

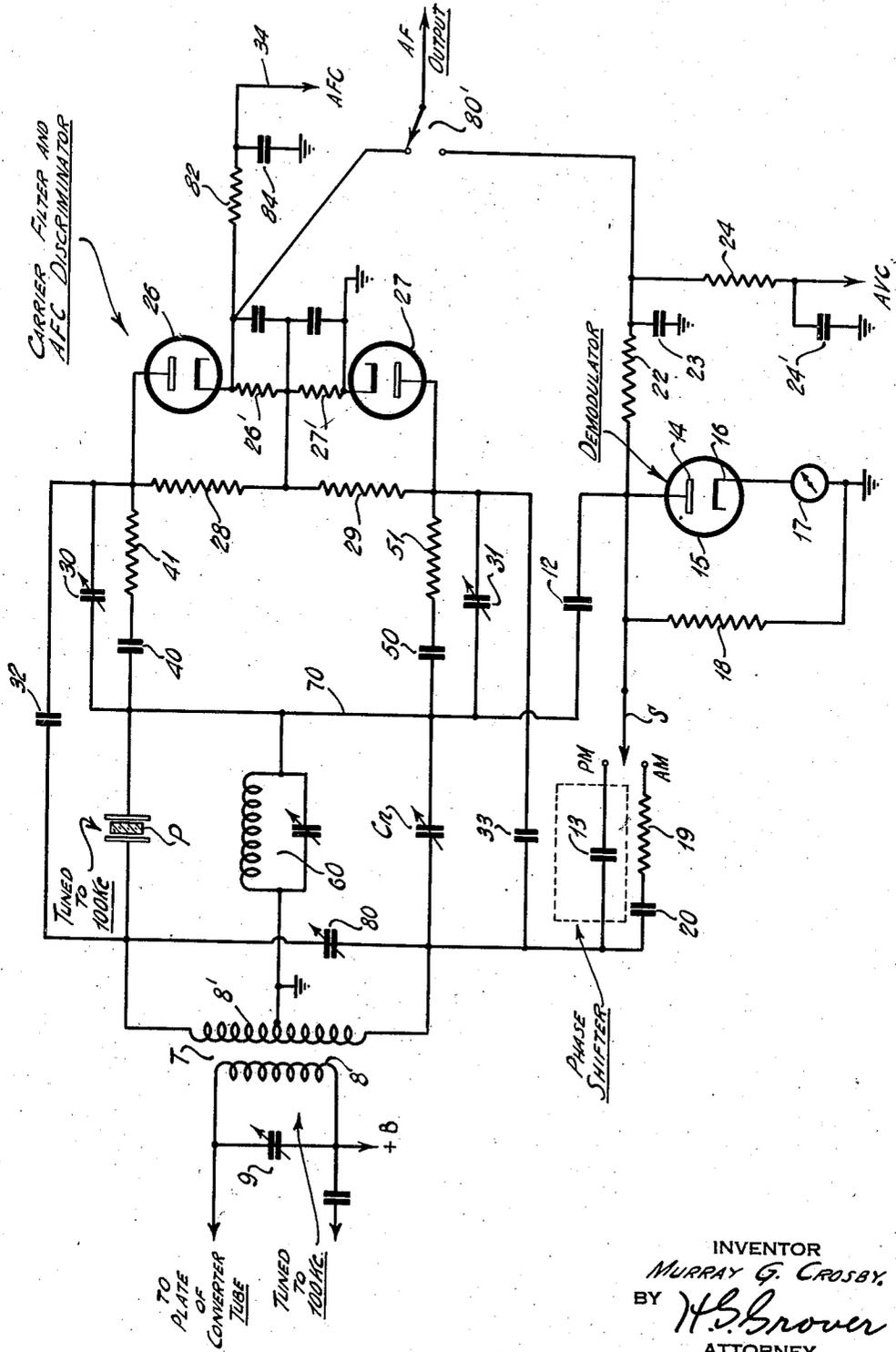
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CARRIER-EXALTED RECEIVER

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CARRIER-EXALTED RECEIVER

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1

My present invention generally relates to carrier-exalted receivers, and more particularly to a system for receiving phase modulated (PM), or amplitude modulated (AM) carrier waves with carrier exaltation.

Carrier-exalted reception should come into more and more general use in all wave bands in which multi-path fading distortion is encountered. This includes the present AM broadcast band of 550 to 1600 kilocycles (kc.) in which fading distortion is experienced in a region about 50 to 100 miles from the transmitter due to interference between the sky wave and the ground wave. Such fading causes a cancellation of the carrier frequency, leaving the sidebands to beat together and cause unintelligible distortion. This distortion is severe, and is responsible for the "fading wall" which limits the night-time coverage of a broadcast station in the 550 to 1600 kilocycle band. Carrier-exalted reception is very effective in removing this distortion.

Another wave band affected by multi-path distortion is the band from 1.5 to about 25 megacycles (mc.). This band is used for point-to-point communication, or for short-wave broadcasting. The multiplicity of paths is caused by unequal numbers of ricochets of the signal between the ionosphere and the earth. The distortion that results is the same type that is experienced in AM broadcast reception, except that it is present at all times instead of just at night. Hence carrier exaltation is even more important in this band.

When carrier exaltation is applied to certain known forms of AM receiver circuits, it is a simple matter to convert them to phase modulation reception by inserting a 90° phase shifter either in an unfiltered signal energy circuit or in a filtered carrier circuit. Phase modulation then becomes the most economical transmission to use because of its advantages at the transmitter. Carrier-exalted reception is especially advantageous in plane-to-ground communication where the band from 1.5 to 20 megacycles is used, and where the decreased weight of a phase modulation transmitter relative to other types of transmitters is of importance. In addition, the elimination of the carrier-fading distortion would be realized. It has been found that in the presence of strong noise, use of carrier exaltation gives improved reception. This improvement is apparently due to the elimination, brought about by the carrier exaltation, of the beats which otherwise occur between the individual noise components. In particular, carrier-exalted reception

2

gives an improved signal-to-noise ratio in the presence of strong man-made noise of the impulse type. In the case of this type of noise carrier-exalted reception appears to provide an elimination of low-frequency noise components, which improves the overall character of reception.

In my Patent No. 2,397,840 dated April 2, 1946, I have disclosed a novel detection network for PM, or AM, wave energy. The detection network utilizes a piezo-electric crystal filter element to provide substantially unmodulated carrier energy. Automatic frequency control (AFC) voltage is, also, provided by the network in response to a shift in mean frequency of applied signal waves from a predetermined desired reference or center frequency. In my application Serial No. 489,924, filed June 7, 1943, I have shown a carrier-exalted receiver system utilizing some of the principles of the type of detection described in said Patent No. 2,397,840.

In said application Serial No. 489,924 there is disclosed and claimed a compact carrier-exalted receiver circuit which is capable of receiving either PM or AM signal waves with a minimum of tubes; the circuit being readily adapted to various types of receiving systems. In the latter application there is provided a receiving circuit employing a converter to reduce the mean or carrier frequency of applied PM or AM carrier waves. There is further provided a multi-grid detector tube of the type shown in my U. S. Patent No. 2,063,588, granted December 8, 1936, which has the signal waves applied to one grid thereof, and a piezo-electric crystal filter network providing filtered carrier energy for a second grid of the detector tube. AFC voltage is derived from a balanced rectifier circuit connected to the crystal filter network for controlling the effect of a reactance-simulation tube on the oscillator section of the converter.

It is one of the main objects of my present invention to improve and simplify the carrier-exalted receiver circuit of my aforesaid application Serial No. 489,924 with a view towards providing a carrier-exalted adapter for any receiver system, the adapter being capable of confinement in a single transformer can.

An important object of this invention is to provide in conjunction with a piezo-electric crystal filter type of discriminator-rectifier circuit, a simple diode rectifier functioning to produce carrier-exalted detection of PM or AM carrier waves.

A further object of my invention is to provide a compact and simple form of adapter, employing

a minimum number of tubes not exceeding three in number, to convert a standard AM receiver to a carrier-exalted PM or AM wave receiver.

Still other objects of my invention are to provide circuits which may be employed either for carrier-exalted AM reception, carrier-exalted PM reception, or for balanced PM reception, thereby to improve the efficiency and reliability of PM-AM receivers; and more especially to provide an economical system for PM reception or for carrier-exalted AM reception.

Still other features and objects of my invention will best be understood by reference to the following description, taken in connection with the drawing, in which I have indicated diagrammatically a circuit whereby my invention may be carried into effect.

Referring now to the accompanying drawing there is shown only the crystal filter network and demodulator, since my application Serial No. 489,924 shows the remaining circuits adapted to cooperate with those disclosed herein. For this reason general reference will be made to the omitted cooperating circuits of my last mentioned application. The input transformer T may be supplied with signal energy from the output circuit of a pentagrid converter tube which may be of the 6SA7 type. Its circuits are very well known. The converter functions to reduce the carrier, mean or center frequency of applied PM, or AM, carrier wave energy in conventional manner. The specific nature of the signal receiver circuits prior to the converter is immaterial to this invention. The collected PM, or AM, carrier waves may be in the megacycle (mc.) or in the kilocycle (kc.) ranges. Prior to the converter the collected waves may be heterodyned, either one or more times, until the mean or center frequency of signal energy at the signal input grid of the final converter is equal, for example, to 450 kc. This is a suitable intermediate frequency (I. F.) value of the usual superheterodyne receiver.

Whether the wave energy at the converter input grid is PM or AM, the treatment thereof according to my invention is in some respects the same. It may be desired first to reduce the mean or center frequency of the received signal energy to a lower value. Thereafter, it is desired to derive from the energy of reduced frequency substantially unmodulated carrier wave energy and to employ it in carrier-exalted PM or AM detection. Preferably AFC voltage is also obtained. These functions are accomplished in the following manner.

The plate of the prior converter or other tube (not shown) is connected to a positive point +B of a suitable direct current source through the primary winding 8 of transformer T. If desired, the transformer may be of the iron core type. Shunt condenser 9 tunes winding 8 to the frequency of the signal energy impressed on the circuit 9-8. This may be a beat frequency which may be lower or higher than that of the signal energy applied to the input of a final converter tube, and may be assumed to be a frequency of 100 kc. There will therefore be developed across tuned primary circuit 9-8 signal energy whose mean frequency is that of the resonant frequency of the circuit. The passband of transformer T should be sufficiently wide to pass all the sideband components in the case of AM or PM carrier energy. Of course, in the case mentioned above by way of illustration, the converter tube will be provided with a local oscillator section producing local oscillations of a suitable frequency, e. g.

550 kc., so that the applied 450 kc. signal energy may be reduced to the proper 100 kc. value.

The signal wave energy appearing across secondary winding 8' is passed through a crystal filter to provide substantially unmodulated carrier energy. The filter consists of piezo-electric crystal P tuned to 100 kc. The inter-electrode capacitance of the crystal filter is neutralized by shunt condenser C_n. The input and output electrodes of the crystal P may be separate metal electrodes, or they may be metallic coatings provided on the opposite faces of the crystal. My aforesaid Patent No. 2,397,840 has described the functioning of the general type of crystal filter network and its associated opposed rectifiers shown herein. The filtered carrier energy output of crystal P is transmitted through condenser 12 to the anode 14 of a detector tube 15 of the diode type. Condenser 12 is large, and has substantially no effect on the phase of the filtered carrier energy transmitted therethrough.

The cathode 16 of diode 15 is connected to ground through a current indicator 17 which functions visually to indicate the magnitude of space current of diode 15. The indicator 17 may, therefore, be employed as a mean for visually indicating the carrier intensity of received signals, i. e. as a tuning indicator. The load resistor 18 is connected from the anode 14 to ground, and is traversed by the diode space current. In addition to filtered carrier energy, there is applied unfiltered signal energy to the anode 14. This is accomplished through switch S which may be connected either to the contact designated "AM" or that marked "PM," depending upon whether AM or PM signals are being received. The "PM" contact is connected to the lower end of winding 8' through condenser 13. The "AM" contact is connected by series-arranged resistor 19 and condenser 20 to the lower end of winding 8'. Hence, either AM or PM wave energy in unfiltered form may be applied to diode rectifier 15, and operation of switch S determines the general phase relation of the unfiltered signal energy relative to the filtered carrier energy at diode 15.

The diode detector tube 15 functions to demodulate either PM signal waves or AM signal waves. The elements 13 and 19-20 may be adjusted properly to phase the modulated carrier wave energy applied to anode 14 so that the rectified voltage across load resistor 18 will correspond to the modulation components of the originally-modulated signal energy for either AM or PM detection. In other words, if there is transmitted through condenser 12 to the anode 14 the filtered carrier of AM signal energy, then with switch S on the "AM" position there will be simultaneously applied to anode 14 through condenser 20 and resistor 19 unfiltered AM signal energy which has its phase properly adjusted for AM detection. The carrier energy transmitted through condenser 12 will be substantially unmodulated, and its phase will be substantially the same as the phase of the carrier of the AM signal energy transmitted through condenser 20 and resistor 19. With this in-phase relation between the energies applied to the tube 15 the latter will function to provide across output resistor 13 the desired modulation signal components. The values of condenser 20 and resistor 19 are so chosen as to attenuate the unfiltered AM signal waves, including their sideband components, but so as not substantially to affect the phase of the carrier. Hence, selective fading effects are overcome, due to the adjustment of the relative am-

5

plitudes of the AM carrier and sideband components at the anode of diode 15. In other words, the effect of attenuating the AM signal energies prior to application to diode 15 is to exalt or augment the carrier relative to its sidebands. If desired, the filtered carrier passing through condenser 12 may be amplified for further carrier exaltation before being impressed on diode 15.

Assume, now, that PM signal energy is transmitted to transformer T. In that case the phase modulated carrier energy applied to anode 14 must be adjusted to be substantially 90° out of phase, i. e. to be in phase quadrature, with the filtered carrier energy, by moving the switch S to the contact point "PM." This phase quadrature relation is required for providing a resultant AM wave at diode 15 whose variations correspond to the phase variations of the PM wave. Condenser 13 is sufficiently small to impart a substantially 90° phase shift to the PM wave transmitted therethrough. The filtered carrier of the PM wave passed through condenser 12 suffers no phase shift, and due to the action of the crystal in removing phase modulation from it, is similar in phase and wave form to the carrier generated at the transmitter. The vector sum of the filtered carrier and the unfiltered signal voltage at any instant increases with the degree of departure of the phase of the unfiltered wave energy from the quadrature relation. Hence, at the anode 14 there will be provided a resultant AM voltage whose vector length, i. e. amplitude, is proportional to the instantaneous phase deviations of the PM signal wave with respect to the normal quadrature phase relation of the unfiltered PM carrier. The diode 15 is now readily capable of detecting the received energy as it has been changed into an AM signal wave.

The action of the detector tube 15 will, therefore, be to demodulate the PM signal energy, and provide demodulation signal components across output resistor 18. In PM signal energy detection, carrier exaltation will also result since the condenser 13 attenuates the sideband components of the PM signal wave. Such carrier-exalted detection is of especial value in connection with AM and PM reception in the frequency range below 30 megacycles, because in that range the effect of selective fading on the transmitted signal energy is to produce an apparent increase in percentage modulation which may result in distortion due to over-modulation. Further advantages of carrier-exalted reception have been cited heretofore in the description.

The modulation signal voltage, whether for AM or PM reception, is transmitted through resistor-capacitor filter 22—23 to any desired form of modulation signal voltage amplifier network. If the modulation frequencies are in the audio frequency range, then the filter 22—23 will remove all I. F. currents, and the audio amplifier will feed the amplified audio voltage to a final reproducer. Automatic volume control (AVC) may be derived from the rectified voltage across resistor 18. The resistor 24 and condenser 24' provide AVC filter network to remove all alternating current components. The AVC bias magnitude will substantially follow the variations in carrier amplitude, since there is applied to diode 15 through condenser 12 substantially pure carrier energy. Hence, any variation in amplitude of such filtered carrier will produce a change in AVC bias, and the latter may be applied to one or more of the signal transmission tubes prior to transformer T to control the gains of such tubes in a

6

sense to overcome the carrier amplitude variation.

Balanced PM detection and AFC voltage are provided by the opposed rectifiers 26 and 27. While these rectifiers are symbolically represented as separate diodes, it is preferred that the diodes be separate diode sections of a tube of the double diode type, such as a 6H6 type of tube. The load resistors of the rectifiers 26 and 27 are denoted by numerals 26' and 27' respectively. The cathode of rectifier 27 is grounded, and each of the load resistors is suitably bypassed for alternating currents. The junction of the load resistors is connected to the junction of a pair of direct current return or isolation resistors 28 and 29.

As explained in my aforesaid Patent No. 2,397,840, the filtered carrier energy at the output electrode of crystal P is applied in like polarity, i. e. in parallel, to the anodes of the respective rectifiers 26 and 27. As shown herein, this is done through respective circuits 30—40—41, and 41—50—51, which will be further described hereinafter. The modulated, or unfiltered, signal energy existing at the opposite ends of secondary winding 8' is applied to the rectifiers 26 and 27 in opposite polarity, or in push-pull, by virtue of the shunt coupling condensers 32 and 33 respectively. Winding 8' has its midpoint grounded, and parallel resonant circuit 60 connects the grounded midpoint of coil 8' to the output electrode of the crystal P; that is, circuit 60 is connected between the output side of crystal P and ground. Circuit 60 may be tuned to crystal frequency, or may be somewhat detuned relatively thereto, and acts as a coupling circuit of finite impedance between the output of crystal P and the anodes of rectifiers 26 and 27. The circuit 60 increases the "Q" of the crystal beyond what it would be if the resistance of circuit 60 were infinite. As shown, circuit 60 connects to lead 70 between the crystal P and rectifier 27. Condenser 80 may shunt winding 8' to tune it to crystal frequency.

As explained in my last-named application, each rectifier 26 and 27 has applied to it filtered and unfiltered signal energy in phase quadrature relation. This phase quadrature relation of the two voltages at each rectifier results from the fact that the unfiltered signal energy is applied to the rectifiers by condensers 32 and 33 which are sufficiently small to effect a 90° phase shift, and are also of substantially equal capacities so as to produce equal phase shifts both of the unfiltered carrier and of signal components. The condensers 32 and 33 are non-selective to phase or frequency variations of the unfiltered carrier, and accordingly permit all signal components to pass to the rectifiers 26 and 27. The crystal P, however, effects no substantial phase shift of the filtered carrier wave at modulation frequencies, but by its inertia effect substantially removes the phase modulation of the signal thereby restoring the carrier substantially to the phase and wave form which it had before modulation at the transmitter. The crystal P due to its sharp selectivity is, of course, selective against frequencies off resonance, but will nevertheless pass a band of frequencies varying over a narrow range.

Circuit 60 which, as heretofore indicated, is employed to control and improve the "Q," or selectivity, of crystal filter P may introduce reactance into the circuit of the crystal tending to change somewhat the phase of the filtered carrier output from the crystal. The filtered output on its way to rectifier 26 passes through a network

consisting of variable condenser 30 in association with condenser 40 and resistor 41. This network may be designed to compensate for such phase change. Similarly, a network consisting of variable condenser 31 in association with condenser 50 and resistor 51 may similarly compensate for dephasing effects of circuit 60 on filtered energy supplied to rectifier 27. Should slight detuning of circuit 60, which may be effected to increase the "Q" of crystal P, cause a change from the desired normal phase quadrature relation between the filtered carrier and unfiltered signal wave, then condensers 30 and 31 may be adjusted to compensate for the dephasing so as to restore the normal phase quadrature relation.

The rectifiers 26 and 27 function to rectify the respective resultant vector voltages of these aforesaid quadrature-related energies. When the applied signal energy at transformer T is unmodulated, i. e. has a frequency and phase corresponding to the predetermined reference characteristics of crystal P, then the respective resultant vector voltages applied to rectifiers 26 and 27 are equal, each of them being the sum of the filtered carrier voltage from crystal P without phase change and of an unfiltered carrier voltage substantially 90° different in phase from the filtered carrier. Accordingly, the differential direct current voltage output of the rectifiers is substantially zero, since the voltages across resistors 26' and 27' are equal and of opposite polarity.

However, when the received carrier is phase-modulated, and as described more fully by aid of vector diagrams in my Patent No. 2,397,841 dated April 2, 1946, the filtered carrier remains as before, but the unfiltered signal energy is supplied to the rectifiers 26 and 27 in phases differing from the 90°, or quadrature, relation to an extent determined by the degree of phase modulation. If the degree of phase modulation is small, a relatively small direct current voltage is built up at the cathode end of resistor 26' due to a component of the signal voltage adding to the filtered carrier voltage at one of the rectifiers and subtracting from it at the other. The greater the degree of phase modulation the greater the sum or vector voltage of the unfiltered signal energy and the filtered carrier from crystal P on one of the rectifiers and the less the sum of such voltages on the other rectifier. The polarity of the direct current voltage drop across the load resistors 26' and 27' of the opposed rectifiers depends on the direction of the phase change of the received signal energy.

The direct current potentials across resistors 26' and 27', described above as derived by rectification of a PM wave, follow one another in frequency and polarity to accord with the modulations of the received carrier wave. Accordingly, audio or other modulation signals may be taken off at the cathode of diode 26. Assuming that the modulations will be at audio frequency, I have shown an audio frequency output switch 30' which may be alternatively connected with diode 15 for AM, or exalted-carrier PM, reception, or with rectifiers 26 and 27 for balanced PM reception.

The circuits of rectifiers 26 and 27 are also preferably employed for the derivation of AFC potentials. The crystal P can respond to frequency changes over a limited range, and, in particular, to slow frequency changes such as may, for example, result from local oscillator drift in a superheterodyne receiver. As to such frequency changes within the band of frequencies passed by

it, the crystal P acts as series-connected inductance and capacity. When the received frequency is exactly that of the crystal, it produces no phase change and the filtered carrier remains at 90° from the unfiltered energy passing through condensers 32 and 33 respectively. When, however, the incoming frequency changes slowly toward one side of the passband of the crystal, the filtered output changes in phase in a direction toward the phase of the current in one of condensers 32 and 33, and away from the phase of the current in the other of such condensers. In this way there is produced increased energy on one of rectifiers 26 and 27 and decreased energy on the other so as to create a direct current potential across rectifier load resistors 26' and 27'. Upon change of the incoming frequency in the opposite direction, the phase of the filtered output of the crystal changes in the opposite direction thereby decreasing the energy on the rectifier where it before was increased, and increasing the energy on the other rectifier so as to produce a reversed direct current potential drop across resistors 26' and 27'.

This frequency discrimination action is similar in certain of its aspects to that described in my Patent No. 2,363,652 dated Nov. 28, 1944. The direct current voltage output of the opposed rectifiers is utilized as AFC bias, after filtering off of modulation frequency voltages by resistor 82 and condenser 84, and may be applied over lead 34 to a frequency control device of the reactance tube type. The reactance tube and its associated circuits are of the well-known form, and are shown in my aforesaid application Serial No. 489,924. The AFC discrimination action is the same for AM and PM signal waves. In explaining the functioning of the reactance tube, it is pointed out that its plate to cathode impedance is connected in shunt across the oscillator tank circuit of the converter tube. By suitable connections to a phase shifter connected to the oscillator circuit the plate to cathode impedance of the reactance tube will function as if it was reactive, and the latter effect will appear across the tank circuit. The magnitude of this simulated reactance will then be a function of the gain of the reactance tube. Obviously, the direction and extent of variation of the reactive impedance of the reactance tube will depend upon the variation in AFC bias transmitted over lead 34. This, of course, is the well-known AFC action which is familiar to those skilled in the art. In this case the AFC circuit functions to maintain the mean frequency of the signal energy applied to circuit 9—3 substantially equal to the predetermined reference frequency which is the resonant frequency of the crystal P for best operation of the circuit.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention.

What I claim is:

1. In combination with a diode rectifier circuit, means providing either amplitude modulated carrier waves or angle modulated carrier waves, means for deriving from either of said waves the carrier thereof substantially free of modulation, means for applying the carrier energy to said rectifier, means for selecting either of said modulated waves in a predetermined phase relation relative to the said modulation-free carrier

energy, means applying the selected waves to said rectifier, and means for deriving from the rectifier circuit modulation signals corresponding to the modulation on the said selected waves.

2. In combination with a diode rectifier circuit, means providing either amplitude carrier waves or phase modulated carrier waves, piezo-electric crystal filter means for deriving from either of said waves the carrier thereof substantially free of modulation, means for applying the carrier energy to said rectifier, adjustable phase shift means for selecting either of said modulated waves in a predetermined phase relation relative to the said modulation-free carrier energy, means applying the selected waves to said rectifier, and means for deriving from the rectifier circuit modulation signals corresponding to the modulation on the said selected waves.

3. In combination with a rectifier consisting of a single diode, means for applying to the diode electrodes a phase modulated carrier wave, means for applying a modulation-free carrier derived from the modulated carrier wave to said diode electrodes in predetermined phase relation, and means for deriving modulation signals from the rectifier output.

4. In combination with a source of phase modulated carrier waves, a pair of opposed rectifiers having a common output circuit, means including a piezo-electric crystal filter having an input electrode coupled to said source, parallel output connections from the output electrode of said crystal to the respective rectifiers, separate means applying modulated carrier wave energy from said source to said opposed rectifiers in push-pull relation, a rectifier circuit including a single diode, means connecting the crystal output electrode to the diode anode for applying to the latter filtered carrier energy derived from the phase modulated carrier waves, and an additional phase-determining connection between said source and said diode electrodes for applying thereto phase modulated carrier wave energy in predetermined phase relation to said filtered carrier energy.

5. In combination with a diode rectifier circuit, means providing either amplitude modulated carrier waves or phase modulated carrier waves, crystal filter means for deriving from either of said waves the carrier thereof substantially free of modulation, means for applying the derived carrier energy to said rectifier, means for selecting either said phase modulated carrier waves in a normal phase quadrature relation relative to the said modulation-free carrier energy or said amplitude modulated carrier waves in in-phase relation to said carrier energy, said selecting means attenuating sideband components of the modulated waves, means applying the selected modulated waves to said rectifier, and means for deriving from the rectifier circuit modulation signals corresponding to the modulation on the said selected waves.

6. In combination with a diode rectifier circuit, means providing either amplitude modulated carrier waves or phase modulated carrier waves, crystal filter means tuned to the carrier frequency for deriving from either of said waves the carrier

thereof substantially free of modulation, means for applying the derived carrier energy to said rectifier with no phase shift, adjustable phase shift means for selecting either said phase modulated waves in phase quadrature relation relative to the said modulation-free carrier energy or said amplitude modulated carrier waves in in-phase relation to said carrier energy, means applying the selected waves to said rectifier, means for deriving from the rectifier circuit modulation signals corresponding to the modulation on the said selected waves, and means for deriving from the modulation-free carrier energy a variable direct current voltage for automatic volume control.

7. In combination with a rectifier consisting of a single diode, means for applying to the diode electrodes a phase modulated carrier wave, means for applying to said diode electrodes a modulation-free carrier derived from the modulated carrier wave in phase quadrature relation, said first means attenuating sideband components of the modulated wave, and means for deriving from the diode output modulation signals.

8. In combination with a source of phase modulated carrier waves, a pair of opposed diode rectifiers having a common output circuit, means including a crystal filter having an input electrode coupled to said source, parallel output connections from the output electrode of said crystal to the respective rectifiers, separate condensive means applying modulated carrier wave energy from said source to said opposed rectifiers in push-pull relation, a diode rectifier circuit, non-phase shift means connecting the crystal output electrode to said rectifier circuit for applying to the latter filtered carrier energy derived from the phase modulated carrier waves, and an additional phase determining connection between said source and said diode rectifier circuit for applying thereto phase modulated carrier wave energy in phase quadrature relation to said filtered carrier energy, said phase determining connection including an element for attenuating sideband components.

9. In combination with a diode rectifier, means for applying to the diode electrodes an angle modulated carrier wave, said means attenuating sideband components, means for applying a modulation-free carrier derived from the modulated carrier wave to said diode electrode in predetermined phase quadrature relation, means for deriving from the rectifier output modulation signals, and an additional means for deriving from the rectifier output a direct current voltage whose magnitude is a direct function of the magnitude of said modulation-free carrier.

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