Jan. 7, 1947. W. R. KOCH 2,413,977

ANGLE-MODULATION WAVE RECEIVER

Filed Nov. 18, 1944 2 Sheets-Sheet 1

Fig. 1.

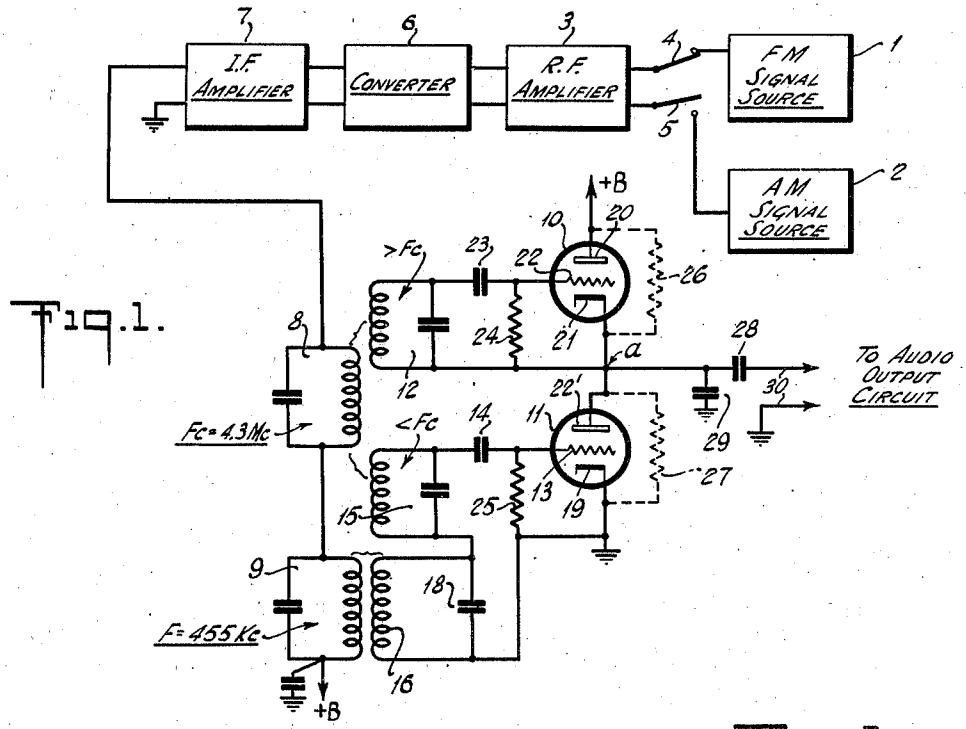
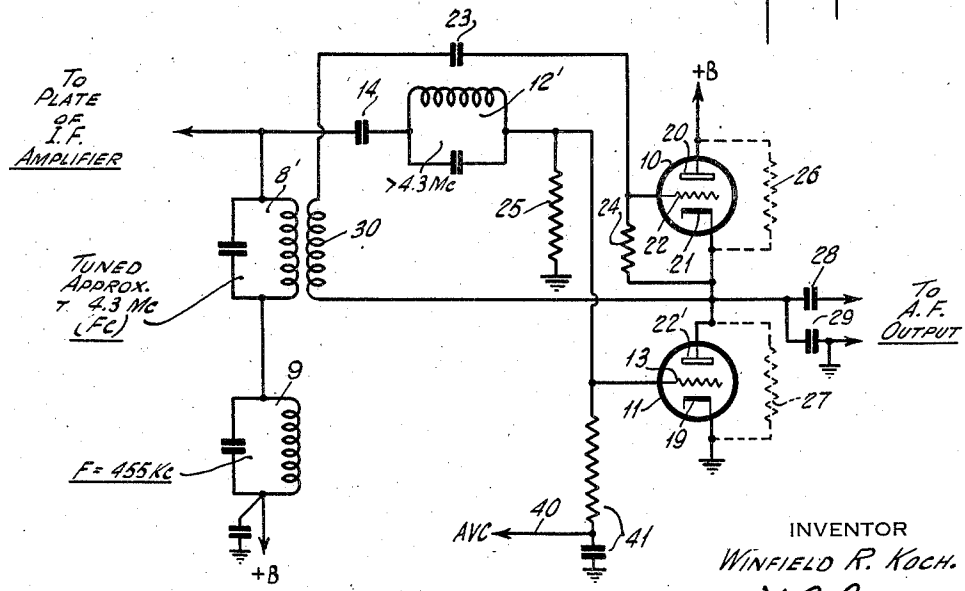



Fig. 2.




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Fig. 3.

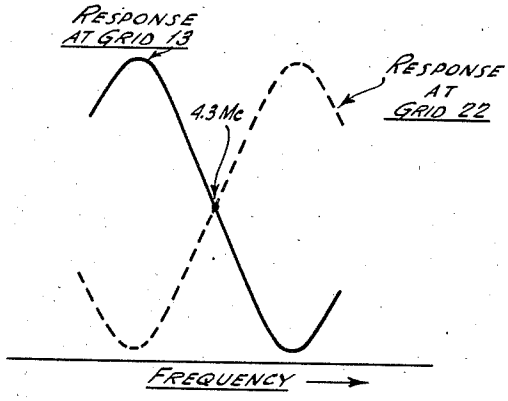
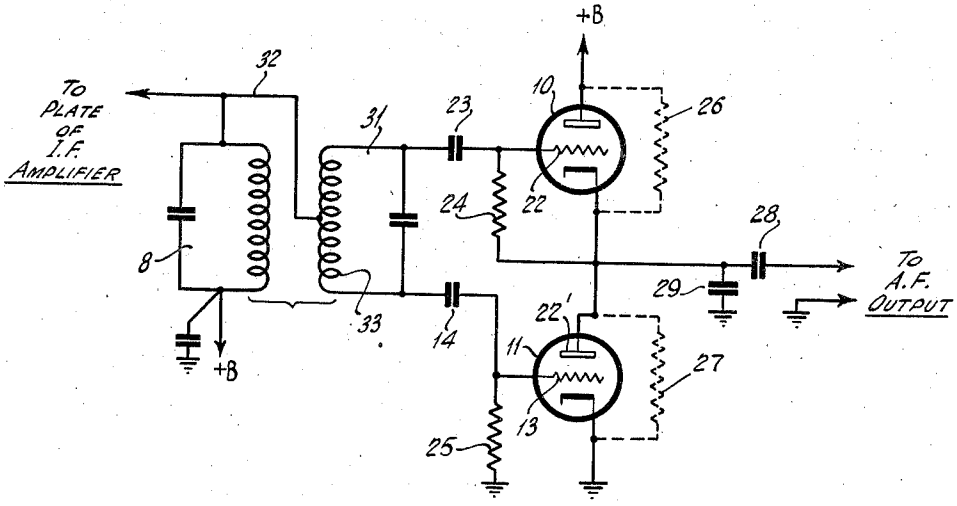



Fig. 4.




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# UNITED STATES PATENT OFFICE

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## ANGLE-MODULATION WAVE RECEIVER

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12 Claims. (Cl. 250—27)

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My present invention relates to receivers of frequency modulated (FM) or amplitude modulated (AM) carrier waves, and more particularly to radio receivers utilizing novel FM detector circuits.

An important object of my present invention is to provide a novel detector of angle modulated carrier waves wherein each of a pair of rectifier tubes concurrently functions as a load impedance for its companion tube.

Another important object of my invention is to provide an FM-AM detection network wherein no actual detector output load resistors are employed, but instead the detector tubes per se are employed for that purpose.

Another object of my invention is to provide a switchless FM-AM detector network wherein triode detection is utilized, and each triode serves as the output load element for another triode.

Still other objects of my present invention are to improve generally the efficiency of FM-AM receivers, and more especially to provide economical detector circuits for FM receivers.

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

In the drawings:

Fig. 1 shows, in partial schematic form, an FM-AM receiver employing one embodiment of my invention;

Fig. 2 shows a modification of the detector network of Fig. 1;

Fig. 3 illustrates the FM detection characteristic of the detector circuit of Fig. 2; and

Fig. 4 shows a further modification of the FM detector circuit.

Referring now to the accompanying drawings, wherein like reference characters in the different figures designate similar circuit elements, Fig. 1 shows an illustrative receiving system embodying a demodulator network adapted to provide audio frequency voltage in response to FM or AM signal reception. The receiver circuits prior to the demodulator are schematically represented. Those skilled in the art of radio reception are well acquainted with the nature of the circuits customarily employed in multi-band receivers. While my invention is readily adapted for FM and AM reception on respective bands of 40 to 50 megacycles (mc.) and 550 to 1700 kilocycles (kc.), it is to be clearly understood that the invention is not limited to such frequency bands. The 40 to

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50 mc. band is presented by way of illustration, since it is the FM broadcast band presently assigned to such transmission. The 550 to 1700 kc. band is the present AM broadcast band assigned to transmission of AM signals.

It will further be understood that in the present description and following claims the generic expression "angle modulated" is intended to include frequency modulation or phase modulation. From a very general viewpoint my invention relates to a demodulator network having separate input circuits for carrier waves of different frequencies and of different modulation characteristics.

The numerals 1 and 2 in Fig. 1 denote respectively different sources of modulated carrier waves. Source 1 may be the usual signal collector, such as a dipole, employed for collecting FM waves. The FM carrier waves are transmitted from FM transmitters at a center, or carrier, frequency assigned to the particular transmitter. In the assumed FM band of 40 to 50 mc. the radiated carrier wave frequency would be in that range, and would be a wave of variable frequency and substantially uniform amplitude. As is well known, the frequency modulation of the carrier wave would be in accordance with the modulation signals at the transmitter. The extent of frequency deviation of the carrier frequency is a function of the modulation signal amplitude, while the rate of frequency deviation is dependent upon the modulation signal frequencies per se. The permissible extreme frequency deviation in the FM band of 40 to 50 mc. is 75 kc. to either side of the carrier frequency. These frequency values are purely illustrative.

Source 2 may be a suitable grounded antenna circuit employed in AM broadcast reception. The allotted channels are 10 kc. wide in this band. In AM transmission the carrier wave is modulated in amplitude in accordance with the modulation signals. The carrier frequency is maintained constant in value at the transmitter. The numeral 3 designates a tunable radio frequency amplifier having suitable signal selector circuits for FM and AM reception. Switching devices 4 and 5 are provided for separate connection of the sources 1 and 2 to respective selector circuits of amplifier 3. It will be understood that when switch 4 is in closed position, collected FM signal energy will be applied to selector circuits of amplifier 3 capable of selectively amplifying the FM signals over a band at least 150 kc. wide. Upon closing of switch 5, and opening switch 4, the same amplifier 3 will have the FM selector cir-

cuits thereof operatively replaced by AM selector circuits. These latter circuits will select the collected AM signals, and permit amplifier 3 to amplify the same over a 10 kc. band. Multi-band selector circuits and switching devices for suitable change-over are well known to those skilled in the art of radio communication.

Assuming the system is of the superheterodyne type, as is the usual practice at present, the converter 6 and intermediate frequency (I. F.) amplifier 7 will, also, be provided with suitable FM and AM signal selector circuits. At the converter 6 the FM signals will have the center frequency thereof reduced to a value which may be chosen from a range of 1 to 20 mc., as for example 4.3 mc. The AM signals are reduced to an I. F. of 455 kc., as an illustrative frequency value, the latter being a commonly employed frequency in AM broadcast receivers of the superheterodyne type. The I. F. amplifier 7, which may consist of one or more separate stages of amplification, will have an ultimate output circuit from which may be derived, at separate points thereof, the amplified FM signals or AM signals.

The selective circuits 8 and 9 are to be understood as being arranged in series in the plate circuit of the last I. F. amplifier tube. Each of circuits 8 and 9 is resonated to its respective operating I. F. value for FM or AM reception. Thus, circuit 8 is tuned to 4.3 mc., while circuit 9 is tuned to 455 kc. There will be developed across tuned circuit 8 the FM signals at the 4.3 mc. mean frequency when switch 4 is closed, and all FM selector circuits of amplifier 3, converter 6 and I. F. amplifier 7 are in operative electrical connection. Conversely, when switch 5 is closed, and switch 4 is open, and all AM selector circuits are in operative electrical connection, there will be developed across circuit 9 the AM signals at the I. F. value of 455 kc. The impedance of circuit 9 is negligible at 4.3 mc. Hence, the insertion of circuit 9 in series with circuit 8 will not affect the development of FM signal voltage across circuit 8. Similarly, the impedance of circuit 8 is negligible at 455 kc., and circuit 8 will not affect development of AM signal voltage across circuit 9.

The present demodulator comprises two electron discharge devices of the triode type. The triode 10 is provided with a resonant input circuit 12 which is inductively coupled to the circuit 8. Triode 11 has its cathode 19 established at ground potential, while its grid 13 is connected through condenser 14 to the high alternating potential side of its resonant input circuit 15. Circuit 15 is, also, inductively coupled to the circuit 8. The low potential side of circuit 15 is connected to the grounded cathode 19 through the coil 16. Coil 16 is magnetically coupled to circuit 9, and condenser 18 shunts coil 16 to provide a resonant circuit 16—18 tuned to 455 kc.

The input circuits 12 and 15 of respective triodes 10 and 11 are oppositely and equally mistuned with respect to the operating I. F. value for FM reception. In other words, if the circuit 8 has an operating frequency $F_c$ of 4.3 mc., then circuits 12 and 15 will be detuned in opposite senses by equal predetermined frequency values relative to $F_c$. Thus, circuit 12 is indicated as tuned to a frequency in excess of $F_c$, and circuit 15 is represented as being tuned to a frequency less than $F_c$. For example, circuit 12 could be tuned to 100 kc., more than 4.3 mc. (4.4 mc.) while circuit 15 could be tuned to 4.2 mc. These are only illustrative values. It will be recognized that circuits 8, 12 and 15 provide the well known frequency discriminator network of U. S. Patent No. 2,057,640 to Conrad. The action of this form of discriminator circuit is well known to those skilled in the art. It functions to translate FM high frequency signals into corresponding AM high frequency signals.



At the 4.3 mc. frequency used for FM reception the impedance of circuit 16, 18 is negligible. Therefore, the low potential side of circuit 15 is effectively at the cathode potential of detector triode 11. The detector triodes are shown arranged in series relation so far as the space current paths thereof are concerned. The plate 20 of triode 10 is connected to the +B terminal (say, for example, +200 volts) of a suitable direct current supply source. The cathode 21 is connected directly to the plate 22' of triode 11. The low potential side of input circuit 12 is connected to cathode 21. The control grid 22 of triode 10 is connected by direct current blocking condenser 23 to the high alternating potential side of input circuit 12. Resistor 24 provides a direct current return path for grid 22. Similarly in the case of detector triode 11, the resistor 25 returns grid 13 to the grounded cathode 19.

It will be seen that a unique feature of my present circuit is the complete absence of output or load resistors external of tubes 10 and 11. The internal cathode to plate impedance of each of triodes 10 and 11 is utilized as the load impedance for the companion triode. The internal resistive impedance of triodes 10 and 11 are indicated by numerals 26 and 27 respectively. The output resistive impedances 26 and 27 are indicated by dotted lines to show that they are the internal resistive impedances of the triodes 10 and 11. The junction of resistive impedances 26 and 27 is connected to the audio frequency coupling condenser 28, the carrier bypass condenser 29 connecting the junction point to ground. Leads 30 function to feed the modulation signals to a subsequent suitable audio output circuit.

The detectors may function as grid leak detectors, or grid current-biased plate detectors. Thus, if the condensers 23 and 14 were each assigned a value of 50 micromicrofarads (mmf.) and each of resistors 24 and 25 a value of 200,000 ohms, the detectors would perform as grid rectification devices. By assigning a value of 0.005 mmf. to each of condensers 23 and 14 and a value of 10 megohms to each of resistors 24 and 25, the detectors perform as grid current-biased, plate rectification devices.

During AM signal reception the I. F. signal energy produced in the circuit 9 will be transferred to input circuit 16, 18. Each of circuits 9 and 16, 18 is tuned to the operating I. F. value of 455 kc. The circuit 15 and the grid to cathode path of triode 11 are in a series circuit with tuned circuit 16, 18. The circuit 15, resonant close to 4.3 mc., has no appreciable effect on the series circuit, since it acts as an extremely low impedance connection at the 455 kc. frequency value. The modulation (AM) signal voltage component of the rectified I. F. energy developed across load resistive impedance 26 during grid leak detection at tube 11 is applied through condenser 28 and leads 30 to the common modulation signal output circuit. Hence, it will be seen that during AM signal reception the tube 11 functions as the detector tube for the AM signals at input circuit 16, 18. The output resistor in that case is the internal cathode to plate resistance of tube 10. In other words, the audio frequency voltage de-

veloped across resistive impedance 26 is utilized through the output leads 30.

For FM signal reception, on the other hand, internal resistances 26 and 27 are alternately used as the frequency of the I. F. energy deviates relative to its mean or center frequency value. Assume, first, that the FM signal is at 4.3 mc. In such case both circuits 12 and 15 apply equal signal energy to the respective detector tubes. Assuming that tubes 10 and 11 are of like construction, the resistance values of impedances 26 and 27 will be equal. Therefore, there will be equal voltage drops across impedances 26 and 27, and the potential at junction point *a* will have a predetermined normal or mean value.

Suppose, now, that the applied FM signal energy at circuit 8 deviates in frequency towards the frequency of circuit 12 (4.4 mc.). The current flow through the tube 10 would decrease, assuming the condenser 23 and resistor 24 are chosen to provide grid leak detection. There would occur a relatively larger voltage drop across resistive impedance 26. This follows from these considerations. When a signal is applied to the grid 22, rectification makes the average grid potential more negative relative to cathode 21. This tends to stop electrons from flowing to plate 20. The electrons start piling up on the cathode 21 thereby making it more negative relative to the plate. Therefore, the voltage across the internal impedance 26 of the tube is greater. This would mean that a smaller voltage drop existed across resistive impedance 27. Hence, the point *a* would be relatively less positive relative to ground. If, now, the FM signal frequency deviates towards the resonance frequency of circuit 15, the reverse takes place. That is, the point *a* becomes more positive relative to ground. The sense and degree of potential change of point *a* will be dependent upon the direction and amount respectively of frequency deviation of the FM signal energy. It will be noted that the audio output circuit is single-ended. Condenser 29 will be chosen to bypass all high frequency components, whether at 455 kc. or at 4.3 mc.

The detection network of Fig. 1 may assume different forms. Figs. 2 and 4 show different modifications of the invention. In Fig. 2 I have shown a modification of the invention wherein for FM signal reception there is used a discriminator which is of the type disclosed and claimed by John D. Reid in U. S. Patent No. 2,341,240 granted February 8, 1944. In this embodiment of the invention the AM circuit 9 provides the input for triode detector 11. The condenser 14 and resistor 25 function to provide grid leak detection for AM reception. Here, again, the resistive impedance 26 acts as the plate load for the grid leak detector tube 11. It will be noted that the high alternating potential side of input circuit 9 is coupled to grid 13 by a series path consisting of tuned circuit 8', condenser 14 and resonant circuit 12'. Since circuits 8' and 12' are tuned in the vicinity of 4.3 mc. they have negligible impedance at 455 kc. Hence, during AM reception the grid 13 is in effect directly connected to the high potential side of circuit 9. An automatic volume control (AVC) connection 40 is made to the grid end of resistor 25 to provide AVC bias for prior gain controlled tubes. Filter network 41 is employed to suppress any pulsating components of the AVC voltage. As the carrier amplitude increases during AM reception, and upon grid current flow through resistor 25, AVC bias is produced.

To detect FM signals the tuned circuits 8' and 12' are employed. Resonant circuit 8' is connected in series with circuit 9 in the I. F. amplifier output circuit, and is tuned approximately to $F_c$ (4.3 mc.). The resonant circuit 12' is tuned somewhat above $F_c$. The control grid 22 of triode 10 is coupled by condenser 23 to the upper end of coil 30. The latter is magnetically coupled to circuit 8', and has its lower end connected to the cathode 21 of triode 10. The resistor 24 connects grid 22 to cathode 21. Hence, during FM reception triode 10 has applied thereto the signal energy across circuit 8', while triode 11 has applied to it the signal energy existing in the circuit including both circuits 8' and 12'. Of course, circuit 9 has no effect at FM reception, since its impedance is negligible at 4.3 mc.

The aforesaid Reid patent fully discusses the operation of an FM discriminator of the type shown in Fig. 2. By virtue of the discriminating action of circuits 8' and 12' the triodes 10 and 11 will have amplitude modulated waves applied thereto which were derived from the received FM signal waves. Resistive impedance 26 acts as the load for triode 11, and develops rectified voltage thereacross. Resistive impedance 27 acts as the load for triode 10, and develops rectified voltage thereacross.

The FM signal voltage across circuit 8' is applied to grid 22 through coil 30. Triode grid 13 has applied to it the signal voltage across its own input circuit. At the frequency where circuit 12' is anti-resonant the voltage across circuit 12' will be high, while that at grid 13 will be very low. At a somewhat lower frequency, circuit 12' will have an inductive reactance which will series resonate with the capacity between grid 13 and cathode 19 thereby making the voltage applied to the triode 11 very high. It is thus apparent that the radio frequency voltage applied to triode 11 changes very rapidly with frequencies between these points. At the first frequency the voltage across circuit 8' will be high thereby causing the voltage applied to triode 10 to be high. At the second frequency the series resonant circuit formed by circuit 12' and the input capacity of triode 11 will load down circuit 8' thereby causing the voltage applied to triode 10 to be low. Hence, the rectified voltage output of triode 11 changes in a direction opposite to that of triode 10 as the instantaneous frequency of the applied FM signals varies. Correct circuit design produces the desired characteristic. In Fig. 3 there is illustrated the frequency response characteristics at grid 13 (solid line curve) and grid 22 (dotted line curve) respectively. The cross-over frequency is at 4.3 mc.

In Fig. 4 there is shown a further modification of my invention, wherein the AM input circuit 9 is omitted and the I. F. amplifier includes the FM circuit 8 tuned to 4.3 mc. The latter is coupled magnetically to resonant circuit 31 tuned to 4.3 mc. The plate side of circuit 8 is connected by lead 32 to the midpoint of coil 33 of secondary circuit 31. Control grid 22 is coupled by direct current blocking condenser 23 to one side of circuit 31, and control grid 13 is coupled by direct current blocking condenser 14 to the opposite side of circuit 31. The frequency discriminator of Fig. 4 is of the type disclosed and claimed by S. W. Seeley in U. S. Patent No. 2,121,103 granted June 21, 1938.

The discriminator circuit of Fig. 4 functions

to provide at each of grids 22 and 13 a signal voltage whose magnitude is the resultant of two signal voltages. The magnetic coupling between primary circuit 8 and secondary circuit 31 results in the application to grids 22 and 13 of signal voltages in polarity opposition and in phase quadrature relative to the primary circuit signal voltage. The direct connection of circuit 8 to the midpoint of coil 33 causes signal voltages to be applied to grids 22 and 13 in like polarity and in parallel. Hence, at signal frequency $F_c$ each grid has applied thereto the resultant vector voltage of a phase-shifted signal voltage and a non-shifted voltage in normal phase quadrature. The resultant vector voltages at grids 22 and 13 are equal at $F_c$. However, for signal frequencies different from $F_c$ (the operating I. F. value) the resultant vectors become unequal, because the phase shift due to the magnetic coupling between circuits 8 and 31 changes. The respective resultant vector voltages at grids 22 and 13 will vary in sense and magnitude in response respectively to the direction and extent of signal frequency deviation.

These resultant signal voltages will cause corresponding voltage drops across the internal resistive impedances 26 and 27. The operation is quite similar to that described in connection with Fig. 1. If desired, an AM input circuit could be added to cooperate with one of the detector tubes 10 or 11. Of course, the triodes could be located in a single tube envelope, in the manner of a twin triode, if compact construction were desired. Grid leak detection can be made to give only a small variation in audio frequency output voltage for a considerable range of input signal amplitudes. A reduction in noise and distortion is accomplished in the circuits described through this type of detection. Low mu tubes are recommended where there is available sufficient signal amplitude to provide AVC. AVC action could be secured in either of the systems of Fig. 1 or Fig. 4, in which case low mu tubes are preferred. For maximum sensitivity it is preferred to use high mu tubes, and will be suitable for signals too weak to furnish AVC bias.

While I have indicated and described several systems 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 a detection system for angle modulated carrier waves, a pair of electron discharge devices having the space current paths thereof connected in series relation, means for deriving from said waves a pair of carrier voltages each variable in amplitude, means separately controlling the space current flow of each device in response to the relative amplitudes of said pair of voltages, and modulation signal output connections connected across the space current path of one of said devices.

2. In combination with a pair of triodes, means connecting the internal plate to cathode impedances thereof in series relation, a frequency discriminator input circuit, separate connections from said frequency discriminator circuit to a respective control grid of each of said triodes, and a modulation signal output circuit connected across one of said internal plate to cathode impedances.

3. In combination with a pair of triodes, means connecting the plate to cathode impedances thereof in series relation, a frequency discriminator input circuit, separate connections from said frequency discriminator circuit to a respective control grid of each of said triodes, a modulation signal output circuit connected across one of said plate to cathode impedances, a signal input circuit tuned to a frequency sufficiently different from the resonant frequency of said discriminator circuit to have negligible impedance effect on the latter, and connections between the input electrodes of one of said triodes and said signal input circuit.

4. In a frequency modulation receiver, a pair of detector tubes each including at least a cathode, control grid and anode, means for establishing the cathode of one of the tubes at ground potential, means connecting the anode of said one tube directly to the cathode of the second tube, means for applying a positive potential to the anode of the second tube whereby the space current paths of the two tubes are in series relation, modulation signal output connections connected to the anode and cathode of one of said tubes, and a frequency discriminator network having separate signal input connections to the control grids of said pair of tubes.

5. In combination with a source of amplitude modulated carrier waves, a detector tube having input, cathode and plate electrodes, an input circuit tuned to the carrier frequency coupling said source to said detector tube input and cathode electrodes, a second tube provided with an input, cathode and plate electrodes and having its internal plate to cathode impedance in series relation with the plate to cathode impedance of said detector tube, means connecting the plate of the second tube to a source of positive voltage, and modulation signal output connections connected across the plate to cathode impedance of said detector tube.

6. In a demodulator circuit for modulated carrier waves, a pair of triodes whose respective internal plate to cathode impedances are connected in series between a point of relatively high positive voltage and ground, means for varying the voltages of the control grids of said triodes in accordance with frequency deviation of a frequency-variable wave to be demodulated, and means responsive to the voltage variations of the junction of said plate to cathode impedances for producing a modulation signal representative of said frequency deviations.

7. In a detection system for frequency modulated carrier waves, a pair of electron discharge tubes having the space current paths thereof connected in series relation, discriminator means for deriving from said waves a pair of carrier voltages each variable in amplitude, control grid means separately controlling the space current flow of each tube in response to the relative amplitudes of said pair of voltages, and modulation signal output connections connected across the internal impedance of one of said tubes.

8. In combination with a pair of grid leak detector triodes, means connecting the internal impedances thereof in series relation, a frequency discriminator input circuit, separate connections from said frequency discriminator circuit to a respective control grid of each of said triodes, and a modulation signal output circuit connected across one of said internal impedances.

9. In combination with a pair of grid detection triodes, means connecting the internal plate to cathode impedances thereof in series relation, a

frequency discriminator input circuit, separate connections from said frequency discriminator circuit to a respective control grid of each of said triodes, an audio signal output circuit connected across one of said plate to cathode impedances, an amplitude modulation signal input circuit tuned to a frequency sufficiently different from the resonant frequency of said discriminator circuit to have negligible impedance effect on the latter, and connections between the input electrodes of solely one of said grid detection triodes and said signal input circuit.

10. In a frequency modulation receiver, a pair of grid leak detector tubes each including at least a cathode, control grid and anode, means for establishing the cathode of one of the tubes at ground potential, means connecting the anode of said one tube directly to the cathode of the second tube, means for applying a positive potential to the anode of the second tube whereby the space current paths of the two tubes are in series relation, audio frequency signal output connections connected to the anode and cathode of one of said tubes, and a frequency discriminator network



having respective signal connections to the control grids of said pair of tubes.

11. In a receiver circuit for frequency modulated carrier waves, a pair of grid leak detector triodes whose respective internal plate to cathode impedances are connected in series between a point of relatively high positive direct current voltage and ground, means for varying the voltages of the respective control grids of said triodes in accordance with frequency deviation of a frequency modulated wave to be demodulated, and means responsive to the voltage variations of the junction of said plate to cathode impedances for producing a modulation signal representative of said frequency deviations.

12. In combination, a pair of grid leak detector tube circuits, means connecting the internal impedances of said detector tubes in series relation, means for varying the voltages of the control grids of the tubes in accordance with received frequency modulated waves, and a modulation signal output circuit connected across the internal impedance of one of said detector tubes.

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