

Sept. 15, 1942.

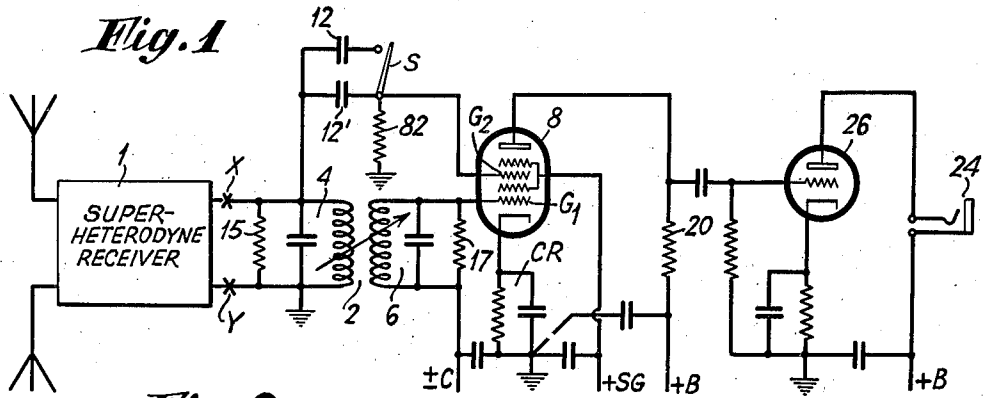
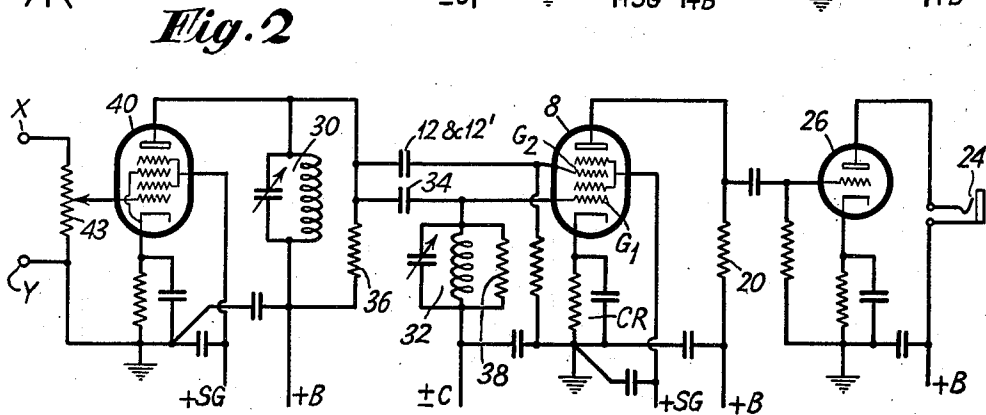
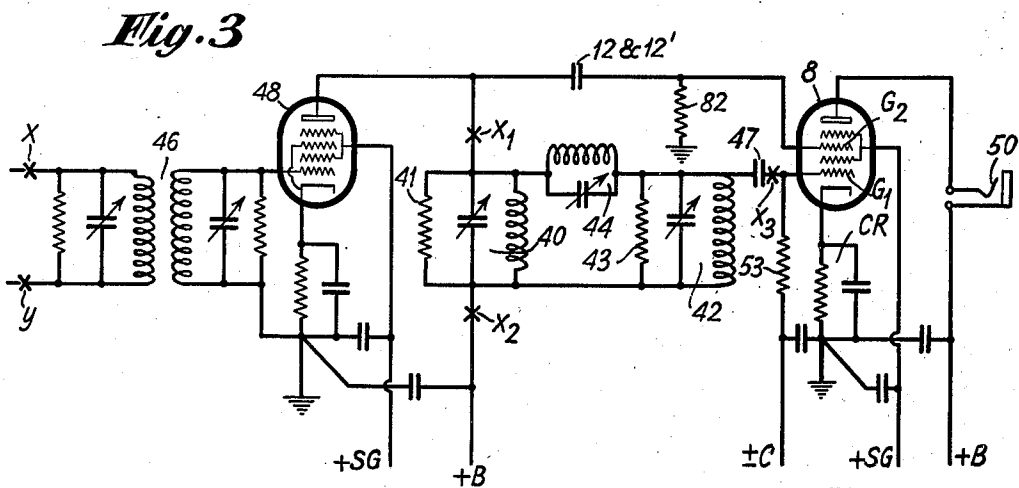
M. G. CROSBY

2,296,090

FREQUENCY MODULATION RECEIVER

Filed April 6, 1940

3 Sheets-Sheet 1



INVENTOR
MURRAY G. CROSBY
BY *H. S. Brown*
ATTORNEY

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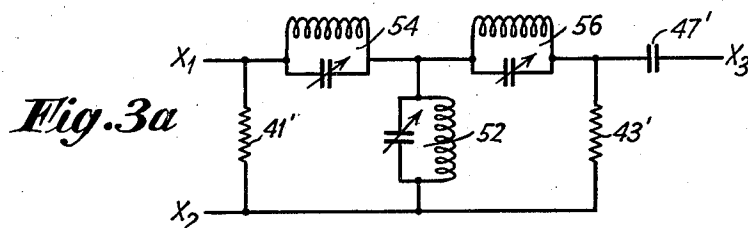
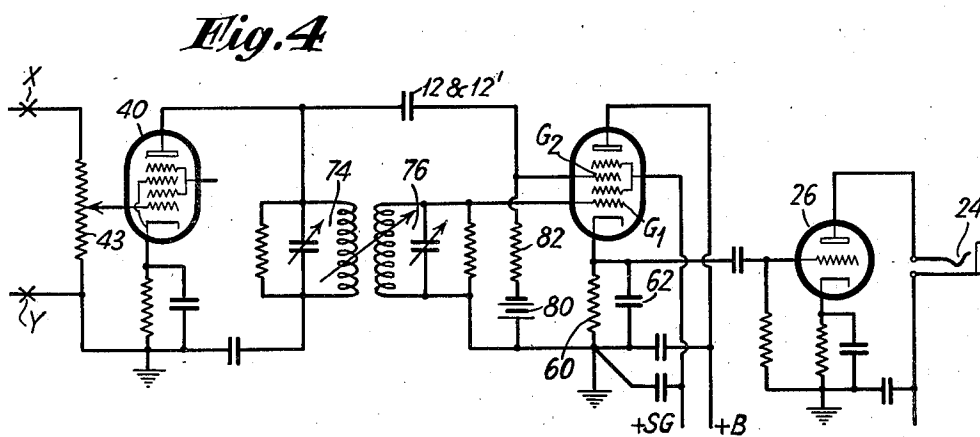
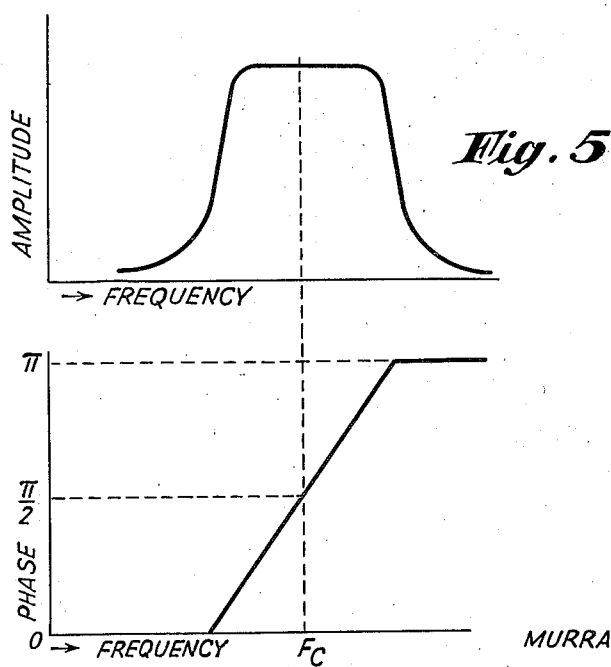
M. G. CROSBY

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FREQUENCY MODULATION RECEIVER

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3 Sheets-Sheet 2



INVENTOR
MURRAY G. CROSBY
BY *H. S. Brown*
ATTORNEY

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FREQUENCY MODULATION RECEIVER

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3 Sheets-Sheet 3

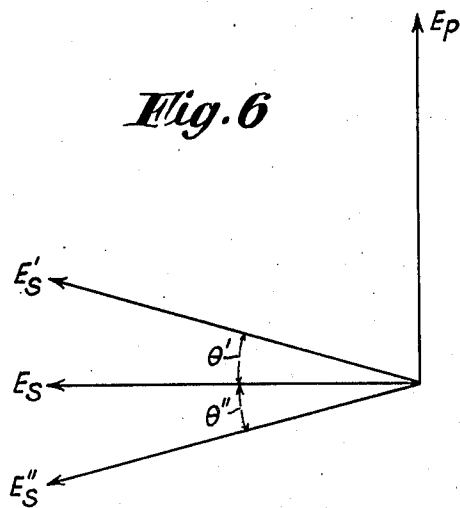
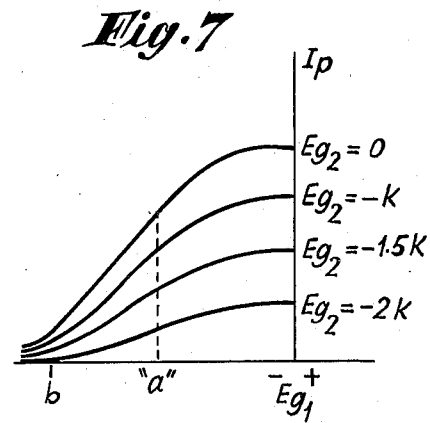
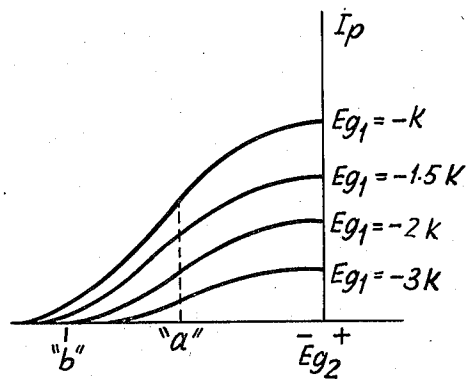


Fig. 8



INVENTOR
MURRAY G. CROSBY
BY *H. S. Brown*
ATTORNEY

UNITED STATES PATENT OFFICE

2,296,090

FREQUENCY MODULATION RECEIVER

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

Application April 6, 1940, Serial No. 328,353

4 Claims. (Cl. 250—27)

This application concerns new and improved detectors of the type in which the frequency modulated energy is passed through a wave phase or frequency retarding circuit and is caused to co-act with frequency modulated wave energy unretarded. Various circuits incorporating band-pass filters for the retard circuits are shown. Multi-grid detectors are used to combine the retarded and unretarded energy and produce a detected output.

In the prior art of frequency modulation detection by combining modulated waves with modulated waves passed by a retarding circuit as described in United States application #618,154, filed June 20, 1932, artificial lines have been used for the retard circuits and square-law detectors for the detector tube. In this application, I make use of band-pass filters to retard the modulated wave and the retarded voltage and unretarded voltage are applied to multi-grid detectors. That is, in this application the principle disclosed in my United States Patent #2,087,429, dated July 20, 1937, is utilized.

In describing my invention reference will be made to the attached drawings wherein:

Figs. 1, 2, 3 and 4 each show different forms of my frequency modulated wave demodulator comprising the multi-grid detector to the grids of which the voltage to be demodulated is fed over a direct path and a phase retarding path.

Fig. 3a illustrates a modification of the arrangement of Fig. 3.

Fig. 5 illustrates graphically the phase and amplitude characteristics of the band-pass filters or retard circuits plotted against frequency.

Fig. 6 is a vector diagram used to describe the operation of the detectors.

Figs. 7 and 8 are characteristic curves for the grids of the multi-grid detector tubes.

In the circuit of Fig. 1, the retard circuit takes the form of transformer 2 having a tuned primary 4 coupled to a tuned secondary winding 6 which feeds one of the grids, say grid G_1 , of multi-grid detector 8. The modulated wave input to this retard circuit may be derived in any manner such as for example from a radio-frequency amplifier or as shown from the intermediate-frequency amplifier of a superheterodyne detector and amplifier illustrated diagrammatically at 1. As stated above, voltage at the intermediate frequency is furnished by way of the retard circuit from superheterodyne receiver 1 to the grid G_1 and also is supplied over a more direct path to another grid G_2 of the detector 8 via coupling condensers 12 and 12' and switch S. Resistors 15 and 17 properly damp the tuned input and tuned output windings of the transformer. By virtue of the multi-grid detector action as described more completely in my United States Patent #2,087,429 dated July 20, 1937, the

frequency modulated energy appearing at intermediate frequency at the output of the receiver 1 is detected so that the signal waves appear across resistor 20. These signalling waves are made available for utilization at jack 24 by means of amplifier tube 26.

In the circuit of Fig. 2, the same principles of Fig. 1 are applied with a slightly different band-pass filter or retard circuit. In Fig. 2 the band-pass filter consists of tuned circuits 30 and 32 which are coupled capacitively by condenser 34. The input and output of this filter are properly damped by resistors 36 and 38. Coupling and amplifying tube 40 receives the frequency modulated energy upon its grid from potentiometer 43. Terminals X and Y are connected to the intermediate-frequency output of receiver 1 of Fig. 1. One of the grids, say G_1 , of multi-grid detector 8 is fed by the output of the band-pass filter, comprising tuned circuits 30 and 32 and the other grid, say G_2 , is fed by unretarded intermediate-frequency voltages via coupling condenser 12. Consequently, retarded and unretarded frequency modulated energy will be present on the two grids so that the signalling waves will appear across resistor 20 as in Fig. 1. Amplifier tube 26 makes the output available for utilization at jack 24. In this circuit the band-pass filter is shown capacitively coupled instead of inductively coupled as in Fig. 1. It will be apparent to those skilled in the art that condenser 34 of Fig. 2 may be replaced by an inductance and a blocking condenser or a resistance and a blocking condenser.

The circuit of Fig. 3 utilizes a retard circuit employing tuned circuits 40 and 42 which are coupled together by means of tuned circuit 44. Intermediate-frequency energy is applied to transformer 45 and amplified by coupling and amplifier tube 49. Tuned circuits 40 and 42 are damped by resistances 41 and 43, respectively. The retarded voltage is supplied through the retard path to condenser 47 and from condenser 47 to the grid G_1 of tube 8. The unretarded voltage is supplied over a more direct path including condenser 12 to the grid G_2 . Detection takes place here as in the prior modifications as will be described below and the detected output is made available for utilization in the plate circuit of multi-grid detector 8 by means of jack 50.

Fig. 3a shows an alternative connection of the band-pass filter or retard circuit. The connections of Fig. 3 are broken at X_1 , X_2 , and X_3 and the circuit elements of Fig. 3a between the said points of X_1 , X_2 and X_3 damping resistors 41' and 43' are connected across the ends of the phase retarding network. In Fig. 3a, two series parallel-tuned circuits 54 and 56 are connected between the anode of tube 49 and coupling condenser 47' which corresponds to condenser 47 of

Fig. 3. The circuit 52 is connected in shunt to the series connections as shown and tuned to the mean intermediate frequency.

In the circuits of Figs. 1, 2, and 3 and 3a, cathode bias is shown for the detector tubes. This bias is produced in the condenser resistance units CR in the cathode circuits. This cathode bias may be utilized for either grid of the detector and a differential amount of bias may be applied to the other grid to take care of the different biases which might be required on the two grids. Consequently, the first grid bias may be plus or minus depending upon whether its normal operating point is more or less negative than the operating point of the second grid.

In the circuit of Fig. 4 the multi-grid detector 8 is connected so as to produce a detector of the so-called "infinite impedance" type. With this type of detection the audio output from the multi-grid detector 8 is taken from its cathode resistor 60 shunted by intermediate-frequency bypass condenser 62. The intermediate-frequency energy is applied to terminals X and Y, amplified by tube 40 and fed directly to the second grid, of the multi-grid G₂ by way of condenser 12. The same energy is retarded by means of tuned transformer 74, 76 and fed to the first grid G₁ of the detector 8. Note these circuits are quite similar to those shown in Fig. 1 of the drawings. Differences in bias of the two grids G₁ and G₂ is taken care of by means of direct-current source 80 which feeds bias voltage to the second grid G₂ through grid leak 82. However, by proper design of tube, this battery may be eliminated. The detected output is amplified by tube 26 and made available for utilization at jack 24.

All of the receivers shown in Figs. 1, 2, 3, 3a and 4 have retard circuits consisting of band-pass filters having amplitude and phase characteristics as shown in Fig. 5. For further information in that respect, reference is made to the "Electrical Engineers Handbook," by Pender and McIlwain, volume V, section 7, pages 49 to 50. It will be noted that the phase characteristic is such that there is a permanent shift of 90 degrees for the carrier frequency and that the phase varies above and below 90 degrees as the frequency is shifted above and below the carrier frequency. Thus, the vector diagram of the primary and secondary voltages is as shown in Fig. 6 where E_p indicates the voltage at the primary or input terminals of the retard circuit and E_s indicates the voltage on the secondary or output terminals. When the frequency is shifted above and below the carrier frequency the output vector takes the positions E_s' and E_s'' with the phase shifts θ' and θ''.

The operation of the system disclosed here which causes demodulation of the frequency modulations to take place when one voltage is displaced 90 degrees and has a superimposed phase shift with frequency will now be described.

The pentode detector 8 has a voltage fed to one grid, G₁, which has a phase given by

$$\phi = \frac{\pi}{2} + K F_d \quad (1)$$

where F_d is amount the frequency is deviated with modulation from the carrier frequency. K is a constant which relates the phase shift due to off-tuning in the tuned circuit to the frequency deviation from the in-tune position. In the case of the frequency modulated wave, F_d varies in accordance with the modulation so that it has

the value F_d sin pt where p=2π times the modulation frequency, F_m. Hence,

$$\phi = \frac{\pi}{2} + K F_d \sin pt \quad (2)$$

When the frequency modulated wave given by:

$$e_1 = E_1 \cos (\omega t - F_d / F_m \cos pt) \quad (3)$$

where ω=2π times the carrier frequency, F_c, is applied as E in Fig. 1, the drop across tuned circuit 2 will have the phase given by (2) added to it or:

$$e_2 = E_2 \cos (\omega t - F_d / F_m \cos pt + \pi/2 + K F_d \sin pt) \quad (4)$$

The grids of the detector 8 are adjusted according to the characteristics of Figures 7 and 8. Both grids are adjusted to point a which is the linear portion of the characteristic. Thus, in accordance with the general detailed description of this detector given in my United States application Serial No. 716,469, filed March 20, 1934, Patent #2,063,588, dated December 8, 1936, the variable current in the output of the detector would be substantially given by:

$$J = a_1 a_2 e_1 e_2 \quad (5)$$

where a₁ and a₂ are constants of the tube and e₁ and e₂ are the two grid voltages. Applying the unshifted voltage of Equation 3 to one grid, say G₂, and the phase shifted voltage of (4) to the other grid, say G₁, gives as the variable output:

$$J = a_1 a_2 E_1 E_2 \cos (\omega t - F_d / F_m \cos pt) \cos \{ \omega t - F_d / F_m \cos pt + \pi/2 + K F_d \sin pt \} \quad (6)$$

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

$$J = \frac{a_1 a_2 E_1 E_2}{2} \cos (\pi/2 + K F_d \sin pt) \quad (7)$$

and since

$$\cos (\pi/2 + \alpha) = \sin \alpha \quad (8)$$

$$J = \frac{a_1 a_2 E_1 E_2}{2} \sin (K F_d \sin pt) \quad (9)$$

By applying the Bessel function expansion:

$$\sin (X \sin \phi) = 2J_1(X) \sin \phi + 2J_3(X) \sin 3\phi + \dots \quad (10)$$

the following is obtained:

$$J = a_1 a_2 E_1 E_2 [J_1(K F_d) \sin pt + J_3(K F_d) \sin 3pt + \dots] \quad (11)$$

Thus, the output of detector 8 consists of the fundamental frequency, sin pt, proportional to a first order Bessel function of (K F_d), and all the odd harmonics of the modulation frequency. The even harmonics are absent in the output of this detector. The frequency modulations on the wave have been demodulated and appear in the output circuit 20 of detector 10. This method of demodulation has been described in Crosby application #25,231, filed June 6, 1935, Patent No. 2,087,429, July 20, 1937.

If the waves fed to the two grids G₁ and G₂ are amplitude modulated instead of frequency modulated, the two waves fed to the grids will be:

$$e_1 = E_1 (1 + m \sin pt) \cos \omega t \quad (12)$$

$$e_2 = E_2 (1 + m \sin pt) \cos (\omega t + \pi/2) \quad (13)$$

where m is the amplitude modulation factor. Substituting these in (5) gives:

$$J = a_1 a_2 E_1 E_2 (1 + m \sin pt)^2 \cos \omega t \cos (\omega t + \pi/2) \quad (14)$$

which when simplified gives only radio-frequency, or no detected, output. Thus, under these conditions, the detector is unsusceptible to amplitude modulation as long as no frequency modulation is present. With frequency modulation present, the phase angle deviates from the value $\pi/2$ so as to let the amplitude modulation through. If the phase shift, $\pi/2$, is made zero, (14) may be simplified to:

$$J = a_1 a_2 E_1 E_2 (1 + m \sin pt)^2 (1/2 + 1/2 \cos 2 \omega t) \quad (15)$$

This gives a radio-frequency term and a detected output given by:

$$J = \frac{a_1 a_2 E_1 E_2}{2} (1 + 2m \sin pt + m^2 \sin^2 pt) \quad (16)$$

$$J = \frac{a_1 a_2 E_1 E_2}{2} \left[1 + 2m \sin pt + \frac{m^2}{2} - \frac{m^2}{2} \sin 2 pt \right] \quad (17)$$

The desired fundamental output is indicated by the term " $2m \sin pt$ " in (17). It will also be noted that there is a second harmonic component " $m^2/2 \sin 2 pt$." This shows that amplitude modulation may be received if the carrier phase shift is made zero instead of 90 degrees. This phase shift may be obtained by making blocking condenser 12 and 12' small so as to have a high reactance in comparison to grid-return resistor 82; for frequency detection 12 is small in reactance compared to the resistance of 82. The value of these blocking condensers is reduced by opening switch S to remove condenser 12' from the circuit. It is apparent that the optimum condition for amplitude modulation reception is with a phase shift of zero (or 180, or 360, etc.) degrees and the optimum condition for frequency modulation reception is with a phase shift of 90 (or 270, etc.). Thus it can be seen that if a frequency modulated wave is being received which is also amplitude modulated, the amplitude modulation is rejected in the absence of frequency modulating, during which time the phase is 90 degrees but as frequency modulation is applied, the phase departs towards zero and 180 degrees to let amplitude modulation through as the frequency deviates from the carrier frequency.

The above description principally concerns the type of detectors shown in Figs. 1, 2, and 3 in which the output is taken directly from the plate circuit of the tube. In the circuit of Fig. 4, the output is taken from the cathode circuit of the tube. However, since the cathode circuit is common to the plate circuit, it will be apparent that the operational characteristics are similar and need no further description.

There are two tunings which may be used in the circuits of Figs. 3 and 3a. In one the shunt-connected tuned circuit, or circuits, are tuned to the lower cut-off frequency of the band-pass filter and the series-connected tuned circuit, or circuits, are tuned to a higher frequency. In the other tuning, the shunt-connected tuned circuit, or circuits, are tuned to the upper cut-off frequency of the filter and the series-connected tuned circuit, or circuits, are tuned to a lower frequency. Either of these tunings work equally well since one effects a positive 90 degree phase shift at the carrier frequency and the other effects a negative shift.

What is claimed is:

1. In a system for demodulating a frequency modulated wave or an amplitude modulated wave,

an electron discharge tube having an output electrode, a first control electrode, a second control electrode and a cathode, a condenser for impressing either amplitude modulated wave energy or frequency modulated wave energy substantially directly between one of said control electrodes and cathode, a circuit parallel resonant substantially at the mean frequency of said amplitude modulated wave or frequency modulated wave energy a connection between spaced points on said parallel resonant circuit and the other of said control electrodes and cathode, means for adjusting the condenser to have a large reactance to demodulate said amplitude modulated wave and to have a small reactance to demodulate a frequency modulated wave, an output circuit connected with said cathode and said output circuit including a load resistor connected between the cathode and a point of relatively fixed alternating potential.

2. A system as recited in claim 1 wherein said parallel resonant circuit is shunted by an impedance to broaden its resonance characteristic.

3. In a system for demodulating amplitude modulated or frequency modulated wave energy, an electron discharge tube having an output electrode, a cathode and a plurality of control grid electrodes, a resistive load connected between the cathode and ground, a plurality of reactive circuits one of which is excited by either amplitude modulated or frequency modulated wave energy, a coupling between said reactive circuits, a coupling between one of said reactive circuits and one of said grid electrodes and ground, a reactance means for applying either amplitude modulated or frequency modulated wave energy substantially directly to the other of said grid electrodes, means for adjusting said reactance means to have a high reactance value for demodulating amplitude modulated waves and to have a low reactance value for demodulating frequency modulated waves, and a modulation frequency voltage output circuit connected across said resistive load.

4. In a system for demodulating amplitude modulated or frequency modulated wave energy, an electron discharge tube having an output electrode, a cathode and a plurality of control grid electrodes, a plurality of parallel resonant circuits one of which is excited by said either of said amplitude modulated or frequency modulated wave energy, said resonant circuits being tuned to the mean frequency of applied waves and there being sufficient coupling between said parallel resonant circuits to impart a band pass response characteristic thereto, a coupling between one of said parallel resonant circuits and one of said grid electrodes and said cathode, condensive means for impressing either amplitude modulated or frequency modulated wave energy substantially directly on the other of said grid electrodes and said cathode, a resistor connected from said other grid electrode to a point of invariable potential, means to adjust the condensive means to have either a large reactance relative to said resistor for amplitude modulation demodulation or a small reactance for demodulation of frequency modulated waves, and a modulation voltage output impedance in the space current path of said tube.

MURRAY G. CROSBY.