

July 20, 1937.

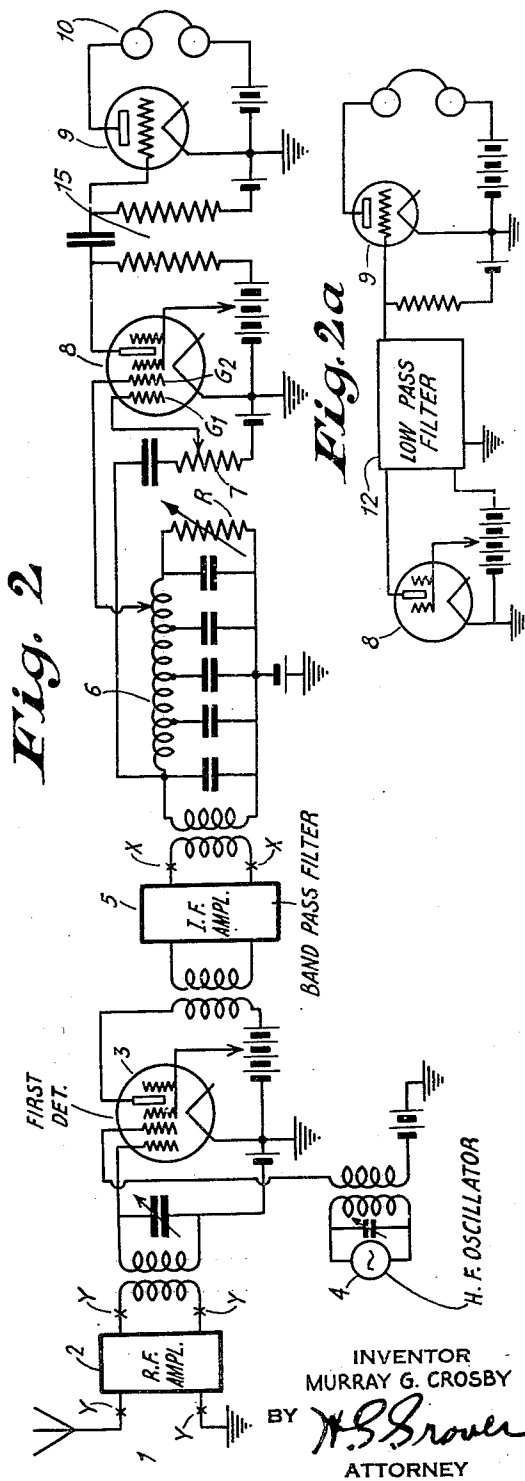
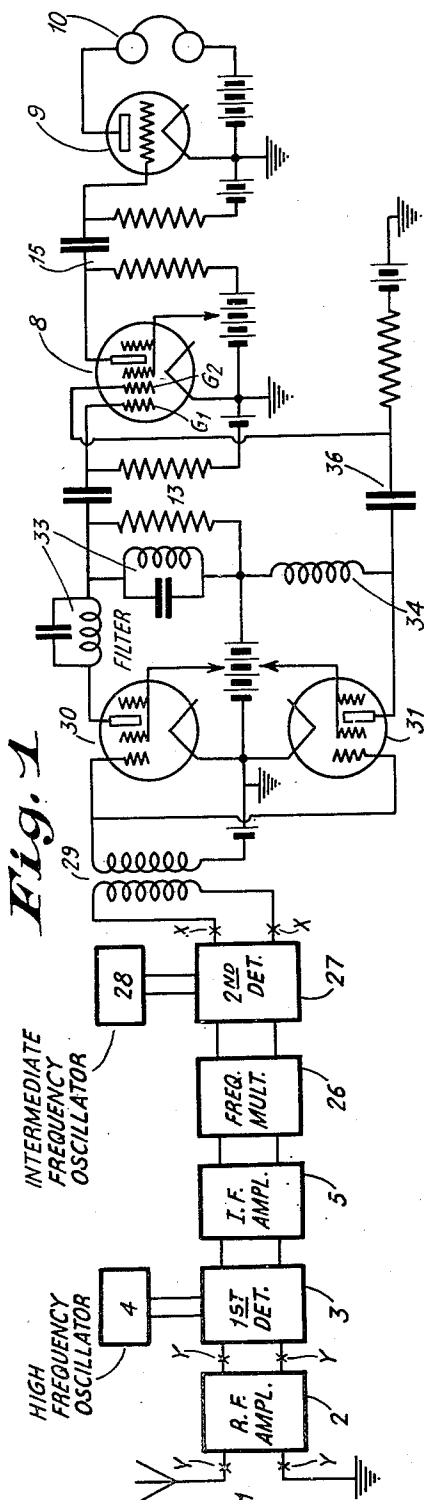
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2,087,429

PHASE AND FREQUENCY MODULATION WAVE RECEIVING SYSTEM

Filed June 6, 1935

2 Sheets-Sheet 1



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Fig. 3

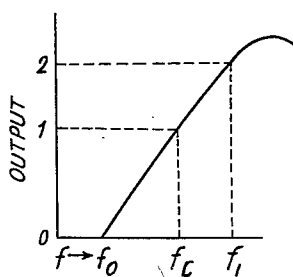


Fig. 4

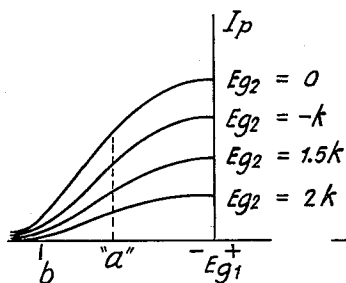


Fig. 5

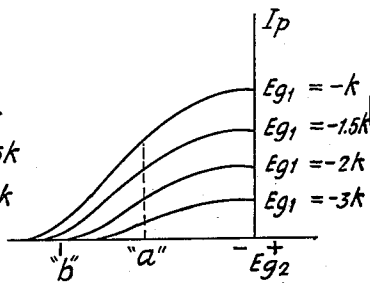


Fig. 6

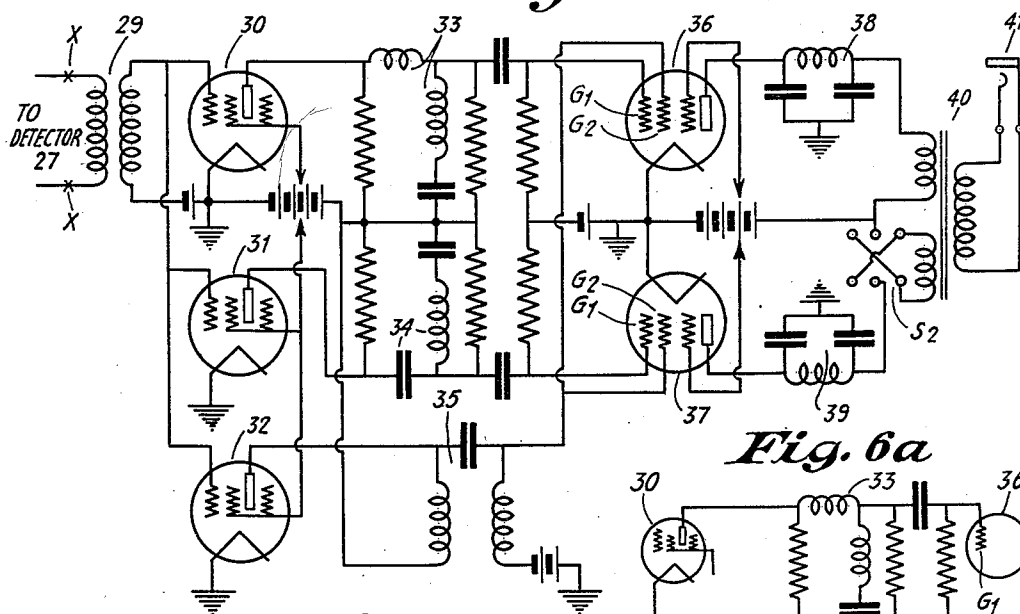


Fig. 6a

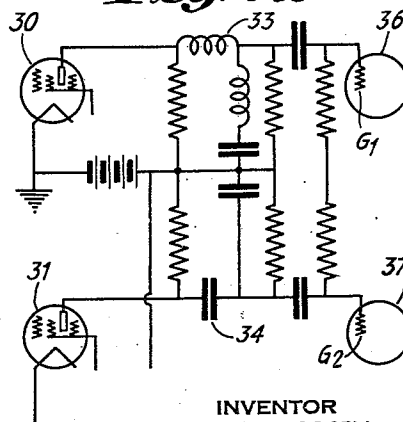
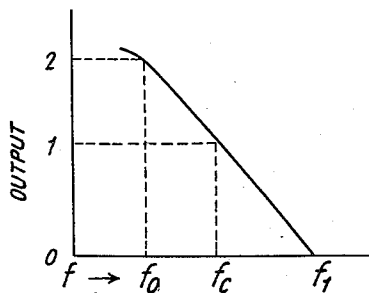


Fig. 7



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2,087,429

PHASE AND FREQUENCY MODULATION
WAVE RECEIVING SYSTEMMurray G. Crosby, Riverhead, N. Y., assignor to
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Application June 6, 1935, Serial No. 25,231

16 Claims. (Cl. 250-20)

This invention relates to a new and improved means for receiving, amplifying and demodulating high frequency waves modulated in phase or in frequency by intelligence to be transmitted.

More in detail this disclosure describes phase or frequency modulation receiving systems wherein a multi-grid detector is utilized. By feeding the filtered or retarded signal to one grid and the unfiltered signal to another grid, detection is accomplished by the use of a single detector tube without losing any of the advantages of a differential or dual detector system.

In the prior art, frequency modulation has been received by receivers which convert the frequency modulation to amplitude modulation and detect in the normal square-law manner. By utilizing two converting systems which produced amplitude modulated waves with their envelopes 180 degrees out of phase, together with two detectors whose detected outputs were combined differentially, unwanted amplitude modulation could be balanced out together with the second-harmonic square-law detector distortion.

In the receivers of this disclosure, the multi-grid detector takes the place of the differential detectors and does not require two conversion branches to produce amplitude modulations with envelopes 180 degrees out of phase. In this way design is simplified without losing any of the advantages of the more complicated systems.

The novel features of my invention have been pointed out with particularity in the claims appended to the end of this specification as required by law. The nature of my invention and the manner of operation thereof will be understood from the following detailed description of several specific embodiments of my novel receiving means and therefrom when read in connection with the attached drawings, throughout which like reference characters indicate like parts insofar as possible, and in which:

Fig. 1 illustrates the essential elements of a frequency modulated wave receiving, amplifying and demodulating system including a multiple grid tube detector connected in a novel circuit;

Figs. 2 and 6 are modifications of the system of Fig. 1;

Figs. 2a and 6a are modifications of portions of the circuits of Figs. 2 and 6, respectively;

Figs. 3 and 7 are curves illustrating the characteristics of filters in the output of the detectors of Figs. 2, 2a and 6, 6a, respectively; while

Figs. 4 and 5 are tube characteristic curves showing the mode of operation of the detector tubes of Figs. 1, 2, 2a, 6 and 6a.

In describing my invention, reference will first be made to Fig. 2. Fig. 2 shows an adaptation of a retard circuit type of frequency modulation receiver of the type disclosed in my copending U. S. application Ser. No. 618,154, filed June 20, 1932. In Fig. 2, the novel demodulation means of the present invention replaces the differential demodulator of said prior application. Here, the signal is fed from antenna 1 to radio frequency amplifier 2, comprising the desired number of thermionic amplifiers. The amplified signal is fed from the radio frequency amplifier 2 to a first detector comprising a thermionic tube 3 of the multi-grid electrode type, and a source of high frequency oscillations 4, which produces oscillations to be beat with the signal in 3 to produce an intermediate frequency output which is fed to the intermediate frequency amplifier 5. The signals from the amplifier 2 may be fed to either of the grids in 3, while the high frequency oscillations from 4 may be fed to the other grid in 3. The intermediate frequency amplifier 5 may also include a bandpass filter. The intermediate frequency energy from the output of amplifier and filter 5 is fed to the input end of a retard circuit 6, which is terminated at the other end by a variable resistance R. The applied intermediate frequency wave sets up incident and reflected waves in the series inductance of the retard circuit 6. The relative phases of the incident and reflected waves in 6 may be regulated as desired by means of the adjustable resistance R and/or the values of the capacities and inductance in the circuit 6. Intermediate frequency potential variations are applied from the input end of the retard circuit 6 to one of the grids, say grid G1 of detector tube 8 by way of a tapped resistance 7. Intermediate frequency potentials are also applied from a point on the retard circuit 6 directly to the other grid, say grid G2 of detector 8. The audio output of detector 8 is resistance coupled by a resistance and capacity unit 15 to the control grid of an audio frequency amplifier 9 and will appear in the indicator or recording device 10. In a more specific application, the resistance coupling 15 between the output of detector 8 and the input of audio frequency amplifier 9 may be replaced by a low pass filter 12, as shown in Fig. 2a. The filter 12 removes the remaining carrier frequency components from the energy in the output of the detector 8 and from the input of the audio frequency amplifier 9, and also provides a low impedance path for the carrier frequency.

The novel part of the invention of Fig. 2 and 2a

lies in the circuits, following the intermediate frequency amplifier 5, wherein the frequency modulation is translated. The following analysis describes the operation of this type of demodulating circuit. The retardation circuit 6 may be any kind of circuit which produces a time delay. This would include a low-pass filter, high-pass filter, band-pass filter, tuned transformer, artificial line or any of the many available time delay networks. Calling the time de-

lay D , the phase of the output of such a circuit would be:

$$\alpha = 2\pi \frac{D}{T} \quad (1)$$

where T is the period of the wave applied and α is in radians. This may be rewritten:

$$\alpha = 2\pi Df \quad (2)$$

$$\alpha = 2\pi l f / V \quad (2a)$$

where f is the frequency of the applied wave, l is the electrical length of the retard circuit and $V = 3 \cdot 10^8$ meters per second.

Thus, the phase of the output of the retard circuit is directly proportional to the applied frequency. In the case of a frequency modulated wave given by:

$$e = E \cos (wt - fd/fm) \cos pt \quad (3)$$

where $w = 2\pi$ carrier frequency, fd = frequency deviation with modulation and $p = 2\pi/fm$ where f = the modulating frequency, the instantaneous frequency is given by

$$\frac{d(wt - fd/fm \cos pt)}{dt} = 2\pi(fc + fd \sin pt) \quad (4)$$

$$f = (fc + fd \sin pt) \quad (5)$$

Substituting (5) in (2) gives:

$$\alpha = 2\pi D(fc + fd \sin pt) \quad (6)$$

Hence, the wave passed through the retardation circuit has the phase given by (6) added to it or

$$e = E \cos \{wt - fd/fm \cos pt + 2\pi D(fc + fd \sin pt)\} \quad (7)$$

The grids of the detector 8 are adjusted according to the characteristics of Figs. 4 and 5. Both grids are adjusted to point "a" which is the linear portion of the characteristic. Thus, in accordance with the general description of this detector given in my U. S. application Ser. No. 716,469, filed March 20, 1934, Patent No. 2,063,588, December 8, 1936, the variable current in the output of the detector would be substantially given by:

$$J = a_1 a_2 e_1 e_2 \quad (8)$$

where a_1 and a_2 are constants of the tube and e_1 and e_2 are the two grid voltages. Applying the unretarded voltage of Equation (3) to one grid, say G1, and the retarded voltage of (7) to the other grid, say G2, gives as the variable output:

$$J = a_1 a_2 E_1 \cos (wt - fd/fm \cos pt) \times E_2 \cos [wt - fd/fm \cos pt + 2\pi D(fc + fd \sin pt)] \quad (9)$$

simplifying and eliminating radio frequency terms which would be eliminated by the low pass filter in the detector output, the variable output would be:

$$J = \frac{a_1 a_2 E_1 E_2}{2} [\cos 2\pi Dfc \cos 2\pi Dfd \sin pt - \sin 2\pi Dfc \sin 2\pi Dfd \sin pt] \quad (10)$$

In practice $2\pi Dfc$ is adjusted to equal $\pi/2$, $3\pi/2$, $5\pi/2$, etc., so that

$$J = \frac{a_1 a_2 E_1 E_2}{2} \sin 2\pi Dfd \sin pt \quad (11)$$

by applying the Bessel Function Expansion:

$$\sin (X \sin \phi) = [2J_1(X \sin \phi) + 2J_3(X \sin 3\phi) + \dots] \quad (12)$$

the following is obtained:

$$J = \frac{a_1 a_2 E_1 E_2}{2} [J_1(2\pi Dfd) \sin pt + J_3(2\pi Dfd) \sin 3\phi + \dots] \quad (13)$$

Thus, the output of the detector consists of the fundamental frequency $\sin pt$ proportional to a first order Bessel function of $2\pi Dfd$, and all the odd harmonics of the modulation frequency. The second harmonic, which normally is present in square-law detection, is absent from the output of this detector.

The circuit of Fig. 1 shows a sloping filter type of receiver utilizing the multi-grid detector and also showing the utilization of the principle described in my U. S. application Ser. No. 25,026, filed June 5, 1935, wherein frequency multiplication is employed at the receiver. The output of the intermediate frequency amplifier 5 is supplied to a frequency multiplier 26. This multiplier may be any type known, such as a harmonic generator, a multiplier of the overloaded thermionic tube type, etc. The signal modulation carrying energy of increased frequency is supplied from the output of the frequency multiplier 26 to the input of a second detector 27, which is also coupled to an intermediate frequency oscillator 28. The frequency multiplier in 26 increases the depth of modulation of the frequency modulated wave, or depth of modulation of the phase modulated wave, where phase modulation is to be received and the final detector is to be followed by a correction circuit, the output of which is inversely proportional to the modulation frequency. The manner in which the modulation depth is increased by multiplying the frequency of the wave is set forth in my U. S. application Ser. No. 704,257, filed Dec. 28, 1933 and also my U. S. application Ser. No. 25,026, filed June 5, 1935. An audible frequency correction circuit having the characteristics described above to be inserted in the circuit after the final detector has been described in my U. S. appn. Ser. No. 618,154, filed June 20, 1932. Heterodyning the frequency multiplied wave to a different frequency in 27 does not affect the depth of modulation of the frequency or phase modulated wave. The theory of this operation has been disclosed in detail in my U. S. appn. Ser. No. 704,257, filed Dec. 28, 1933. If frequency multiplication at the receiver is not desired, the output of the intermediate frequency amplifier 5 may be fed directly to the primary of transformer 29, thereby eliminating units 26, 27 and 28.

Transformer 29 supplies energy to the control grids of tubes 30 and 31. The plate circuit of coupling tube 30 includes a filter 33, having a sloping characteristic, such as shown in Fig. 3. Such a filter may take many alternative forms, such as the side of a bandpass filter, band elimination filter, low-pass or high-pass filter, all of which are known in the filter art. The main requirement is that the characteristic slope linearly from substantially zero output at one side of the wave channel to a maximum at the other

side of the wave channel, as shown in Fig. 3. The output of filter 33 is connected by the resistance and capacity coupling 13 to one of the grids, say grid G1, of detector tube 8. The output of the coupling tube 31 is fed by way of the coupling impedance 34 and capacity 36 to the other grid, say grid G2, of detector tube 8. The control grid of the audio frequency amplifier 9 is resistance coupled by way of 15 to the plate electrode of the detector tube 8. The resistors and condenser of coupling unit 15 may be replaced by the low-pass filter, as shown in Fig. 2a, for eliminating the carrier wave components and other unwanted frequency, as well as providing a low impedance path for the carrier frequencies. The output of amplifier 9 may be supplied to any recording device or indicating device or utilization device 10.

In the type of receiver of Fig. 1, the filter 33 converts the frequency modulation to amplitude modulation. However, since the grids of detector 8 are operating on the linear part of their characteristics, there will be no detection with only the output of the filter fed to the detector grid. Consequently, the unfiltered output must be fed to the other grid via impedance coupling 34 so that the two waves may coact to produce detection. The manner in which the detection takes place is explained in the following:

When an alternating voltage is passed through a filter having a characteristic as shown in Fig. 3, the output will be given by:

$$E_{out} = E \sin \frac{2}{(f - f_0)}(f - f_0) \quad (14)$$

where f is the frequency of the input voltage. (14) may also be written:

$$E_{out} = E \sin \frac{1}{(f_c - f_0)}(f - f_0) \quad (15)$$

Applying the frequency modulated wave of Equation (3) which has a frequency given by Equation (5) to the input of this filter gives the following output voltage:

$$e = E \left[\frac{1}{f_c - f_0} \times (f_c + f_d \sin pt - f_0) \right] \cos (wt - fd/fm \cos pt) \quad (16)$$

Simplifying:

$$e = E \left[1 + \frac{fd}{f_c - f_0} \sin pt \right] \cos (wt + fd/fm \cos pt) \quad (17)$$

Thus, the frequency modulated wave is given an envelope $[1 + fd/fc - f_0 \sin pt]$ which has the same form as the familiar amplitude modulation envelope and whose percentage of modulation is $fd/fc - f_0$.

Detector 8 of Fig. 1 has applied to one grid, say, grid G1 the voltage given by Equation (17) and to the other grid, say grid G2, the voltage given by Equation (3). Substituting these in Equation (8) gives as the variable output (neglecting direct current terms and radio frequency terms removed by detector output filter):

$$J = \frac{a_1 a_2 E_1 E_2}{2} (fd/fc - f_0) \sin pt \quad (18)$$

From (18) it can be seen that the fundamental of the modulation is received free from harmonics and linearly dependent upon the depth of modulation.

The circuit of Fig. 6 makes it possible to balance out the undesired amplitude modulation for the sloping filter type of circuit. In the retard circuit type of detection, the amplitude modulation is inherently balanced out with the use of

one detector only. In order to balance out the amplitude modulation when sloping filters as in Fig. 1 are used, a differential detection arrangement as shown in Fig. 6 must be utilized.

Referring to Fig. 6, intermediate frequency energy from a superheterodyne receiver is fed to transformer 29 and distributed to coupling tubes 30, 31 and 32. In the plate of coupling tube 30 is a filter providing a characteristic as shown in Fig. 3. In the plate of coupling tube 31 is a filter providing a characteristic of opposite slope to Fig. 3, such as shown in Fig. 7. The outputs of filters 33 and 34 are fed to detector grids G1 of detectors 36 and 37. The output of coupling tube 32 is fed via aperiodic impedance coupling 35 to the second grids G2 of detectors 36 and 37. Filters 38 and 39 remove the carrier energy from the detector output. Transformer 40 combines the detector outputs in the push-pull or series connection, depending upon the position of switch S2. The output is made available at jack 41. For frequency modulation reception, switch S2 would have the push-pull connection. For amplitude modulation reception, the parallel connection would be used. When frequency modulation is being received, the amplitude modulation would be balanced out and when amplitude modulation is being received, the frequency modulation would be balanced out.

From the preceding mathematics, it is fairly easy to understand the balancing action of the circuit of Fig. 6. Since the two filters have opposite slopes, the amplitude modulation envelopes fed to the two detectors will be 180 degrees out of phase and their detected outputs will combine in-phase with the push-pull connection of transformer 40. The undesired amplitude modulation will be unaffected by the filters and will produce detector outputs in-phase; consequently, the push-pull connection will cancel or balance out the undesired amplitude modulation.

In the circuit of Fig. 6 it would be possible to substitute an aperiodic coupling, such as an impedance or resistance coupling, as shown in Fig. 6a, in place of one of the filters 33 or 34. This would make one of the detectors receive the frequency modulation plus the undesired amplitude modulation and the other detector, only the undesired amplitude modulation. Consequently, the push-pull connection of transformer 40 would balance out the undesired amplitude modulation and leave the frequency modulation.

As is well known in the art of frequency modulation, limiting could be used in conjunction with any of these receivers. In the case of the sloping filter type circuit, if limiting were used, the balanced circuits of Fig. 6 and 6a would not be required since the limiter would remove the undesired amplitude modulation. The limiter could be inserted at the points "X" in the intermediate frequency leads following the intermediate frequency amplifier of any of the circuits or could be inserted in the radio frequency circuits at the points "Y", if desired.

Any of these receivers could be used for the reception of phase modulation by the addition of a correction circuit following the output jack. This correction circuit would have its output inversely proportional to the modulation frequency as is described in my U. S. appln. Ser. No. 618,154, filed June 20, 1932.

The principle described in my U. S. appln. Ser. No. 25,026, filed June 5, 1935, wherein frequency multiplication is employed at the receiver to increase the depth of modulation, could

be applied to the receiver of Figs. 2 and 2a as well as the one of Fig. 1. This would probably be most conveniently accomplished by tuning oscillator 4 to approximately twice the signal frequency and operating the grids of detector 3 at points "b" of their characteristics.

What is claimed is:

1. In a system for demodulating a frequency modulated wave, a wave retarding circuit comprising inductive and capacitive reactances, means for applying frequency modulated waves to be demodulated to said circuit to produce therein wave energy of a phase directly proportional to the frequency modulations on the applied wave, a thermionic tube having a plurality of control electrodes, a circuit connecting one of said control electrodes to a point on said wave retarding circuit to apply produced wave energy to said control electrode, and a circuit coupling the other of said control electrodes to said means to apply original frequency modulated wave energy to said other electrode.

2. In a system for demodulating a frequency modulated wave, a wave retarding circuit comprising inductive and parallel capacitive reactances, means for applying frequency modulated waves to be demodulated to said circuit to produce therein wave energy of a phase directly proportional to the frequency modulations on the applied wave, a thermionic tube having an anode, a cathode and a plurality of grid-like electrodes, a connection between one of said grid-like electrodes and a point on said wave retarding circuit to impress produced energy on said one of said grid-like electrodes, a connection between the other of said grid-like electrodes and said means to apply original frequency modulated wave energy to said other electrode, means for applying biasing potentials between said grid-like electrodes and said cathode, and an indicator coupled to the anode of said tube.

3. A system as recited in claim 2 in which a low pass filter is interposed between said indicator and the anode of said tube.

4. In a system for demodulating a frequency modulated wave, wave receiving means, a thermionic tube having a cathode and a plurality of grid-like electrodes, a tuned reactance acting as a filter having a sloping characteristic connecting one of said grid-like electrodes to said wave receiving means, and an impedance acting as a filter having a characteristic which is uniform over the frequency range of the received wave coupling a second grid-like electrode in said tube to said wave receiving means.

5. In a system for demodulating amplitude or phase or frequency modulated waves, wave receiving means, a plurality of thermionic tubes each having a plurality of grid-like electrodes, a cathode and an anode, separate circuits each including a filter having sloping characteristics which slope in opposite sense coupling like grid-like electrodes in said tubes to said wave receiving means to excite the said like grid-like electrodes differentially in accordance with the amplitude variations superimposed on said modulated waves passed by said filters, and a second circuit including a filter having a flat topped characteristic coupling like grid-like electrodes in each of said tubes in phase to said wave receiving means.

6. A system as recited in claim 5 in which each of said separate circuits includes a coupling tube.

7. In a system for demodulating amplitude or phase or frequency modulated waves, wave re-

ceiving means, a plurality of electron discharge tubes each having a plurality of grid-like electrodes, a cathode and an anode, separate circuits each including a filter having sloping characteristics which slope in opposite sense coupling like grid-like electrodes in said tubes to said wave receiving means, a third circuit including a filter having a flat topped characteristic coupling like grid-like electrodes in each of said tubes to said wave receiving means, and a circuit connecting the anode of each of said tubes to indicating means.

8. In a system for demodulating an amplitude, phase or frequency modulated wave, wave receiving means, a plurality of electron discharge tubes each having a plurality of grid-like electrodes, a cathode and an anode, two circuits each including a filter having sloping characteristics which slope in opposite sense coupled at their outputs to like grid-like electrodes in said tubes, a third circuit including an impedance coupled at its output to like grid-like electrodes in each of said tubes, and a separate coupling tube coupling the input of each of said circuits to said wave receiving means.

9. In an amplitude or phase or frequency modulated wave demodulating system, wave receiving means, wave amplifying means coupled to said receiving means, frequency multiplying means coupled to said amplifying means, a pair of electron discharge tubes each having a control grid and an anode, a circuit connecting the control grids of both of said tubes to the output of said frequency multiplier, a filter circuit having a sloping characteristic coupled to the anode of one of said tubes, a circuit having a flat topped characteristic coupled to the anode of the other of said tubes, a detector tube having an anode, a cathode and a plurality of grid-like electrodes, a connection between one of the grid-like electrodes of said detector tube and the filter circuit of sloping characteristics connected with the anode of one of said first named tubes, and a circuit connecting another grid-like electrode of said detector tube to said circuit having a flat topped characteristic connected with the anode of the other of said first named tubes.

10. In a phase or frequency modulated wave demodulating means, signal receiving and amplifying means, a frequency multiplier connected to said amplifying means, said frequency multiplier having an output, two thermionic coupling tubes each having a control grid a cathode and an anode, a circuit coupling the control grid and cathode of each of said coupling tubes in phase to the output of said frequency multiplier, a filter circuit having a sloping characteristic coupled to the anode of one of said coupling tubes, a separate filter circuit having a flat topped characteristic coupled to the anode of the second of said coupling tubes, a thermionic detector having a cathode, and a plurality of grid-like electrodes, and circuits connecting said filter circuits to different grid-like electrodes in said detector tube.

11. In a frequency or phase modulated wave demodulating means, wave receiving means, a frequency multiplier connected to said wave receiving means, three thermionic coupling tubes each having a control grid a cathode and an anode, a circuit coupling the control grid and cathode of each of said coupling tubes to said frequency multiplier, a filter circuit having a sloping characteristic coupled to the anode of one of said coupling tubes, a filter circuit having a

characteristic which slopes in a different direction with respect to the characteristic of said first named filter circuit coupled to the anode of the second of said coupling tubes, an impedance coupled to the anode of the third of said coupling tubes, a pair of thermionic detector tubes each having a cathode and a plurality of grid-like electrodes, circuits connecting said filter circuits in push-pull relation to like grid-like electrodes in said pair of detector tubes, and a circuit coupling said impedance in parallel to other like grid-like electrodes in said detector tubes.

12. In a system for demodulating a phase or frequency modulated wave, wave receiving means, an electron discharge tube having an output electrode, a cathode and a plurality of control electrodes, a circuit including a filter whose attenuation varies substantially linearly with the frequency of the received frequency modulated wave connecting one of said control electrodes to said wave receiving means, an additional circuit including a filter whose attenuation is substantially uniform for all frequencies of the received frequency modulated wave coupling a second control electrode in said tube to said wave receiving means, and an output circuit connected with the output electrode of said tube.

13. A system as recited in claim 12 in which a low pass filter is connected in said output circuit.

14. In a system for demodulating a phase or frequency modulated wave, means for receiving said wave, an electron discharge tube having an anode, a cathode and a plurality of grid-like electrodes, a circuit including a filter connecting one of said grid-like electrodes to said wave receiving means to impress wave energy on said grid-like electrode from said receiving means, an additional circuit including an impedance coupling a second grid-like electrode in said tube to said wave receiving means to impress additional wave energy on said second grid-like electrode from said wave receiving means, said circuits having outputs which vary in different respects relative to the variations in phase or frequency of the received wave energy, biasing means connected between the cathode of said

tube and each grid-like electrode, and a utilization circuit coupled to said anode and cathode.

15. The method of demodulating phase or frequency modulated wave energy by means of an electron discharge device having a plurality of control electrodes, a cathode, and an anode, which consists in producing wave energy the phase of which is varied as a function of the phase or frequency modulations of the said phase or frequency modulated wave energy, applying said produced wave energy between the cathode and one of said control electrodes, applying phase or frequency modulated wave energy whose phase has not been so altered between the other of said control electrodes and the cathode, and biasing both of said control electrodes relative to the cathode by potentials such that said tube operates on the linear portion of the control electrode potential plate current characteristic curves, and utilizing the resultant energy from the anode and cathode of said tube.

16. In a signalling system, a source of phase or frequency or amplitude modulated wave energy, three electron discharge devices each having a control grid, a cathode and an anode, a circuit coupling the control grids and cathodes of all of said tubes in parallel to said source of modulated wave energy, a filter circuit having a sloping characteristic connected at its input to the anode and cathode of one of said tubes, said filter circuit having an output, a second filter circuit having a sloping characteristic connected at its input to the anode and cathode of a second one of said tubes, a pair of electron discharge detector tubes each having a plurality of control electrodes, a cathode and an anode, circuits connecting the outputs of said filter circuits in push-pull relation to like control electrodes in said detector tubes, a circuit having a flat topped characteristic connected at its input to the anode of the third of said first named three tubes, said last named circuit having an output, means connecting the output of said last named circuit in parallel with other like control electrodes in said pair of detector tubes, and means for connecting the anodes of said detector tubes in push-pull or in parallel.

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