

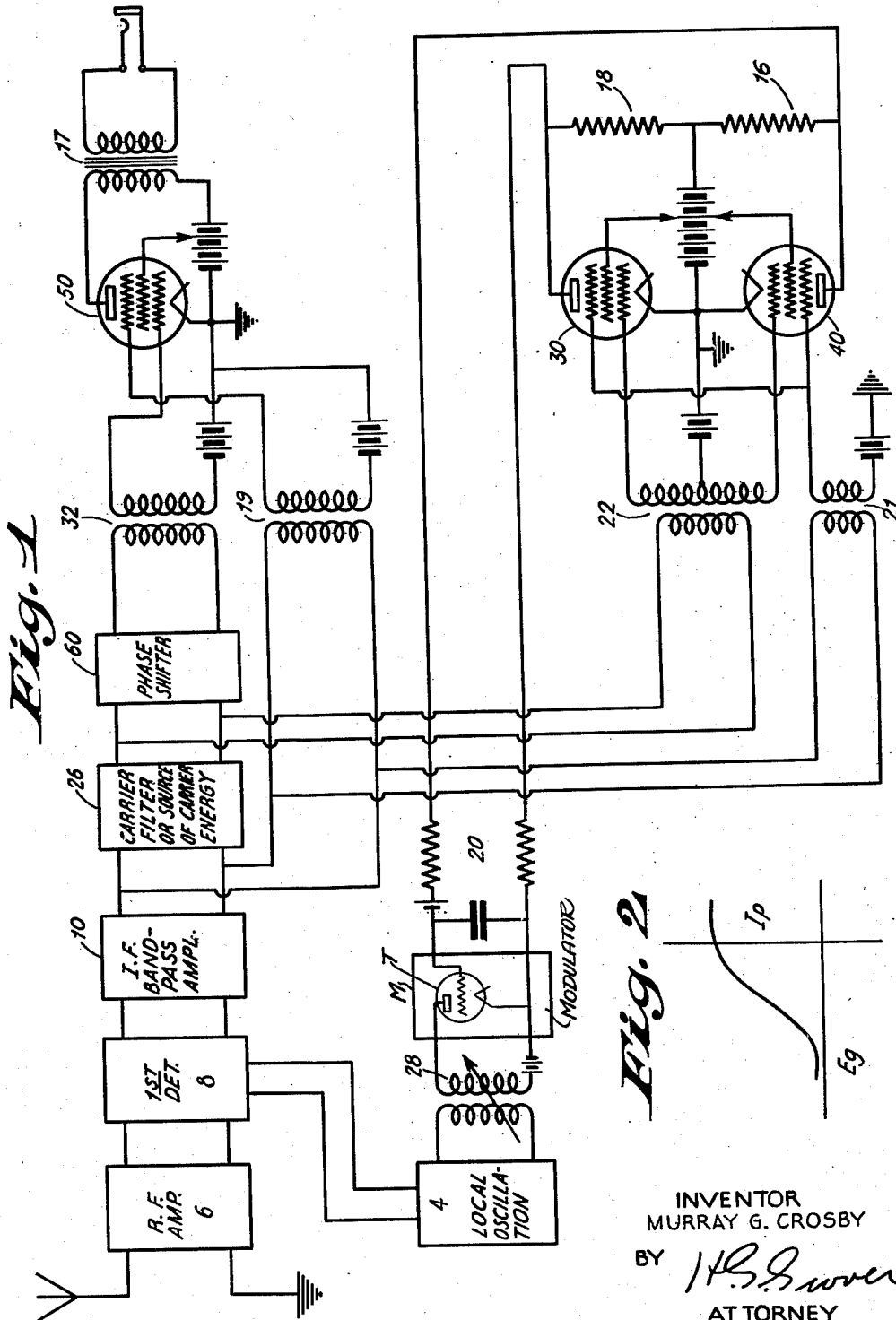
Dec. 8, 1936.

M. G. CROSBY

2,063,588

PHASE OR AMPLITUDE MODULATED WAVE DEMODULATOR

Filed March 20, 1934



UNITED STATES PATENT OFFICE

2,063,588

PHASE OR AMPLITUDE MODULATED WAVE
DEMODULATORMurray G. Crosby, Riverhead, N. Y., assignor to
Radio Corporation of America, a corporation of
Delaware

Application March 20, 1934, Serial No. 716,469

20 Claims. (Cl. 250—20)

This invention relates to a new and improved means for demodulating modulated waves. More in detail the present invention relates to a detector for use in signal modulated wave receiving systems wherein an auxiliary carrier is combined with the signal modulated wave to obtain or render the signal on the wave or to obtain energy for control purposes such as for example automatic frequency control of a tunable circuit in the receiver. The auxiliary carrier may be obtained from or produced by the received carrier or may be generated locally by a self-excited generator or by a generator excited by the received carrier.

Receivers for demodulating signal modulated waves which involve combining the received energy with an auxiliary carrier or carrier energy free of the signals have been known heretofore in the art. For example, Crosby United States application No. 588,309 January 23, 1932, Crosby United States application No. 616,803 June 13, 1932, Crosby United States application No. 704,122 December 27, 1933 and, Crosby United States application No. 704,257 December 28, 1933 each show a signal demodulating system wherein signal energy is combined with carrier energy in various manners to render the modulations on the signal energy. In all of these systems, except the last one mentioned, a pair of differential detectors of the triode type are employed and the carrier and modulated wave energy are combined before the demodulating action takes place. The combined energy is demodulated in the square law manner. Each of these systems utilize, in addition to other novel features, combining circuits preceding the demodulating device. The demodulating device employs a pair of detectors arranged in such a manner that one of the energies is applied in phase opposition to like electrodes in the tubes while the other energy is applied in phase to like electrodes in the tubes.

In the signal demodulating means of the present invention, a multi-element tube is utilized. Preferably this tube is one of the pentode type having carrier energy fed to one grid electrode of the tube and signal modulated energy fed to another electrode in the tube. By this means, difficulties of combining the carrier and modulated energies before detection are removed, since the combination takes place within the tube dur-

ing detection. Hence, the present invention permits the circuits preceding the detectors to be simplified considerably and thereby improved. Moreover, when the multi-element tube is used, as in the present invention, to obtain the energy, only a single tube is required to obtain the same advantages with respect to demodulation distortion and with respect to the reception of unwanted modulations.

The novel features of my invention have been pointed out with particularity in the claims appended hereto as required by law. The nature of my invention and the operation thereof will be better understood from the following detailed description thereof and therefrom when read in connection with the attached drawing in which Figure 1 shows for purposes of illustration only a circuit arrangement including the essential elements of my novel demodulating system. Of course I contemplate the use of any other elements known in the art which facilitate the reception and demodulation of signal modulated waves. Figure 2 is a curve illustrating the relation between the plate current and the voltage applied to either of the grids in the demodulator.

Referring to the drawing, Figure 1 shows a circuit wherein detectors of the type involved in this invention are utilized. 10 is the intermediate frequency amplifier of a superheterodyne receiver adapted to receive signal modulated waves. The unit 10, which includes an intermediate frequency band pass filter and amplifier, may derive its energy from a first detector 8, which is in turn energized on the one hand by radio frequency energy from a radio frequency amplifier 6 and on the other hand by oscillations from a local oscillation source 4. The circuits in the units 4, 6, 8 and 10 form no part of the present invention, may be conventional, and need no detailed description in this specification. The energy from the output of the intermediate frequency band pass amplifier in 10 is fed by way of a transformer 19 to one grid electrode of the signal demodulator 50 and by way of a transformer 21 to like grid electrodes of the differential detectors 30 and 40. The intermediate frequency energy from 10 is also fed to a carrier wave filter 26. 26 may be replaced by a local oscillator which may be tuned to produce a new carrier synchronized with the received carrier.

This oscillator may be held in synchronism by the intermediate frequency energy supplied from 10 or it may be synchronized in any other known manner to produce oscillations of the proper frequency and phase. Energy from the output of the unit 26 is fed to the automatic frequency control detectors 30 and 40 by way of transformer 22 which when connected as shown energizes like grid electrodes in the tubes 30 and 40 in phase opposition. When signal energy is impressed as shown on transformers 22 and 21 differential currents will flow in the anode circuits of 30 and 40.

Energy may also be supplied from the unit 26 by way of a phase shifter 60 and a transformer 32 to a grid electrode in the signal wave demodulator 50.

The differential currents which will appear in the resistances 16 and 18 connected with the anodes of tubes 30 and 40 may be utilized by way of a time constant device 20 to control the inductive value of a reactance 28 coupled as shown to a reactance in one of the frequency determining circuits of the local oscillation generator 4. The currents in the time constant device may vary the reactance 28 in accordance with the changes in the differential current in 16 and 18 by controlling the input of a modulator M which in turn controls the inductive reactance of 28. The modulator M may comprise a thermionic tube T having its input electrodes coupled to the time constant device 20 and its output electrodes coupled to the reactance 28. Thus, in a manner disclosed more in detail hereinafter, the frequency of the intermediate frequency energy in 10 may be maintained constant by varying the frequency of the local oscillations in the proper direction to offset a change in the frequency of the received wave.

Thus the detectors 30 and 40 may be used to obtain differential energy for automatic frequency control purposes by differentially detecting the signal and the carrier, or may be used to translate the signal wave on the carrier by combination of the signal modulated energy and the carrier alone. A more complete description of the manner in which the differential energy appearing in the output of tubes 30 and 40 is used has been given in United States application No. 616,803, filed June 13, 1932. Of course the signal may be obtained from the output of the detector 50.

The manner in which the detectors of the present invention operate to eliminate undesired modulation and to obtain energy for automatic frequency control purposes and audio or signal energy is contained in the following mathematical analysis;

Assuming a signal modulated in both amplitude and phase given by

$$e = E_1(1 + m \sin pt) \sin (wt + \phi \sin qt) \quad (1)$$

where m is the percentage amplitude modulation, p the angular velocity of the amplitude modulating wave, ϕ the depth of phase modulation, q the angular velocity of the phase modulating wave, and w is the angular velocity of the carrier wave.

Figure 2 shows a static characteristic of either of the grids of the multi-grid detector of this invention. That is, if either grid voltage is varied according to the abscissa of Figure 2, the plate current will vary according to such a curve.

Hence, the overall characteristic of the varying

current in the output due to the two grids will be represented by:

$$i = (k_1 E' + a_1 e_1 + b_1 e_1^2 + C_1 e_1^3 + \dots) + (k_2 E'' + a_2 e_2 + b_2 e_2^2 + C_2 e_2^3 + \dots) \quad (2)$$

where E' and E'' are the constant grid biases of the two grids, e_1 and e_2 are the alternating current voltages applied to the two grids and k_1 , k_2 , a_1 , a_2 , etc., are constants depending upon the tube.

Multiplying (2) out gives:

$$i = (k_1 k_2 E' E'' + k_2 E'' a_1 e_1 + k_2 E'' b_1 e_1^2 + k_2 E'' c_1 e_1^3 + \dots + k_1 E' a_2 e_2 + k_1 E' b_2 e_2^2 + k_1 E' c_2 e_2^3 + \dots + a_1 b_2 e_1^2 e_2 + a_2 c_1 e_1^3 e_2 + \dots + a_1 b_2 e_1^2 e_2^2 + b_1 b_2 e_1^2 e_2^2 + \dots + k_1 E' c_2 e_2^3 + a_1 c_2 e_1 e_2^3 + b_1 c_2 e_1^2 e_2^3 + \dots) \quad (3)$$

Since the tubes are adjusted so that a_1 and a_2 are large compared to b_1 , c_1 and b_2 , c_2 etc., the majority of the output current is given by:

$$i = a_1 a_2 e_1 e_2 \quad (4)$$

after the permanent direct current and radio frequency terms have been eliminated.

In the receivers of the type portrayed in Figure 2, the alternating current voltage to one grid is given by Equation (1) and the voltage to the other grid is either the filtered carrier or a locally synchronized carrier given by:

$$e_2 = E_2 \sin (wt + B) \quad (5)$$

Hence, the detector output would be:

$$i = a_1 a_2 E_1 E_2 (1 + m \sin pt) \sin (wt + \phi \sin qt) \sin (wt + B) \quad (6)$$

which, simplified and with radio frequency terms eliminated, reduces to:

$$i = \frac{a_1 a_2 E_1 E_2}{2} (1 + m \sin pt) (\cos (\phi \sin qt) \cos B + \sin (\phi \sin qt) \sin B) \quad (7)$$

Applying the Bessel function expansions transforms (7) to:

$$i = \frac{a_1 a_2 E_1 E_2}{2} (1 + m \sin pt) (J_0(\phi) + 2J_2(\phi) \cos 2qt + 2J_4(\phi) \cos 4qt \cos B + 2J_1(\phi) \sin qt + 2J_3(\phi) \sin 3qt + \dots) \sin B \quad (8)$$

Simplifying and neglecting all terms involving Bessel functions of a higher order than $J_2(\phi)$, gives as the direct current terms:

$$i_{d.c.} = \frac{a_1 a_2 E_1 E_2}{2} (J_0(\phi) \cos B) \quad (9)$$

and as the alternating current terms (neglecting above $J_4(\phi)$):

$$i_{a.c.} = \frac{a_1 a_2 E_1 E_2}{2} (J_0(\phi) M \sin pt) \cos B + (2J_1(\phi) \sin qt + 2J_3(\phi) \sin 3qt + \dots) \sin B + (2J_2(\phi) \cos 2qt + 2J_4(\phi) \cos 4qt + \dots) \cos B + (2J_2(\phi) m \cos 2qt \sin pt + 2J_4(\phi) m \cos 4qt \sin pt + \dots) \cos B + (2J_1(\phi) m \sin qt \sin pt + 2J_3(\phi) m \sin 3qt \sin pt + \dots) \sin B \quad (10)$$

When it is desired to receive the amplitude modulation component, the local carrier phase is adjusted so that B is 0 or 180, 360, etc., degrees. The alternating current output will then be

$$i_{a.c.}(B=0) = \frac{a_1 a_2 E_1 E_2}{2} J_0(\phi) m \sin pt + 2J_2(\phi) \cos qt + 2J_4(\phi) \cos 4qt - \dots + (2J_2(\phi) m \cos 2qt \sin pt + 2J_4(\phi) m \cos 4qt \sin pt + \dots) \quad (11)$$

When it is desired to receive phase modulation B is adjusted to 90 or 270, etc., so that

$$i_{a,c}(B=90^\circ) = \frac{a_1 a_2 E_1 E_2}{2} (2J_1(\phi) \sin qt + 2J_3(\phi) \sin 3qt + \dots) + (2J_1(\phi) m \sin qt \sin pt + 2J_3(\phi) m \sin 3qt \sin pt + \dots) \quad (12)$$

Equation (11) indicates that when amplitude modulation is being received, the detector output contains: 1. The desired amplitude modulation fundamental output. 2. The even harmonics of the phase modulation component. 3. The beats between the amplitude modulation fundamental and the phase modulation even harmonics. The amplitude modulation fundamental is partially dependent upon the depth of modulation of the phase modulation component since it is proportional to $J_0(\phi)$. With no phase modulation present, the detection of the amplitude modulation is proportional to the percentage modulation, m and free from harmonics.

Equation (12) indicates that when phase modulation is being received, the detector output contains: 1. The desired phase modulation fundamental output. 2. The odd harmonics of the phase modulation. 3. The beats between the amplitude modulation fundamental and the phase modulation fundamental and odd harmonics. The phase modulation fundamental output is unaffected by the presence of the amplitude modulation component and is proportional to $J_1(\phi)$. In the absence of amplitude modulation, only odd harmonics of the phase modulation are present in the detector output.

The automatic frequency control operates from the direct current given by (9). The control is arranged so that it functions to hold the local carrier at a 90 degree phase position with respect to the signal carrier. Consequently, for one of the detectors 30 and 40 of Figure 1, $B = (90 + \alpha)$ and for the other detector, $B = (270 + \alpha)$, where α is the change in phase caused by a departure from synchronism. The 180 degree phase difference (90 to 270) is caused by the anti-phasing transformer 10. Substituting these values of B in (9) for the two detectors gives the two detector control currents.

$$i_1 = \frac{a_1 a_2 E_1 E_2}{2} J_0(\phi) \cos(90 + \alpha) = \frac{a_1 a_2 E_1 E_2}{2} J_0(\phi) \sin \alpha \dots \quad (13)$$

$$i_2 = a_1 a_2 E_1 E_2 J_0(\phi) \cos(270 + \alpha) = -\frac{a_1 a_2 E_1 E_2}{2} J_0(\phi) \sin \alpha \dots \quad (14)$$

Since the control voltage from one of the detectors is reversed, both currents add up with the same sign, producing a positive controlling voltage when the synchronism departure is in one direction producing an α in one direction, and a negative controlling voltage when the departure is in the opposite direction producing an α in the opposite direction. At the point of synchronism α will be zero and no controlling voltage will appear.

Any tube may be used for this type of detector as long as there are enough or more than enough elements to apply the required energies and utilize the output.

In the case of the differential detectors, the specific feeding of the grids shown need not be adhered to. That is, the carrier energy might be fed to the outer grids (outer from the filament)

or the carrier might be fed via the co-phasing transformer and the signal via the push-pull transformer.

Also, in the case of the audio detectors, it is immaterial which set of grids the two energies are fed to.

It would also be possible to apply the energies to more than one element in accordance with the principles described in Peterson et al. United States application No. 695,254 October 26, 1933.

The novel features of this invention are as follows: 1. A multi-element detector wherein modulated signal energy is fed to one grid and carrier energy to another. 2. A differential detector scheme for combining the modulated signal energy with the carrier energy to obtain control energy for maintaining synchronism between the two energies.

Having thus described my invention and the operation thereof, what I claim is:

1. Signal demodulating means to be used with a source of oscillations modulated in phase at signal frequency comprising, a thermionic detector having its anode electrode arranged to be connected with an indicating device, a circuit coupling said source of oscillations to a control electrode and the cathode of said detector, and a second circuit including a filter which passes energy of the mean frequency of said oscillations only and a phase shifter in series connecting said source of oscillations between an additional control electrode and the cathode of said detector.

2. Phase modulated signal demodulating means to be used with a source of signal modulated oscillations including, a thermionic detector of the pentode type having an anode electrode connected with an indicating device, said detector having a plurality of control electrodes and a cathode, a circuit having an input coupled to said source of oscillations and an output coupled to a control electrode and the cathode of said tube, and a second circuit including a filter and phase shifting means having an input coupled to said source of oscillations and an output coupled to another control electrode in said tube.

3. In a signal modulated oscillation receiving means, demodulating means, a tunable circuit comprising a reactance which determines in part the responsiveness of said demodulating means to said oscillations, a thermionic tube having input circuits coupled to said demodulating means, said input circuits being responsive to energy derived from demodulating said oscillations and an output circuit which may be connected with indicating means, a pair of thermionic detectors of the pentode type, a circuit for applying oscillations from said demodulating means in phase opposition to like grid electrodes of said thermionic detectors, a circuit for applying oscillations from said demodulating means 60 cophasally to like electrodes of said detectors and a control device interposed between the output of said pair of detectors and said reactance in said tunable circuit.

4. In a signal modulated oscillation receiving means, signal demodulating means, a tunable circuit the tune of which determines in part the responsiveness of said demodulating means to said oscillations, a thermionic tube having a plurality of input circuits coupled by separate paths to said demodulating means and responsive to energy derived from said oscillations and an output circuit which may be connected with indicating means, a pair of thermionic detectors of the multi-control grid type, a filter circuit for apply-

ing energy from said demodulating means in phase opposition to like grid electrodes in said pair of thermionic detectors, a circuit for applying energy from said demodulating means cophasally to like electrodes of said detectors, and a circuit interposed between the output of said detectors and said tunable circuit to control the tune of said circuit by energy from the output of said detectors.

5. In phase modulated oscillation receiving means, oscillation amplifying and demodulating means, a tunable circuit, the tune of which determines in part the responsiveness of said receiving and amplifying means to said oscillations, a thermionic tube having a plurality of input circuits coupled to said demodulating means to be energized by energy characteristic of said oscillations and an output circuit which may be connected with indicating means, a pair of thermionic detectors of the pentode type, a filter circuit for applying energy characteristic of said oscillations from said demodulating means in phase opposition to like grid electrodes of said thermionic detectors, a circuit for applying oscillations from said demodulating means cophasally to like electrodes of said detectors and a control device interposed between the output electrodes of said detectors and said tunable circuit to control the tune thereof in accordance with the character of the energy in the output of said detectors.

6. In a signal modulated oscillation demodulating system, a heterodyne receiver including a local oscillator, a demodulator and an intermediate frequency amplifier having an output, said local oscillator including a tunable element to determine the frequency of the oscillations produced thereby, a signal wave demodulator of the pentode tube type having a plurality of control grids, a cathode and an anode, a circuit coupling the output of said intermediate frequency amplifier between a control grid electrode and the cathode of said demodulator tube, and a filter circuit and a phase shifter connected in series between the output of said intermediate frequency amplifier and a second control grid and the cathode of said demodulator tube.

7. In a signal modulated oscillation demodulating system, a heterodyne receiver including a local oscillator, a demodulator and an intermediate frequency amplifier having an output circuit, a signal wave demodulator tube of the multi-grid type having a cathode, a circuit coupling the output of said intermediate frequency amplifier to a grid electrode and the cathode of said demodulator, and a circuit for applying unmodulated oscillations of constant phase and of a frequency equal to said intermediate frequency to a second grid electrode and the cathode of said demodulator tube.

8. In a phase modulated signal demodulating means, a heterodyne receiver including a local oscillator, a demodulator and an intermediate frequency amplifier, said local oscillator including a tunable element to determine the frequency of the oscillations produced thereby, a signal wave demodulator of the pentode type, a circuit coupling the output of said intermediate frequency amplifier between a grid electrode and the cathode of said demodulator of the pentode type, a filter circuit and a phase shifter connected in series between the output of said intermediate frequency amplifier and a second grid electrode in said demodulator of the pentode type, and a thermionic control device having input

electrodes and output electrodes, separate circuits coupling said input electrodes to said intermediate frequency amplifier and a circuit coupling said output electrodes to said tunable element.

9. Phase modulated signal demodulating means comprising, a heterodyne receiver having a source of local oscillations, a demodulator coupled thereto and an intermediate frequency amplifier having its input coupled to said demodulator said intermediate frequency amplifier having an output, said source of local oscillations including a tunable circuit which determines in part the frequency of the oscillations, a pentode detector tube having a plurality of grid-like electrodes, a circuit coupling the output of said intermediate frequency amplifier to a grid-like electrode in said tube, a circuit including a phase shifter connected with the output of the intermediate frequency amplifier for applying unmodulated energy of said intermediate frequency to a second grid-like electrode in said tube, a pair of pentode detector tubes each having a plurality of like electrodes, a circuit connected to the output of said intermediate frequency amplifier and to like electrodes in each tube of said pair of tubes for applying energy of a frequency equal to said intermediate frequency in phase opposition to like electrodes in said last named pair of tubes, a circuit connected to the output of said intermediate frequency amplifier and to like electrodes in each tube of said pair of tubes for applying energy from the output of said intermediate frequency amplifier in phase to like electrodes in said last named pair of detectors, a filter in one of said two last named circuits and a circuit including a time constant device coupling the output of said last named detector tubes to the tunable circuit in said oscillator.

10. In a signal modulated oscillation demodulating means, a heterodyne receiver having a source of local oscillations, a demodulator coupled thereto and an intermediate frequency amplifier coupled to said demodulator, said intermediate frequency amplifier having an output, said source of local oscillations including a tunable circuit which determines in part the frequency of the oscillations generated, a pentode detector tube having a plurality of grid like electrodes, a circuit coupling the output of said intermediate frequency amplifier to a grid-like electrode in said pentode tube, a circuit including a filter and a phase shifter in series coupling the output of said intermediate frequency amplifier to a second grid-like electrode in said pentode tube, a pair of pentode detector tubes each having a plurality of grid-like electrodes and an anode, a circuit connected with the output of said filter and with a grid-like electrode in each tube of said pair of tubes for applying energy from the output of said filter in phase opposition to the last mentioned grid-like electrodes in said last named pair of tubes, a circuit connected with the output of said intermediate frequency amplifier and with a grid-like electrode in each pair of said tubes for applying energy from the output of said intermediate frequency amplifier in phase to the last mentioned grid-like electrodes in said last named pair of detectors, a pair of impedances connected between the anodes of said pair of tubes, and a circuit including a time constant device coupling said impedances to the tunable circuit in said oscillator.

11. In a signal modulated oscillation demodulating means, a heterodyne receiver having a

source of local oscillations, a demodulator coupled thereto and an intermediate frequency amplifier coupled to said demodulator, said intermediate frequency amplifier having an output, said source of local oscillations including a tunable circuit which determines in part the frequency of the oscillations, a detector tube having a plurality of grid-like electrodes, a circuit coupling the output of said intermediate frequency amplifier to a grid-like electrode in said detector tube, a circuit including a filter and a phase shifter in series coupling the output of said intermediate frequency amplifier to a second grid-like electrode in said detector tube, a pair of detector tubes each having a plurality of grid electrodes and an anode, a circuit connecting the output of said filter to like grid electrodes in the tubes of said last named pair of tubes, a circuit connecting the output of said intermediate frequency amplifier to like electrodes in said last named pair of detectors and a circuit including a time constant device coupling the output of said last named detectors to the tunable element in said oscillator.

12. Signalling means comprising a source of oscillations modulated in phase in accordance with signals, a detector tube having an anode electrode arranged to be connected with an indicating device, said detector tube being of the pentode type having a plurality of control electrodes, a circuit having an input coupled to said source of phase modulated oscillations, said circuit also having an output coupled to a control electrode in said tube, a source of oscillations of substantially constant frequency and phase and of a frequency equal to the mean frequency of the signal modulated oscillations, and a second circuit including a phase shifter having an input coupled to said source of oscillations of substantially constant frequency, said second circuit having an output coupled to another control electrode in said tube.

13. Signalling means comprising a source of oscillations modulated in phase at signal frequency, a detector tube having an anode, a cathode and a plurality of control grid electrodes, means arranged for connecting the anode and cathode of said tube with a utilization device, a circuit coupling said source of phase modulated oscillations to a control electrode and the cathode of said tube, a source of unmodulated oscillations of a frequency equal to the mean frequency of said first named source of oscillations, and a second circuit including phase controlling means connecting said source of unmodulated oscillations between another control electrode and the cathode of said detector tube.

14. In a system for demodulating carrier waves of substantially constant amplitude, modulated in accordance with signals, wave receiving means having an output circuit, a demodulator tube of the pentode type having a plurality of control electrodes, a cathode and an anode, a first circuit having an input coupled to the output of said receiving means and an output coupled to one of said control electrodes and the cathode of said tube, a device in said first circuit for removing the signal modulations from the carrier, a second circuit coupling the output circuit of said wave receiving means directly to another control electrode and the cathode of said tube, and an output circuit coupled to the anode and cathode of said tube.

15. A system as recited in claim 14 in which phase shifting means is included in one of said first and second circuits.

16. A system as recited in claim 14 in which said pentode includes a screening electrode between said anode and the cathode electrode and in which said screening electrode is connected to the cathode of said tube by way of a source of potential.

17. In a system for demodulating waves modulated at signal frequency, wave receiving means having an output circuit, a pair of demodulator tubes of the pentode type, each having a plurality of control electrodes, a cathode and an anode, and a utilization circuit connected with the anodes and cathodes of said tubes, a first circuit connecting like control electrodes in each of said tubes in push pull relation and to the cathodes of said tubes, a coupling between said first circuit and said output circuit, a second circuit connecting like control electrodes in said tubes in parallel and to the cathodes of said tubes, a coupling between said second circuit and said output circuit, and a filter which primarily passes carrier wave energy in one of said first and second circuits.

18. A system as recited in claim 17 in which a phase shifting device is interposed in one of said first and second circuits.

19. A system as recited in claim 17 in which a phase shifting device is connected in series with said filter in one of said first and second circuits.

20. A system as recited in claim 17 in which each of said tubes has a screen-like electrode between the anode and the other of the electrodes, and in which said screen-like electrodes are connected to the cathodes of said tubes by way of a source of potential.

MURRAY G. CROSBY. 55