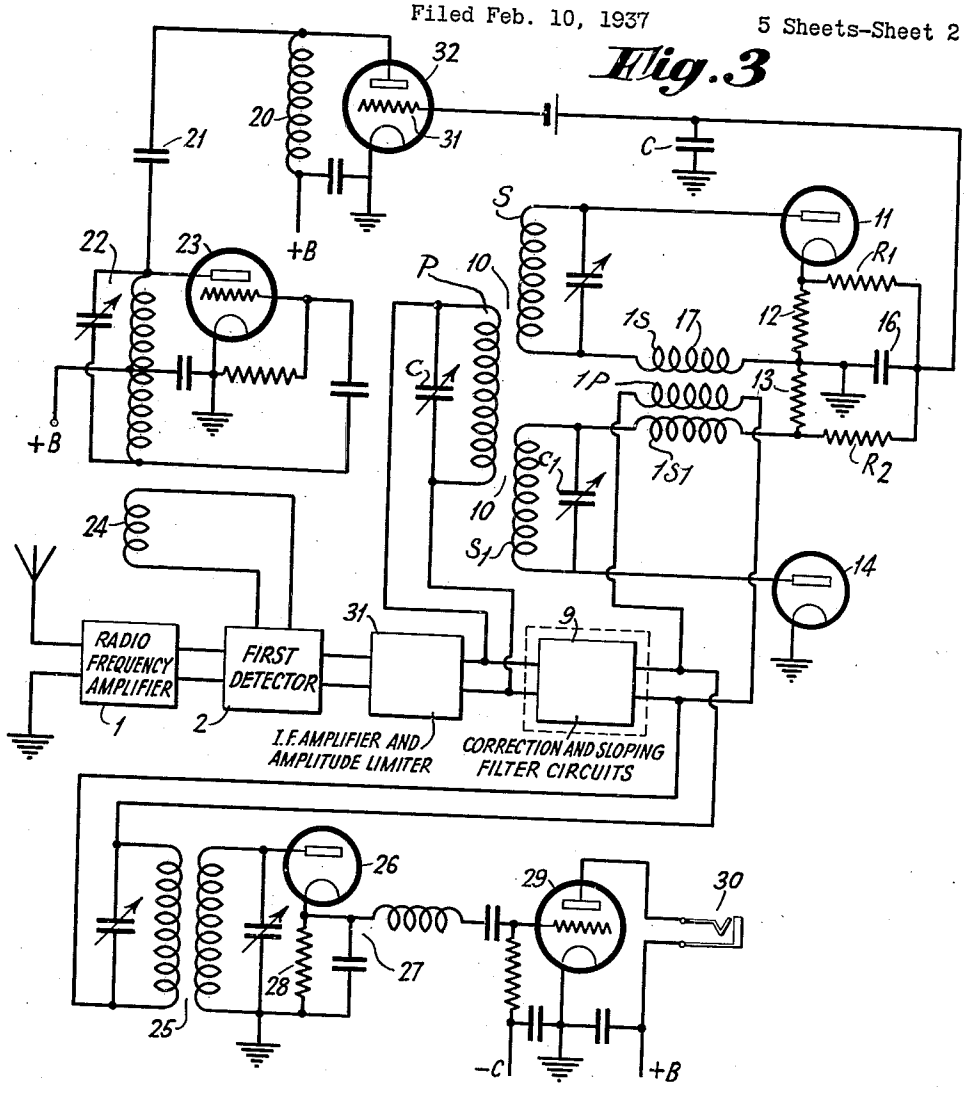
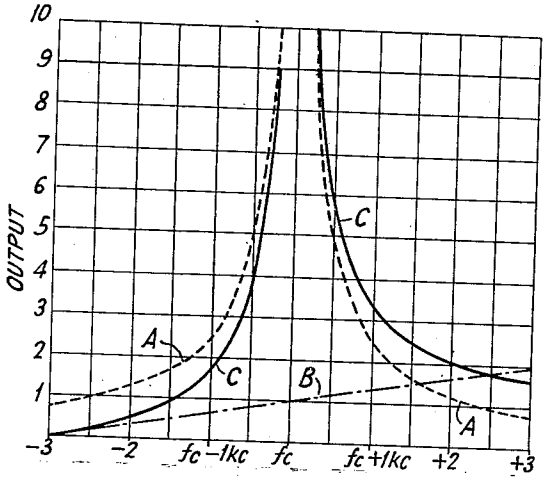


Fig. 4



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PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

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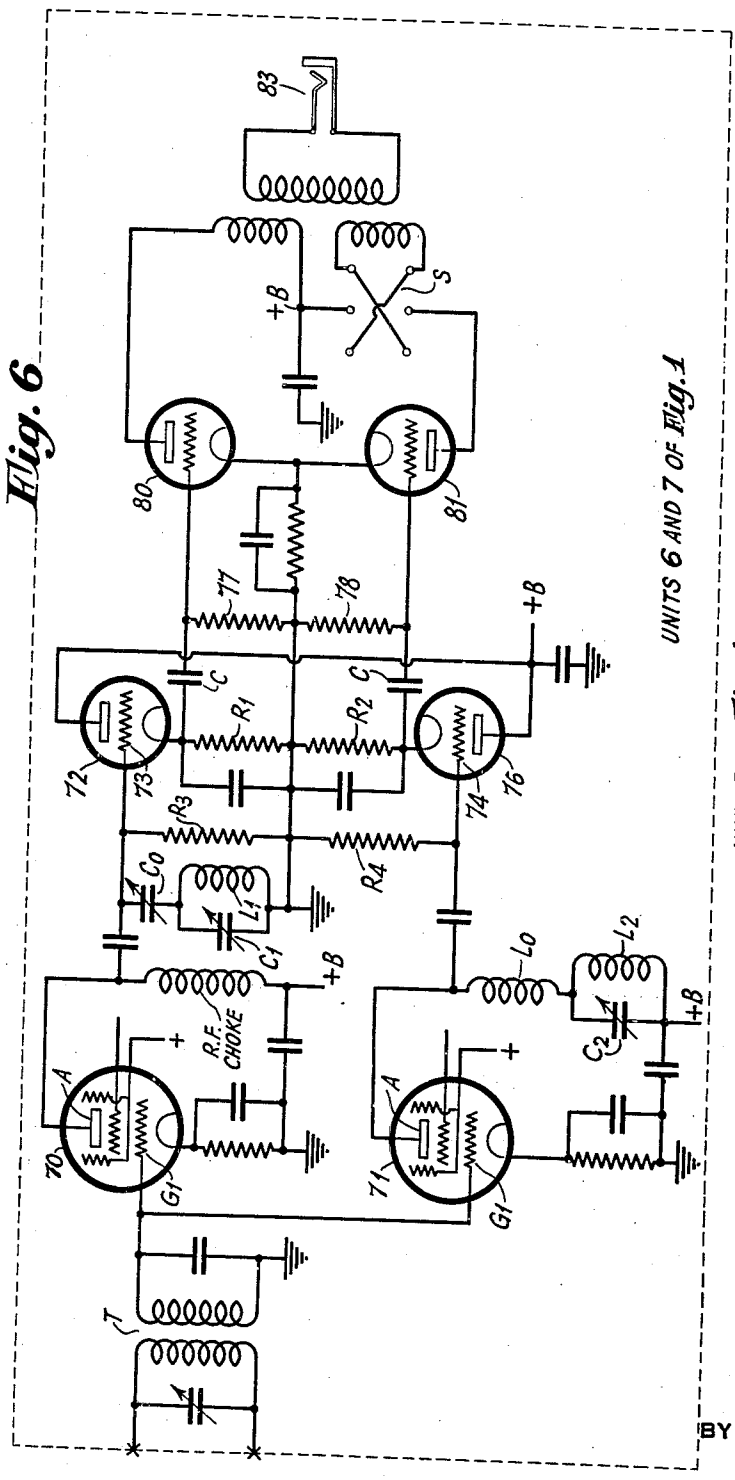


Fig. 6

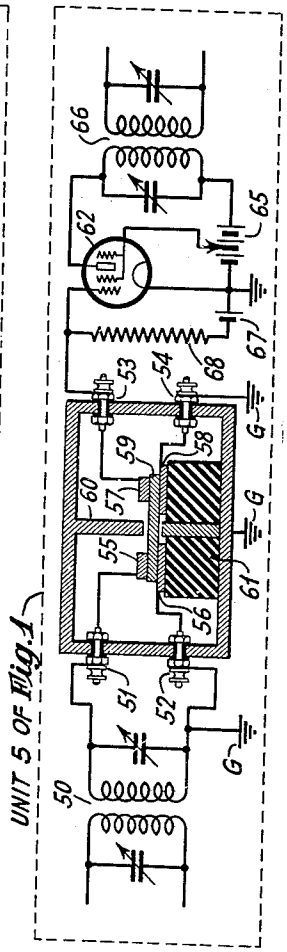


Fig. 5

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PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

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Fig. 7

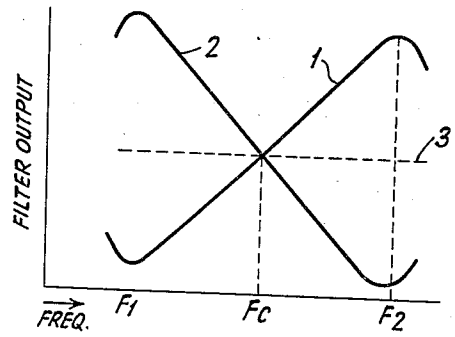


Fig. 8

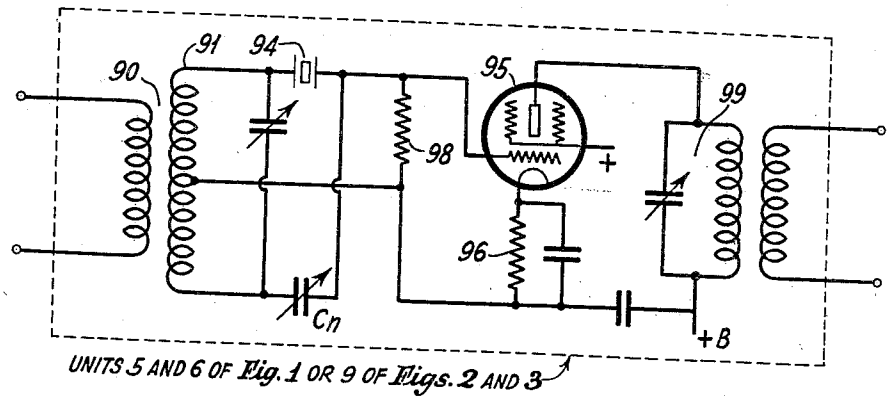
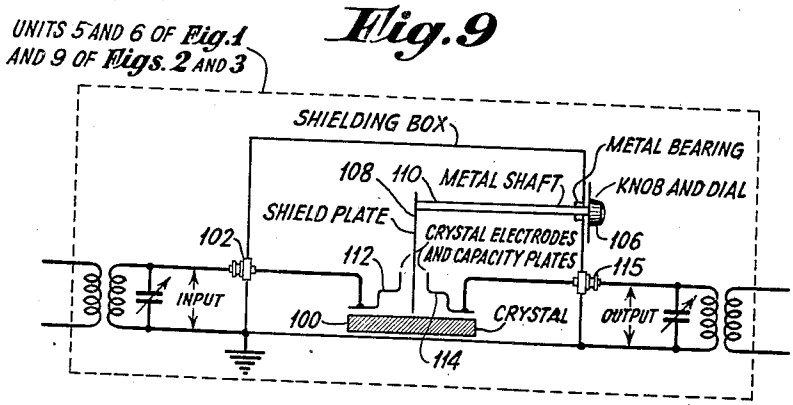


Fig. 9



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PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

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Fig. 11a

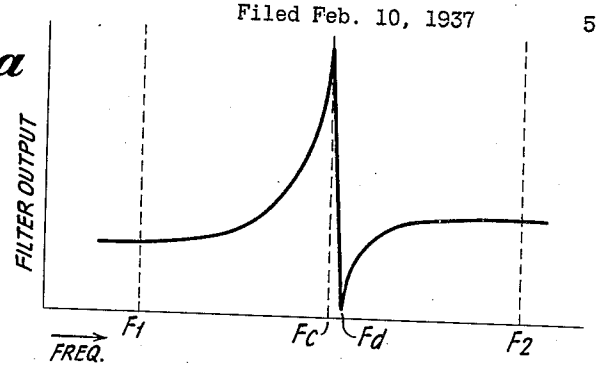


Fig. 11b

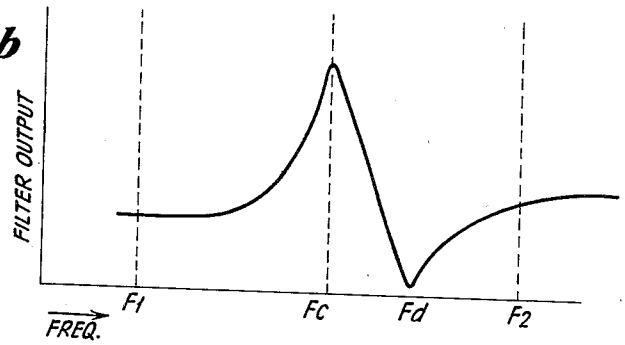


Fig. 11c

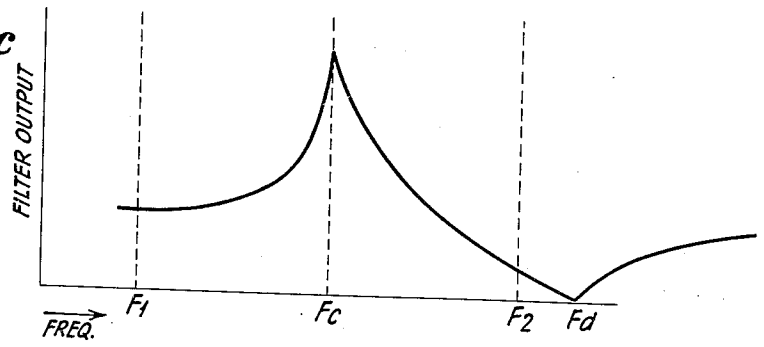
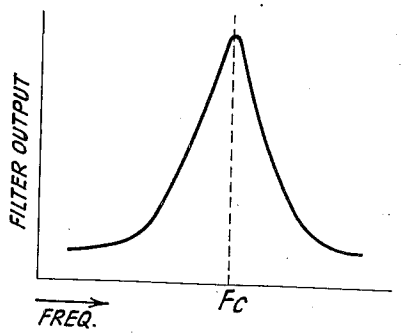


Fig. 10



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Patented July 9, 1940

2,207,691

UNITED STATES PATENT OFFICE

2,207,691

PHASE MODULATION RECEIVER AND AUTOMATIC FREQUENCY CONTROL

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

Application February 10, 1937, Serial No. 124,967

13 Claims. (Cl. 250—20)

The present invention concerns a novel method of and means for demodulating wave energy modulated in phase at signal frequency and a novel method of and means for producing differential potentials characteristic of the deviation of the mean frequency of the received wave energy from its assigned frequency and utilizing said potential to correct for said deviation.

This disclosure describes a phase modulated wave receiver of the type wherein to receive phase modulation a frequency modulation receiver is used in conjunction with a correction circuit which converts the frequency modulation receiver output into a phase modulation output. Intead of the usual audio or modulation frequency correction circuit used for this purpose, an intermediate frequency correction circuit is employed in the present system so that the phase modulation on the wave is corrected to frequency modulation before being impressed on the frequency modulation receiver portion of the system.

In the prior art, a receiver of the nature of the type herein disclosed consisted of a frequency modulation receiver with an audio frequency correction circuit inserted in the receiver output leads. Crosby United States application #618,154 filed June 20, 1932, describes such a frequency modulation receiver for reception of phase modulations. Owing to the inherent difference between frequency and phase modulation, if phase modulation is received on a frequency modulation receiver without the aid of a correction circuit, the receiver output is distorted in the respect that the output is directly proportional to the frequency of modulation. Thus, a 100 cycle modulation would have an output of one, 200 cycles an output of two, and so on. That this is true is shown in the following analysis:

It is well known that the expression for a phase modulated wave is given by

$$e=E \sin (wt+\phi \sin pt) \qquad (1)$$

where w is $2\pi\times$ carrier frequency, f_c; ϕ is the phase deviatic ı with modulation, and $p=2\pi\times$ the modulation frequency f_m. The frequency of the w ,ve of Equation 1 is given by its rate of change of phase or

$$\frac{d(wt+\phi \sin pt)}{dt}=2\pi(f_c+f_m\phi \cos pt) \qquad (2)$$

$$f(\text{cycles})=f_c+f_m \phi \cos pt \qquad (3)$$

From (3) it can be seen that the effective frequency deviation of a phase modulated wave is directly proportional to ϕ and f_m. Consequently, the output of a frequency modulation receiver, receiving phase modulation, would be directly proportional to the modulation frequency f_m, in addition to the depth of modulation ϕ. Therefore, in order to remove this distortion so that the receiver reproduces all modulation frequencies with the same amplitude, a correction circuit must be inserted which applies a correction inversely proportional to the modulation frequency. In the receiver of Crosby United States application #618,154 filed June 20, 1932, this correction was applied in the output audio frequency circuits.

In the receiver of the present disclosure, the correction is applied to the modulated wave in such a manner that the side bands on both sides of the carrier are attenuated an amount directly proportional to their frequency spacing from the carrier. In this manner, the depth of phase modulation on the wave is made inversely proportional to the modulation frequency. Consequently, the directly-proportional-to-frequency output, produced by the reception of phase modulation on a frequency modulation receiver is compensated for. This type of correction will not be bothered by the distortion which is encountered in the audio corrected back-to-back type of phase modulation receiver. In receivers of the audio corrected back-to-back phase modulation type, reception is marred by distortion similar to that effected by carrier fading on amplitude modulation and to about the same extent as the distortion normally encountered on amplitude modulation. In the present receiver wherein correction is accomplished in the intermediate frequency circuits of the receiver, an exhaulted carrier effect is obtained. This eliminates the fading distortion which is encountered with the audio corrected type of receiver. The receiver of the present invention in this respect acts somewhat like a Stenode Radiostat except that in the present case no correction of the audio frequency potentials in the output circuit is required as in the case of the Stenode. For an example of a receiver of the type wherein the side band attenuating effect is compensated for by an audio frequency voltage or potential correcting network see Robinson United States Patent #1,821,032, dated September 1, 1931.

A second novel feature of the present invention resides in the use of diode detectors for producing differential currents for automatic frequency control purposes. Heretofore, the potential drop across resistances connecting the anodes of a pair of differential detectors in push-pull

relation has been used to control the frequency of the local oscillator beating with incoming frequency or phase modulated wave energy to produce intermediate frequency energy which is in turn fed in phase and in phase opposition to control electrodes of the detectors. Such a system has been described in my United States application #616,803 filed June 13, 1932, now Patent #2,065,565. In the present system, the detector inputs are energized in a manner similar to the prior system but the present system differs from the prior system in that diode detectors are used and are used in a novel manner to give the differential potentials necessary for frequency control purposes. The cathode of one diode rectifier is grounded through a resistance, while the cathode of a second diode rectifier is connected directly to ground. The anode of the first diode is connected to ground by an alternating current circuit. The anode of the second diode is connected through an alternating current input circuit and a second resistance to ground. The ground connections are optional, the essentiaal feature being relatively fixed potentials at particular points in the circuit. Both resistances are in series with an input and output circuit so that opposing potentials appear at the terminals of the resistances remote from ground or cathode or point of fixed modulation and radio frequency potential and the state of equality of these opposing potentials indicates the correctness of tune of the received wave with respect to the intermediate frequency channel. Obviously the ground connections are not necessary, the essential feature being the providing for use of opposed potentials at the impedances.

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

Figure 1 illustrates schematically and by rectangles the essential units or elements of a phase modulation wave receiver arranged in accordance with the present invention;

Figure 2 illustrates somewhat more completely the receiver of the present invention and in addition illustrates a novel diode rectifier system and its association with a local oscillator for beating with the received wave, this being an additional novel feature of applicant's invention;

Figure 3 illustrates a modified form of differential diode detectors utilized for producing control potentials to tune the local oscillator;

Figure 4 illustrates by curves and graphs the characteristics which the correction filter and sloping filter and a combined filter having the characteristics of both filters used in the prior figures must have;

Figure 5 illustrates a highly selective filter utilized in the prior figures to attenuate the remote side frequencies to thereby convert phase modulation to frequency modulation;

Figure 6 illustrates one type of filter circuit having a sloping characteristic for converting frequency modulations on the intermediate frequency wave to amplitude modulations and includes also demodulating means;

Figure 7 illustrates graphically the character of the sloping filters of Figure 6 and their relationship which produces the demodulation of the converted phase modulations produced in 5 and compensation of amplitude changes caused by static or other undesired signals;

Figures 8 and 9 illustrate filters of the neutralized type which may be adjusted for a small degree of off-neutralization to produce the combined effect of a highly selective filter and a sloping filter; while

Figures 10, 11*a*, 11*b*, and 11*c* are curves illustrating the characteristics of the filter circuits of Figures 8 and 9 as used in my novel receivers.

The circuit of Figure 1 shows a block diagram of the essential elements of the receiver. Units **1**, **2**, **3**, and **4** are the elements of a superheterodyne receiver which, although it is not an absolute necessity for this receiver, facilitates the design of the correction filter of unit **5**. This filter takes the form of a sharply tuned circuit which is sharp enough to "cut side-bands." It may be a tuned amplifier with or without the application of a negative resistance effect or, more commodiously, it may be a crystal filter such as is shown in Figure 5, which will be described hereinafter. I may also use the filter of Figure 8 when the same is completely neutralized. After the phase modulated intermediate frequency energy is passed through the correction circuit of unit **5**, where, by virtue of the decrease in depth of modulation of the higher modulation frequencies, it is converted to a frequency modulation, accompanied by relative exhaltation of the carrier wave, it is passed to the sloping filter of unit **6**. This sloping filter is of the normal frequency modulation receiver type which has a minimum output at one edge of the band and increases linearly with respect to frequency change to a maximum at the other edge of the band. A simple off-resonate tuned circuit will suffice here. Due to the slope of this filter, the frequency change is converted to an amplitude change so that the energy fed to detector and audio frequency amplifier unit **7** is amplitude modulation which is detected in the conventional way. The output of the receiver is taken from phones or other utilization device **8**. Thus, the energy has been heterodyned, converted to frequency modulation, converted to amplitude modulation, and then detected. In a preferred embodiment, the sloping filter of unit **6** and demodulator of unit **7** are combined as shown in Figure 6.

On the curve sheet of Figure 4, the dotted line curve A shows the required correction characteristic which would correct phase modulation to frequency modulation for the speech band of audio frequencies, 250 to 3000 cycles. The speech band was chosen for simplicity; any other band, such as the program band from 40 to 15000 cycles, might be used. This curve was plotted by plotting the output of each side-band frequency so that its output is inversely proportional to its frequency spacing from the carrier f_c. The dot-dash line B of Figure 4 is the sloping filter characteristic of an ideal frequency modulation receiver for the speech band.

Since the correction filter and the sloping filter are in cascade, the overall characteristic from input terminals of the correction filter to output terminals of the sloping filter will be the product of the two filter characteristics such as is shown by the full line C of Figure 4. Hence, the correction and sloping filters may be replaced as illustrated in Figure 2 by a single filter which has a characteristic as shown by C of Figure 4. Such a characteristic is fairly easy to obtain. A crystal filter of the neutralized type may be adjusted to this characteristic by adjusting the neutralizing condensers for a small degree of off-neutralization. Such a filter circuit has been

shown in Figures 4 and 6 of my United States application #47,933 filed October 5, 1936, now Patent #2,085,008 and in Figure 8 of the present disclosure. The sharply tuned shielded crystal filter of Figure 7 of Crosby United States application #616,803 filed June 13, 1932, now Patent #2,065,565 may also be adapted by varying the completeness of shielding. Of course, the filter of Figure 8 of the present application may be used when the same is off-neutralized. A tuned circuit filter may be given this characteristic by choosing tuning elements whose effective resistance varies with frequency.

The circuit of Figure 2 shows a more complete circuit arrangement of this type of intermediate frequency corrected receiver and frequency control means. In this circuit any wave energy pick-up means supplies phase modulated wave energy to a radio frequency amplifier 1 coupled at its output to a detector 2 which is supplied by oscillatory energy from oscillator 3 by a pick-up means 24 coupled to an oscillator circuit 22. The beat frequency output from 2 is supplied to an intermediate frequency amplifier and amplitude limiter 31. Automatic tuning control is applied to the receiver in order to hold the receiver in tune with the sharp correction filter in unit 9. The output of 31 is fed in phase opposition to the automatic frequency control diode detectors 11 and 14 via transformer 10, and also to the combined or separate correction and sloping filters in unit 9. The output of unit 9 is fed in phase to the automatic frequency control detectors 11 and 14 via transformer 17. More in detail intermediate frequency energy modulated in phase is impressed on the primary winding P of transformer 10 which is tuned to substantially the mean frequency of the said energy by means of the condenser C. This energy is induced in the two secondary windings S and S1 and applied to the anodes of diode detectors 11 and 14 respectively. Corrected and filtered energy is impressed from the output of 9 on the primary winding 1P of transformer 17 which primary is tuned by the condenser C1 to substantially the mean frequency of the energy passed by 9. Voltage is induced from primary winding 1P on secondary windings 1S and 1S1 and supplied therefrom to the anodes of diode detectors 11 and 14, respectively. The adjustments of these circuits are such that the voltages supplied from 31 and 9 to the respective rectifiers are in phase displaced relation. As an example, if the voltages supplied by S and S1 are in phase opposition on the anodes of 11 and 14, the voltages supplied by 1S and 1S1 may be displaced in phase by similar amounts with respect to the aforesaid voltages supplied by S1 and S. Obviously each detector is, due to these two phase displaced voltages, supplied with a resultant, the amplitude of which changes when the phases of one or both of the supplied voltages changes. The variations in the resultants are detected in 11 and 14 and appear in 12 and 13. The automatic frequency control controlling energy is fed from points on resistance R_1 R_2 to modulator tubes 18 and 19 via time constant circuits 15 and 16. Since resistor 12 is in the cathode circuit of rectifier 11 and resistor 13 is on the low potential side of the secondary windings of the transformers 10 and 17, the potential drop due to rectified direct current in 12 will be of opposite polarity with respect to the potential drop in 13. That is, an increase of alternating current voltage to the input of diode 11 will cause resistor 12 to pass a positive voltage through R_1 to the control electrode of modulator 18, while an increase in alternating current voltage to the input of diode 14 will cause 13 to pass a negative voltage through R_2 to the control electrode of modulator 19. Consequently, as the combination of the filtered and unfiltered voltages, in transformers 10 and 17, produce a high resultant voltage to one diode and a low resultant voltage to the other diode (by virtue of any off-tune condition which causes the intermediate frequency not to equal the mean frequency to which 31 is tuned) according to the principles described in Crosby United States application #616,803 filed June 13, 1932, now Patent #2,065,565, one diode will bias its modulator 18 or 19 more negative and the other diode will bias its modulator 19 or 18 less positive. In this way, the resultant effect of the two diodes 11 and 14 is in the same direction so that both modulator tubes are biased in the same direction for a given unbalance of alternating current voltages to the diodes due to an off tune condition. When the grid biases of modulator tubes 18 and 19 are varied, in a direction determined by the direction of deviation of the wave frequency from the desired wave frequency, by the automatic frequency control detector energy passed by time control circuits 15 and 16, the plate resistances of the modulator tubes 18 and 19 vary. These plate resistances are in series with capacity 21 which is placed across the tuned circuit 22 of high frequency oscillator 23. Plate potential for both modulator tubes 18 and 19 is supplied by a source of direct current +B through radio frequency choke 20. Hence, as the plate resistances of modulators 18 and 19 vary, the effective capacity of 21 is varied so that the tuning of the high frequency oscillator is varied. In this manner when the signal is off tune with respect to the intermediate frequency amplifier 31 and the correction filter in 9, the differential combination of alternating current voltages in transformers 10 and 17 causes the modulator tubes 18 and 19 to change the tuning of the high frequency oscillator 23 and bring the intermediate frequency energy back in tune with the intermediate frequency amplifier 31 and the correction filter 9.

The output of correction and sloping filter 9, which is phase modulation converted into amplitude modulation, is fed, via transformer 25, to diode 26 for rectification. Filter 27 removes the intermediate frequency energy from the output and makes the potential drop in 28 characteristic of the phase modulation on the received wave available for amplification in 29, the output of which is available at jack 30.

If desired, the automatic frequency control detector circuit of Figure 3 may be applied to this type of receiver. As will be seen this arrangement is similar in many respects to that shown in Figure 2. However, in Figure 3, the rectified voltages from the automatic frequency control detectors are combined to charge condenser C through resistors R_1 and R_2, the terminals of which are here connected together as shown. Thus, for the condition of balance, the positive voltage from one diode resistor neutralizes or compensates the negative voltage from the other diode resistor so that a mean nominal resulting potential is produced and condenser C is not charged. An unbalance of the detector currents, caused by an off-tune condition in the received wave or oscillator 23 or both, causes the charge of condenser C to be changed and the bias of the modulator tube 32 to be changed in a manner

to vary the effective capacity of condenser 21 in the proper direction to re-tune the circuit 22 and the entire receiver circuit. Due to the similarity between the remaining portions of Figures 2 and 3 and the use of like reference characters for similar parts, no further description of Figure 3 is necessary.

The highly selective filter circuit used in the correction filter unit 5 of Figure 1 and the correction circuit of combined unit 9 of Figures 2 and 3 may comprise any circuit having the desired characteristics. For example, the circuit of unit 5 may be of the crystal filter type as illustrated in Figure 5. In this arrangement wave energy of intermediate frequency from the intermediate frequency amplifier 4 of Figure 1 may be supplied to a transformer 50 having its secondary winding terminals connected to connectors 51 and 52 insulated from the shield and connected to a pair of plates 55 and 56 mounted adjacent a piezo-electric crystal element 59. Another pair of plates 57 and 58 are connected to contacts 53 and 54 insulated from the shield connected to the control grid and cathode respectively, of an amplifier or relay tube 62. The relay tube 62 is supplied with biasing potential by way of a resistance 68 and a source of potential 67 and with anode potential by way of a source 65 and the primary of an output transformer 66. The selected energy may be impressed from the secondary of transformer 66 on the input electrodes of the sloping filter circuit and from the output thereof in phase on the input electrodes of the diode detectors 11 and 14 and also on the input of the tube 26 supplying the signal potentials resulting from demodulation to the utilization circuit.

The sloping filter utilized in the unit 6 of Figure 1 or in the units 9 of Figures 2 and 3 may be of any type and may for example, be as illustrated in my United States applications #618,154 filed June 20, 1932 and #703,770 filed December 23, 1933, now Patent #2,060,611.

In the circuit of Figure 1, the sloping filter and detector units 6 and 7 preferably are replaced by a back-to-back frequency modulation detector. The circuit of Figure 6 shows such a detector unit. The intermediate frequency output is fed from the correction filter 5 of Figure 1 to the terminals XX of Figure 6. Coupling tubes 70 and 71 have sloping filter circuits $L_1C_1C_0$ and $L_2C_2L_0$, respectively, in their plate circuits. These filters produce characteristics such as shown by curves 1 and 2 of Figure 7. Multiple resonance is formed by the circuits so that for the case of the $L_1C_1C_0$ circuit a characteristic like curve 1 of Figure 7 is produced by virtue of a parallel resonance at frequency F_2 and series resonance at frequency F_1. That is $L_1C_1C_0$ is adjusted to parallel resonance at a frequency F_2 which is above the mean frequency of the wave to which the transformer T is tuned and series-resonant at the frequency F_1 which is below the mean frequency to which the transformer T is tuned, the latter frequency being represented by F_c in Fig. 7. Under these circumstances, a maximum voltage will be produced across R_3 when wave energy is impressed on the filter of a frequency of the order of F_2 and this voltage will decrease to a minimum as the said impressed frequency decreases to a frequency of the order of F_1. The filter $L_2C_2L_0$ is series-resonant at the frequency F_2 and parallel-resonant at the frequency F_1 so that it has a characteristic similar to but opposed to the filter $L_1C_1C_0$. The characteristic of the filter $L_2C_2L_0$ is shown at 2 in Fig. 7. Filter $L_2C_2L_0$ produces the opposite slope shown by curve 2 by interchanging the points of parallel and series resonance.

As shown in Figure 6 the wave energy to be converted may be impressed on the input of radio frequency transformer T and from the input of T in phase on the control grids G_1 of tubes 70 and 71. These tubes may be of the suppressor grid type or of any other type, having the desired characteristics. The anodes A of tubes 70 and 71 are connected as shown with the filter circuits of sloping characteristics. The circuit C_0, C_1 etc., is connected at the high potential end of the radio frequency choke connected with 70, while the circuit L_0L_2 etc., is connected directly to the anode A of tube 71. The high potential ends of the series circuits C_0 etc., L_0 etc., are connected as shown to the control grids 73 and 74 of a pair of detectors 72 and 76 operating as diodes. The anodes of tubes 72 and 76 are connected to a source of potential, while the cathodes are connected together and/or to ground by high impedances R_1 and R_2. Coupling condensers C connect the high potential ends of the impedances R_1 and R_2 to the control grids of amplifying tubes 80 and 81, the anodes of which are coupled in parallel or in push-pull by switch S and to an output circuit 83. Self-bias operation is obtained in tubes 80 and 81 by connecting the cathodes thereof to the grids by way of resistances 77 and 78. The series circuits C_0 etc., L_0 etc., are shunted as shown by high impedances R_3 and R_4.

The detectors of this circuit, tubes 72 and 76, are of the infinite-impedance diode type. This type of detector is used in order to obtain a linear detector that does not place a low resistance load on the filter circuits and thereby cause their slope to be decreased. The detected outputs from the detectors are taken from the cathode resistors and coupled to the grids of amplifier tubes 80 and 81. The transformer in the plate circuits of tubes 80 and 81 may be switched by S to either the parallel or push-pull connection so that amplitude modulation may be received (by the parallel connection) as well as phase and frequency modulation (by the push-pull connection). If amplitude modulation were received, the correction filter would be switched out of the receiver. In accordance with the principles described in my United States application #114,894 filed Dec. 9, 1936, now Patent #2,154,398, either of the sloping filters might be replaced by a flat-top impedance coupling giving a characteristic as is shown by the dotted curve 3 of Figure 7. This could be done, for instance, by eliminating the inductance L_0 and making the grid resistance of tube 76 low enough to damp the tuned circuit L_2C_2 to make it a broad impedance coupling.

Of course, the two filters of Figure 6 may, if desired, be replaced by a simple resonant circuit tuned to resonance at one side of the mean carrier frequency so that it is operating on the slope of its resonant curve. This circuit may be followed by a simple amplitude modulation detector such as that shown at 26 in Figure 3.

As an alternative I may replace the units 5 and 6 of Figure 1 and the units 9 of Figures 2 and 3 by filter circuits as illustrated in Figures 8 and 9 which have the combined characteristics of the highly selective filter and sloping filter described in preceding paragraphs. This filter having the combined characteristics may comprise as illustrated in Figure 8 a piezo-electric crystal 94

connected as shown at one terminal with the secondary winding 91 of an input transformer 90 having its primary winding coupled with the output of the intermediate frequency amplifier 4 of Figure 1 or intermediate frequency amplifier and amplitude limiter 31 of Figures 2 and 3. The other terminal of the secondary winding is connected as shown by way of a neutralizing condenser C_n to the other terminal of the piezo-electric crystal 94. This terminal of the crystal is connected as shown to the control grid of a tube 95, the cathode of which is connected by a biasing resistance 96 to a leak resistance 96 and to a point on 91. The anode of tube 95 is connected to an output circuit 99 which may be coupled to 17 and 25 as shown in Figures 2 and 3, or to 7 as shown in Figure 1. The output of the crystal comprises the energy passed by the crystal and also any unneutralized energy passed by the crystal holder.

The energy at the output of the crystal may be impressed directly on the primary winding 1P of transformer 17, the in-phase secondaries 1S and 1S1 of which are connected with the diode detectors and on the input of the utilization circuit or may be impressed on the input electrodes of the amplifier 95 as shown and from the output electrodes of said tubes on the said windings of 17 and from thence to the diode detector system and impressed on 25 and from thence to a utilization circuit. The circuit of Figure 8 as to the crystal effect alone on the wave passed will have a characteristic as shown by curve A of Figure 4. As to the crystal and holder effect the circuit wil be resonant at one side of the carrier or crystal frequency as described herein later and will produce a resultant effect as illustrated by curve C.

The filter of Figure 9 which is in some respects similar to the filter of Figure 5 may also be used to obtain the side band attentuating and sloping filter effects. This filter comprises a shielding box enclosing a piezo-electric crystal 100, capacity members and crystal electrodes 112 and 114 mounted on opposite sides of a movable shield member 108 carried by a movable member 110. The movable member 110 is shown as a shaft mounted for rotation and controlled by a member 106. The input to the filter is between a connection through an insulating member 102 and the shield while the output is between 115 and the shield. More specifically, energy to be filtered is supplied by a tuned circuit to a conductor passing through the shield and insulated therefrom by insulator 102 and a point of ground or shield potential the said conductor and ground point in turn being connected to crystal electrodes as shown. The output from the filter is taken from a second pair of electrodes as shown connected to a contact passing through the shield box and insulated therefrom by insulator 115 and to the shield

The position of the shielding member 108 with respect to the capacity members 112 and 114 determines the shielding between the crystal output and input and consequently the neutralization of the circuit.

I will now describe the two circuits of Figures 8 and 9 which are suitable for the functions of either attenuating the side bands alone or for attenuating the side bands as well as producing a sloping filter. The first of these is the neutralized crystal filter circuit of Figure 8 of this disclosure. When the neutralizing condenser, C_n, of this circuit is adjusted for complete neutralization so that the characteristic of Figure 10 is obtained, the conditions are proper for the attenuation of the side bands alone. This adjustment of the filter will attenuate the side bands so that the phase modulation is corrected to frequency modulation for subsequent conversion to amplitude modulation by a sloping filter following this crystal filter. Without neutralization, or with over-neutralization, a characteristic such as is shown in Figure 11*a* will be obtained. However, as the neutralizaton is made more complete, the dip point F_d in the characteristic of Figure 11*a* is moved farther away from the carrier frequency, F_c as shown in Figures 11*b* and 11*c*. Thus, this dip point may be set outside of the side band channel by an adjustment of the neutralizing condenser. Consequently, a filter may be effected with one side dipped slightly so that it is lower than the other as shown in Figure 4, curve C. In this way a slightly-neutralized crystal filter acts as a combined correcting filter and sloping filter to convert phase modulation directly into amplitude modulation for detection.

The device of the attached Figure 9 is a crystal filter of the shielded type which may be adjusted to the same type of characteristics as the slightly-neutralized type. The shielding takes the place of the neutralization. Hence by varying the shielding, the effect is the same as though the neutralization were varied. That is, the shielded crystal holder of Figure 9 has a grounded shield plate 108 between the crystal electrodes and is carefully constructed so that the capacity of the crystal holder may be completely shielded out. In order to make possible a variability of the shielding effect, the metal shield plate 108 placed between the crystal electrodes is mounted on a rotatable shaft 110 so that the plate may be moved out from between the electrodes 112 and 114. The electrodes are bent to such a shape that a relatively large amount of capacity will be obtained between the crystal electrodes when the shield plate is removed: this insures that a capacity will be present to cause under-neutralization when the shield plate is moved away. Thus by rotating the knob 106 on the shaft where the shield plate is mounted, the crystal filter characteristic may be changed from the completely shielded or neutralized characteristic of Figure 10 to the slightly-neutralized type of characteristic similar to Figure 11*c* but with the dip outside of the side band channel. Consequently this type of filter is also capable of the adjustment which produces either the single function of attenuating the side bands or the dual function of attenuating the side bands and effecting the sloping filter.

In order to clearly disclose the operation of filters 8 and 9 further description of what takes place when the crystal filter is off-neutralized or off-shielded will be given. Reference will be made to Figures 11*a*, 11*b*, and 11*c* which helps to explain the operation of the filters. The curve of Figure 11*a* shows the characteristic of a crystal filter which is un-neutralized. Inspection of this curve shows that at the series resonance frequency of the crystal a high output is obtained at the carrier frequency, F_c. At the parallel resonance frequency obtained by the inductive effect of the crystal and the capacity of the crystal holder, the filter output has a dip at the frequency F_d. This dip point in the characteristic may be moved farther away from the carrier frequency F_c as shown in the curve of Figure 11*b*, by increasing the neutralizing condenser C_n of Figure 8 towards

the completely neutralized point, or by moving the shielding member 108 of Figure 9 towards the completely shielded point. By a further increase in the degree of neutralization or shielding, the dip point F_d may be moved completely out of the working channel (the working channel is between the frequencies F_1 and F_2) as is shown in the curve of Figure 11c. From a study of the curve of Figure 11c, it can be seen that the effect of placing this dip point F_d just outside of the working channel is to lower the output of the filter on one side of the carrier frequency with respect to the output on the other side of the carrier frequency. Consequently the desired characteristic of curve C of Figure 4 is obtained.

The sloping filters and detector units of Figure 1 may be replaced by any type of frequency modulation receiver such as the ones described in Crosby United States applications: #618,154, filed June 20, 1932; #703,770, filed December 23, 1933, now Patent #2,060,611, issued Nov. 10, 1936; #114,894, filed December 9, 1936, Patent #2,154,398, issued April 11, 1939. In this manner, the back-to-back balance effect of the frequency modulation reception could be obtained.

The filters of Figures 8 and 9 may be used in the unit 5 of Figure 1 in place of the filter of Figure 5 in which case they are completely neutralized or shielded to have a characteristic as illustrated in Figure 10.

In any of these receivers, the amplitude limiting may be applied to either the uncorrected or the corrected (corrected from phase to frequency modulation) energy, since both frequency and phase modulation are unimpaired by limiting. In the case of separate correction (attenuation) and sloping filters, it might be more advantageous to limit after the correction in order to eliminate the amplitude modulation which would be caused by an unsymmetrical correction filter.

The type of automatic tuning or frequency control (AFC) which is applied may be of the type wherein the differential detector energy operates a relay controlling a motor drive to rotate a tuning condenser as is described in Goddard United States application #11,915 filed March 20, 1935.

I claim:

1. In a modulated wave receiver, an amplitude modulated wave demodulator having an input circuit, circuits including a piezo-electric crystal forming a filter having a highly selective characteristic and a sloping characteristic, said filter having an input and an output, means for impressing modulated energy on the input of said filter, and means for applying modulated wave energy from the output of said filter on the input circuit of said demodulator.

2. In means for demodulating wave energy modulated in phase at signal frequency, a detector, a filter circuit having a highly selective characteristic and a sloping characteristic, said filter circuit having an input and having an output coupled to said detector, and means for impressing phase modulated wave energy on the input of said filter circuit.

3. The method of receiving and demodulating wave energy modulated in phase and comprising a carrier and side band frequencies which includes the steps of, attenuating side band frequencies remote from the carrier frequency to thereby distort the said phase modulations on said wave energy to obtain modulated wave energy which has the characteristics of frequency modulated wave energy, simultaneously converting said frequency-modulated wave energy into wave energy correspondingly modulated in amplitude and demodulating said amplitude modulated wave energy.

4. The method of demodulating wave energy modulated in phase and comprising a carrier and side band frequencies which includes the steps of, attenuating side band frequency remote from the carrier frequencies to thereby distort the said phase modulated energy so that it has the characteristics of frequency modulated energy, amplifying the resulting energy and imposing frequency discriminations on the amplified energy to convert said frequency modulation into amplitude modulation.

5. In a phase modulation receiver system, a tunable circuit including a tuning reactance and tuning means therefor, a phase modulated wave amplifier coupled to said tuning means, said wave amplifier having an output a highly selective filter circuit coupled to said wave amplifier output, said filter circuit having an output, a second filter circuit having a sloping characteristic coupled at its input to the output of said highly selective filter, said sloping filter circuit having an output, a utilization circuit coupled to the output of said sloping filter circuit and control means coupled between said tuning means and the output of said sloping filter and the output of said amplifier.

6. In a receiving system, a wave amplifier having a tunable circuit, said amplifier having an input on which wave energy may be impressed and having an output from which amplified wave energy may be derived, a pair of diode detectors each having an anode and a cathode, an alternating current circuit and a high impedance connected between the anode and cathode of one of said diode detectors, a connection between a point on said high impedance remote from the cathode of said diode detector and ground, an alternating current circuit including a high impedance connected betwen the anode and cathode of the other of said diode detectors, a connection between the cathode of said last named diode detector and ground, circuits coupling said alternating current circuits to the output of said amplifier, additional impedances connected in shunt to said high impedances, a coupling tube having an anode, a cathode, and a control grid, a circuit connecting the anode of said coupling tube to said tunable circuit, a circuit coupling the control grid of said coupling tube to a point on said additional impedances, and a connection between the cathode of said coupling tube and ground.

7. In a wave energy demodulating means, a source of wave energy having an output, a load circuit having an input, wave filtering means having a selective and sloping characteristic coupled at its input to the output of said source of wave energy, said wave filtering means having an output and means for rectifying the output of said filter and impressing the rectified energy on the input of said load circuit without materially loading said filter comprising a detector tube having an anode, a grid, and a cathode, an impedance connected between said cathode and a point of fixed potential, means for maintaining said anode at a fixed positive potential relative to said point of fixed potential, a circuit coupling said grid and point of fixed potential to the output of said filter, said detector tube being of very high input impedance, and a circuit connecting said load circuit input in shunt to said impedance.

8. In a system for demodulating wave energy modulated in phase at signal frequency, means for attenuating the side frequencies of said wave

energy to distort the phase modulated wave so that it has characteristics of frequency modulated wave energy, a pair of reactive circuits, means for tuning one of said reactive circuits to resonance at a frequency below the mean frequency of said distorted wave energy, means for tuning the other of said reactive circuits to resonance at a frequency above the mean frequency of said distorted wave energy, means for impressing the wave energy on said reactive circuits, a pair of detectors of substantial infinite impedance each having input and output electrodes, means connecting the input electrodes of each of said detectors to the output of one of said filters whereby said input electrodes are excited by energy from the output of said filters, and a load circuit connected to the output of said detectors.

9. In a system for demodulating wave energy modulated in phase and frequency, a pair of filters having opposed sloping characteristics, means for impressing wave energy on the inputs of said filters, and a pair of detectors of very high impedance connecting the outputs of said filters differentially, the very high impedance of said detectors placing minimum loading effect on the outputs of said filters.

10. In a system for demodulating wave energy modulated in phase or infrequency, a pair of filters of the sloping characteristic type connected back-to-back, means for impressing wave energy in phase on the inputs of said filters, a utilization circuit, and a pair of detectors of infinite impedance connecting the outputs of said filters differentially and coupling the same to said utilization circuit, the infinite impedance of said detectors placing minimum load on said filters.

11. In a system for demodulating wave energy modulated in phase at signal frequency, a filter network including a piezo-electric crystal in a holder with means to partially compensate for the capacity of the holder, said network having a highly selective characteristic such that it attenuates the side frequencies of phase modulated wave energy of the proper mean frequency, and a sloping characteristic, a linear detector having an input coupled to said filter network and an output coupled to a load, and means for impressing phase modulated wave energy of said proper mean frequency on said network.

12. Means for converting frequency modulations of wave energy of a particular mean frequency into corresponding amplitude modulations on wave energy of said particular mean frequency comprising, a filter circuit having an input and an output, and having a sloping characteristic such that the voltage at the output thereof varies in amplitude in opposite directions from a selected amplitude as the frequency of wave energy impressed on the input thereof varies about said particular mean frequency, means for impressing frequency modulated wave energy of said particular mean frequency on the input of said filter, a detector of high impedance to the output of all frequencies coupled to said filter, and a circuit responsive to variations of modulation frequency connected to said detector.

13. In a system for demodulating wave energy modulated in phase at signal frequency, means for attenuating the side frequencies of said wave energy to distort the modulated wave so that it has characteristics of frequency modulated wave energy, a pair of reactive circuits, means for tuning one of said reactive circuits to parallel resonance at a frequency above the mean frequency of said distorted wave energy, means for tuning the other of said reactive circuits to parallel resonance at a frequency below the mean frequency of said distorted wave energy, means for tuning said one of said circuits to series resonance at a frequency below the mean frequency of said distorted wave energy, means for tuning said other of said reactive circuits to series resonance at a frequency above the mean frequency of said distorted wave energy, means for impressing the wave energy on said reactive circuits, a pair of detectors of substantial infinite impedance each having input and output electrodes, means connecting the input electrodes of each of said detectors to the output of one of said filters whereby said input electrodes are excited by energy from the output of said filters, and a load circuit connected to the output of said detectors.

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