Dec. 3, 1946. G. W. FYLER 2,412,039

FREQUENCY MODULATION RECEIVING APPARATUS

Filed July 16, 1943 2 Sheets-Sheet 1

Fig. 1.

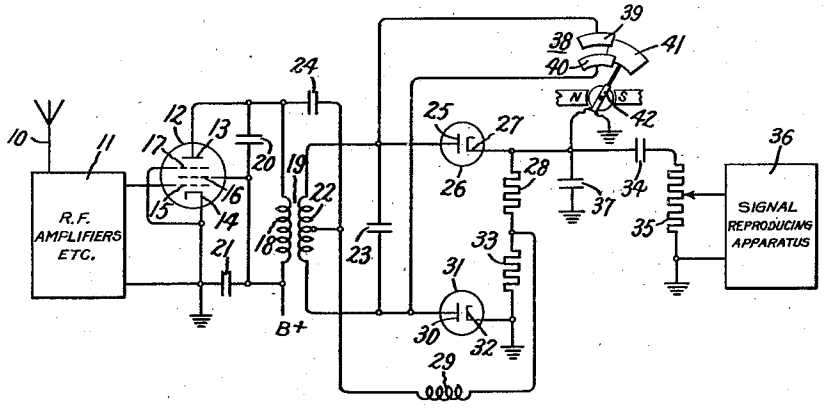
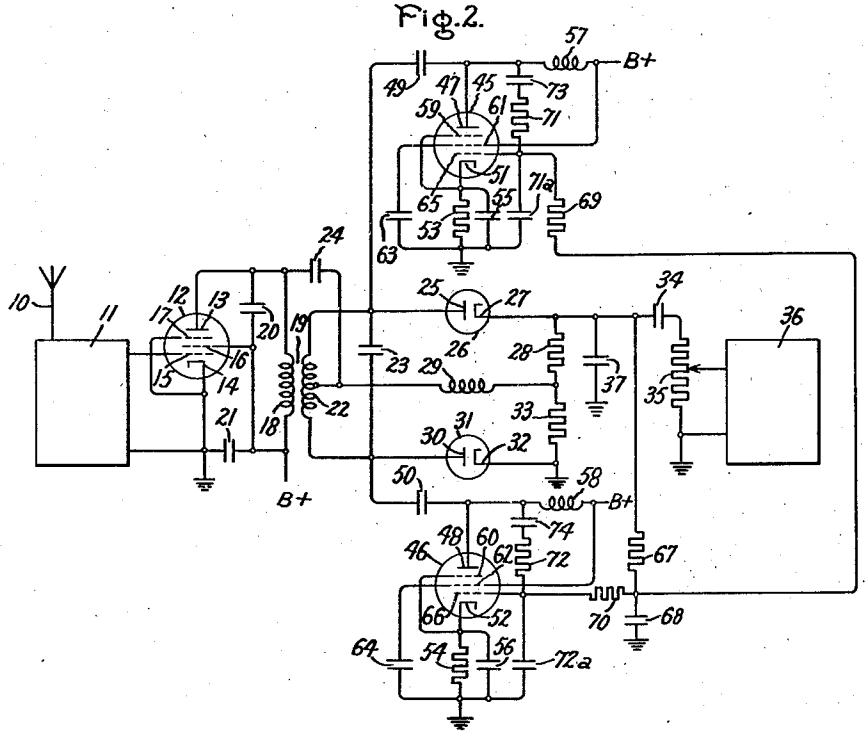



Fig. 2.




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Fig. 3.

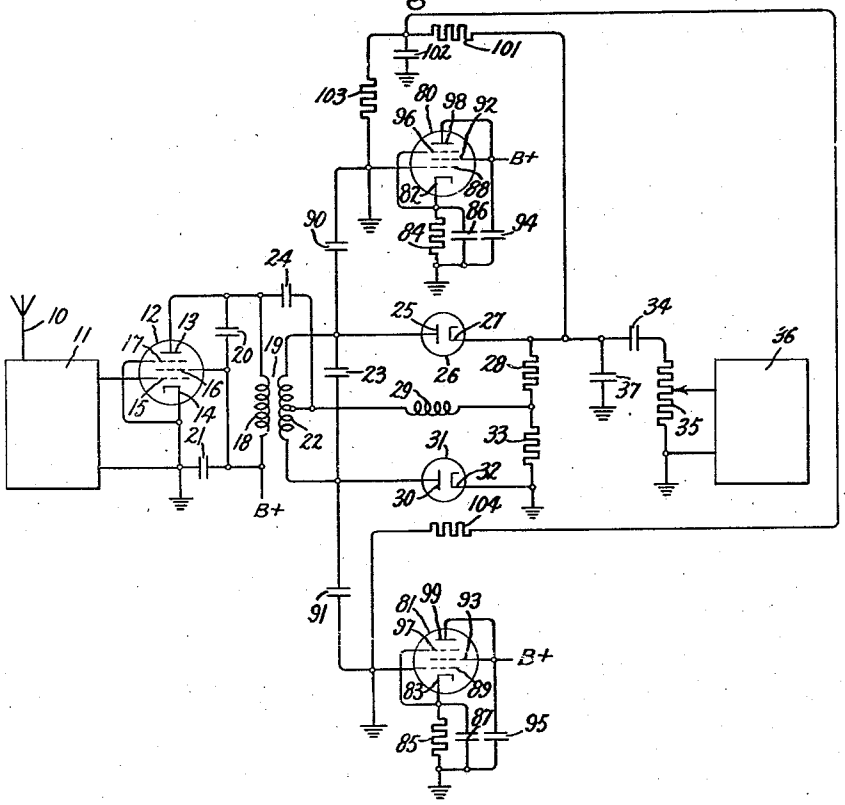
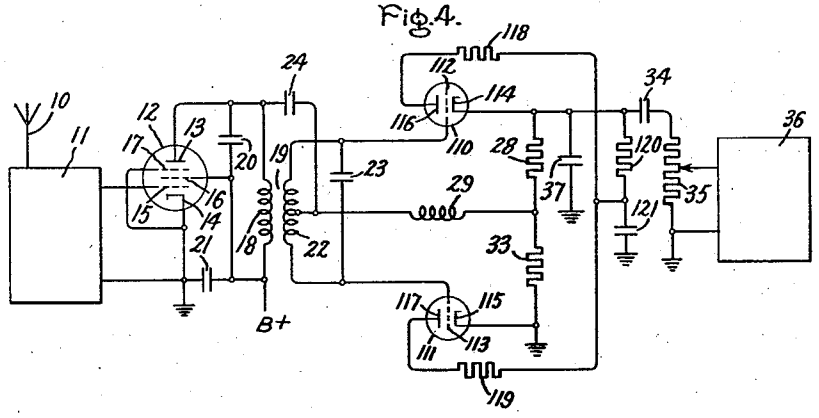



Fig. 4.




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# UNITED STATES PATENT OFFICE

2,412,039

## FREQUENCY MODULATION RECEIVING APPARATUS

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Application July 16, 1943, Serial No. 494,976

10 Claims. (Cl. 250—20)

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My invention relates to frequency modulation receiving apparatus and more particularly to means suitable for automatically controlling the tuning of a frequency discriminating circuit.

Demodulation of a frequency modulated carrier wave is ordinarily carried out by applying the waves first to a frequency discriminating circuit tuned to a resonance at the carrier mean frequency and arranged to convert the frequency modulated waves into an amplitude modulated wave at the same carrier frequency. The amplitude modulated wave thus derived is then impressed upon a suitable detector circuit for demodulation. For satisfactory undistorted discrimination, the mean frequency of the signal wave must coincide with the resonant frequency of the tuned frequency discriminating circuit. Any variation between the mean frequency of the signal wave and the resonant frequency of the tuned discriminator circuit causes a change in the unidirectional component of the discriminator output voltage. For example, in the balanced diode detector type of discriminator described and claimed in Patent 2,121,103, issued to S. W. Seeley on June 21, 1938, the discriminator load is so arranged that the net unidirectional component of voltage thereacross is zero when the mean and resonant frequencies coincide. In a balanced discriminator of this type a positive or negative unidirectional component of voltage is developed across the discriminator load upon any variation between the mean and resonant frequencies, the polarity of the unidirectional potential being determined by the direction of the variation. Such variation between the mean and resonant frequencies may occur in any type of radio receiver. For example, in a receiver employing a number of stages of tuned radio frequency amplification the resonant frequency of the tuned circuit, while relatively fixed when tuned for the reception of a predetermined incoming frequency, may drift slightly for a variety of reasons, such as temperature variation of the tuned circuits, and the like. Furthermore, in a superheterodyne receiver employing a local oscillator and a plurality of amplification and limiter stages tuned to a predetermined intermediate frequency, the resonant frequency of the intermediate frequency channel is subject to slight variation for the same reasons as the tuned circuits of a radio frequency receiver. Additionally, the frequency of the intermediate frequency carrier wave is subject to variation resulting from any change in the frequency of the local oscillator as, for example, the change

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produced by temperature variation in the tuning circuits of the oscillator.

In a superheterodyne receiver coincidence is commonly maintained between the mean intermediate frequency and the resonant frequency of the intermediate frequency channel by an automatic frequency control system comprising means for controlling the frequency of the local oscillator in response to changes in the unidirectional component of discriminator output voltage. While such automatic frequency control is quite satisfactory in applications where the frequency of the signal wave supplied to the discriminator is subject to control, it is not suitable for application to tuned radio frequency receivers and to certain types of superheterodyne receivers in which the frequency of the local oscillator is fixed, as by crystal control.

Accordingly, it is a principal object of my invention to provide new and improved means for controlling automatically the resonant frequency of a tuned circuit.

It is a further object of my invention to provide new and improved electronic means for controlling the resonant frequency of a tuned circuit.

It is a still further object of my invention to provide new and improved means for controlling the tuning of a frequency modulation discriminating circuit in accordance with the mean frequency of an incoming signal wave subject to variation.

It is a specific object of my invention to provide electronic means for controlling the tuning of a frequency modulation discriminator to maintain coincidence between the resonant frequency of the discriminator tuning circuit and the mean frequency of an incoming frequency signal wave subject to variation.

Briefly, my invention comprises an electronic reactance device, either a small trimmer capacitance or inductance, connected across the terminals of a tuned or oscillatory circuit for variation in response to a unidirectional voltage indicative of circuit mistuning to restore the circuit substantially to resonance. As applied to a frequency modulation discriminator, the variable reactance is connected as a trimming condenser or inductance across the terminals of the secondary winding of the tuned discriminator input transformer and controlled in accord with the unidirectional potential appearing across the discriminator load resistor. Suitably an interelectrode reactance of an electron discharge device is connected across the oscillatory circuit for variation in accordance with a bias voltage de-

rived from the discriminator load in response to mistuning.

My invention itself will be more fully understood and its objects and advantages further appreciated by referring now to the following detailed specification taken in conjunction with the accompanying drawings, in which Fig. 1 is a schematic circuit diagram of a radio receiving apparatus illustrating the principle of my invention; and Figs. 2, 3, and 4 are schematic circuit diagrams of radio receivers embodying my invention in a variety of forms.

Referring now to the drawings, and particularly to Fig. 1, I have shown a receiving apparatus of the frequency modulation type employing an antenna 10 and a signal channel 11 including any desired number of stages of amplification. The receiving apparatus may be of any suitable type, such as one involving a number of stages of tuned radio frequency amplification, or one of the conventional superheterodyne type in which the signal channel 11 includes a local oscillator and a converter for supplying a signal wave of predetermined intermediate frequency to an intermediate frequency channel fixedly tuned to the intermediate frequency. Let it be assumed, for the purpose of illustration, that the receiver is of the superheterodyne type and that the intermediate frequency channel terminates in a final amplitude modulation limiting stage comprising an electric discharge device 12 having an anode 13, a cathode 14, a control grid 15, a screen grid 16, and a suppressor grid 17. The anode 13 of the discharge device 12 is connected through a tuned primary winding 18 of a discriminator input transformer 19 to the positive terminal B+ of a suitable source of unidirectional current supply such as a battery (not shown). The primary winding 18 of the transformer 19 is tuned to resonance at the predetermined intermediate frequency by a shunt capacitor 20. The cathode 14 is connected to the negative terminal of the battery through ground. The screen grid 16 is connected to a suitable source of positive potential, such as the B+ terminal of the battery, and is bypassed to ground through a capacitor 21 in the usual manner.

The discriminator transformer 19 includes also a secondary winding 22 tuned to resonance at the predetermined intermediate frequency by a shunt capacitor 23 and having its midpoint connected to the high potential terminal of the transformer primary winding through a blocking capacitor 24. The tuned transformer 19 with the midtap connection through the capacitor 24 constitutes a frequency discriminating circuit so arranged that the electromotive forces at intermediate frequency across the two halves of the transformer secondary winding vary oppositely in intensity with deviations of the signal wave from the mean carrier frequency, the direction of voltage variation being dependent upon the direction of frequency deviation. Across each half of the secondary winding of the transformer 19 is connected a series rectifier circuit for demodulating the amplitude modulated signal waves appearing across the respective halves of the transformer winding 22. These rectifier circuits are connected in balanced opposition, or in back-to-back relation, in a well known manner so that the net voltage across their equal load resistors 28 and 33 is zero when the signal wave is at the desired mean frequency and the resonant frequency of the transformer coincides with the mean frequency.

Specifically, the upper terminal of the transformer secondary winding 22, as shown on the drawings, is connected to an anode 25 of a diode 26, the cathode 27 of which is connected through load resistor 28 and a high frequency choke coil 29 to the midtap of the transformer winding 22. Similarly, the lower terminal of the winding 22 is connected to an anode 30 of a diode 31, the cathode 32 of which is connected through load resistor 33 and the common high frequency choke coil 29 to the midtap of the transformer secondary winding. The discriminator load resistors 28 and 33 are bypassed for high frequencies by a condenser 37 and are grounded at the negative terminal of the resistor 33. The operation of a balanced discriminator of this type is described in detail in the Seeley patent mentioned above, and from that explanation it will be evident to those skilled in the art that a voltage of signal frequency appears across the electrically remote terminals of the load resistors 28 and 33. This signal voltage has no unidirectional component when the mean and resonant frequencies coincide. However, upon variation between the mean and resonant frequencies, the unidirectional component of current increases in one of the diodes 26, 31 and decreases in the other, depending upon the direction of the frequency variation, so that a net positive or negative unidirectional component of potential appears between the remote terminals of the resistors 28 and 33.

The signal voltage may be impressed through a suitable blocking condenser 34 upon a volume control potentiometer 35 from which it may be supplied to any suitable signal reproducing apparatus represented conventionally at 36. Preferably, the signal reproducing apparatus 36 includes a desired number of stages of signal frequency amplification and a loudspeaker, headphone or the like capable of producing the voice or musical sounds represented by signal modulation of the carrier wave.

If, as has been assumed, the mean frequency of the incoming signal wave is not subject to control, proper discriminator tuning may be maintained by controlling the resonant frequency of the discriminator transformer 19 in such a manner as to maintain coincidence between the carrier mean frequency and the resonant frequency. For this purpose I provide in shunt with the tuning capacitor 23 a variable condenser 38 of relatively small capacity. The condenser 38 may comprise a pair of fixed plates 39 and 40 and an adjustable plate 41 mounted for movement upon an arm attached to the moving element 42 of a galvanometer. Since only very slight variations of capacity are necessary in the condenser 38, the moving parts may be made of very small size. For example, the moving condenser plate 41 may be attached to the needle of a micro-ammeter. The micro-ammeter or galvanometer element 42 is connected for response between the electrically remote terminals of the discriminator load resistors 28 and 33, and is sufficiently damped by its own inertia so that it will respond only to unidirectional components of voltage across the terminals of the load resistors. The galvanometer element 42 is voltage responsive and its resistance will, of course, be high as compared to the sum of the resistances of the resistors 28 and 33.

From the foregoing explanation, it will be understood that when the mean frequency of the signal wave coincides with the resonant frequency of the discriminator transformer 19 no unidirec-

tional voltage is impressed upon the galvanometer element 42, so that the needle remains in a predetermined midposition. Preferably, of course, the galvanometer or micro-ammeter 42 is of the zero center scale type so that when deenergized it assumes such a midposition. If now, the mean frequency of the signal deviates in one direction or the other from the resonant frequency of the tuned transformer winding 22, a net positive or negative unidirectional voltage is impressed upon the galvanometer element 42 in dependence upon the direction of the frequency variation. The unidirectional voltage moves the galvanometer element in one direction or the other to change the capacity of the trimming condenser 38 in the proper sense to bring the resonant frequency of the transformer secondary winding substantially into coincidence with the new mean frequency of the incoming signal wave.

At Fig. 2 I have shown an arrangement wherein a pair of electronic reactance devices are connected respectively between the opposite terminals of the tuned discriminator transformer secondary winding and ground. Such reactance tubes may be arranged to act either as capacitative or inductive reactance across the terminals of the oscillatory circuit. In the receiver illustrated at Fig. 2 the conventional portions of the apparatus are similar to those illustrated at Fig. 1, and like parts have been assigned the same reference numerals. At Fig. 2 I have shown a pair of electric discharge devices 45 and 46 connected respectively between the upper and lower terminals of the discriminator transformer secondary winding 22 and ground. The discharge devices 45 and 46 are connected as reactance devices and include anodes 47 and 48, respectively, connected through blocking condensers 49 and 50 to the respective terminals of the transformer winding 22. The cathodes 51 and 52 of the discharge devices 45 and 46 are connected to ground through cathode resistors 53 and 54, respectively. The cathode resistors 53 and 54 are provided with bypass condensers 55 and 56, respectively. The anodes 47 and 48 of the discharge devices 45 and 46 are also connected through separate high frequency choke coils 57 and 58, respectively, to the positive terminal B+ of a suitable source of unidirectional current supply such as a battery (not shown). The negative terminal of the battery is connected through ground to the cathodes 51 and 52 of the devices 45 and 46. The discharge devices 45 and 46 also include suppressor grids 59 and 60 connected, respectively, to the cathodes 51 and 52 and screen grids 61 and 62 connected to the positive terminal B+ of the battery. The screen grids 61 and 62 are bypassed to ground through suitable capacitors 63 and 64, respectively. The effective impedances of the discharge devices 45 and 46 are controlled, respectively, by control grids 65 and 66. The grids 65 and 66 are connected to the positive terminal of the discriminator load resistor 28 through suitable decoupling resistors 69 and 70, respectively, and a signal frequency rejection filter comprising a resistor 67 and a bypass condenser 68. The control grids are also connected to the anodes 47 and 48 through resistors 71 and 72 in series with blocking capacitors 73 and 74, respectively, and to ground through condensers 71*a* and 72*a*, respectively. The resistors 71 and 72 form, with the capacitors 71*a* and 72*a*, phase shifting circuits which will be described in greater detail hereinafter.

In operation of the device of Fig. 2, the frequency discriminating circuit is arranged to supply, at the positive terminal of the discriminator load resistor 28, a potential which varies from a predetermined value as, for example, from ground potential, either positively or negatively depending upon variation of the intermediate carrier frequency from a desired value. These variations in unidirectional potential are impressed upon the control grids 65 and 66 of the discharge devices 45 and 46 through the signal frequency rejection filter 67, 68. The discharge devices 45 and 46 respond to these grid potential variations to effect changes in the reactance between the anode and cathode of each device in a manner presently to be described. Since the anode-to-cathode circuits of the discharge devices 45 and 46 are connected in series between the terminals of the tuned discriminator secondary transformer winding 22, changes in the apparent anode-to-cathode reactances may be arranged to effect desired changes in the tuning of the discriminator transformer secondary winding. It will be understood that upon a change in carrier mean frequency the grid potential variation impressed upon the discharge devices 45 and 46 is such as to change the anode-to-cathode impedances of the devices in a manner tending to make the resonant frequency of the tuned discriminator transformer follow the mean frequency of the received signal wave. The direction of the retuning effected by the discharge devices 45 and 46 may be controlled by the polarity of the coupling between the transformer windings 18 and 22. The polarity of this coupling should, of course, be such that mean frequency change effects a like change rather than an opposite change in the resonant frequency of the discriminator transformer.

The effective reactance between the anode and cathode of the discharge devices 45 and 46 may be rendered either inductive or capacitive. With the circuit arrangement shown the anode-to-cathode impedances of the devices 45 and 46 act effectively as serially connected inductances. It will be observed that in the discharge device 45, for example, the oscillations appearing across the transformer secondary winding 22 are applied through the blocking condensers 49 and 73 and the resistance 71 to the control grid 65, and through the blocking capacitor 49 to the anode 47. The transformer voltage is similarly applied to the device 46. The impedance of the blocking condenser 73 is small compared to that of the resistor 71. Since the impedance between the grid 65 and the cathode 51 is essentially capacitive and the impedance between the grid 65 and the anode 47 is essentially resistive, the voltage on the grid 65 lags behind the voltage of the oscillating circuit 22, 23 by substantially 90 electrical degrees. Accordingly, since the current in the anode 47 is in phase with the voltage of the grid 65, the anode current through the discharge device 45 also lags substantially 90 electrical degrees behind the voltage of the tuned circuit 22, 23. In other words, the anode-to-cathode impedance of the discharge device 45 is effectively inductive. The value of this effective inductance may be varied by varying the unidirectional potential applied to the control grid 65 thereby to vary the intensity of the current flowing in the anode circuit. Thus when the control grid becomes more positive, the effective inductance is reduced, and when the grid becomes more negative, the effective inductance is increased. This effective inductance may be caused to vary the

natural periods or resonant frequency of the tuned circuit comprising the transformer winding 22 and the condenser 23 thereby to effect desired changes in the tuning of the discriminator in accordance with variations of the mean frequency of the received signal wave.

In Fig. 3 I have shown a further modification of my invention wherein the input capacity of an electronic amplifier is used to effect the desired changes in oscillatory circuit capacity. The conventional portions of the receiving apparatus illustrated at Fig. 3 are similar to those illustrated at Figs. 1 and 2 and like parts have been assigned the same reference numerals. At Fig. 3 I have shown a pair of electric discharge devices 80 and 81 of the variable mu type having their grid-to-cathode input circuits connected between the high and low potential terminals of the transformer winding 22 and ground, respectively. Specifically, the discharge devices 80 and 81 include cathodes 82 and 83 connected, respectively, to ground through cathode resistors 84 and 85 provided with bypass condensers 86 and 87. The discharge devices 80 and 81 also include control grids 88 and 89 connected, respectively, to the high potential and low potential terminals of the tuned discriminator transformer secondary winding 22 through blocking capacitors 90 and 91. By way of illustration I have shown the discharge devices 80 and 81 as pentodes including screen grids 92 and 93, respectively, connected to a suitable source of positive potential such as the positive terminal B+ of a battery (not shown) and bypassed to ground through condensers 94 and 95, respectively. The pentodes 80 and 81 also include suppressor grids 96 and 97 connected directly to the cathodes 82 and 83, respectively. The anodes 98 and 99 of the discharge devices, respectively, are connected to the positive terminal B+ of the battery, the negative terminal of the battery being connected through ground to the cathodes 82 and 83.

For control of the input capacities of the discharge devices 80 and 81 the control grids 88 and 89 are connected through a signal frequency rejection filter comprising a resistor 101 and a capacitor 102 to the positive terminal of the discriminator load resistor 28. Decoupling resistors 103 and 104 are included between the audio rejection filter and the control grids 88 and 89, respectively.

It is known that in an electron discharge device having an electron emitter or cathode, an electron collector or plate and a control grid for controlling the flow of electrons between the cathode and the plate there exists certain interelectrode capacity having a fixed value when the discharge device is not in operation and having a different and variable value when the cathode is active and plate current is flowing.

This phenomenon may be explained by the theory that the space charge or cloud of electrons surrounding the cathode in a discharge device of this type constitutes effectively a part of the cathode at least for the purpose of determining the grid to cathode capacity. As the control grid becomes more negative, the cloud of electrons constituting the space charge is repelled from the control grid so that the spacing between the grid and the approximate surface of the space charge is increased. This increase in the spacing is equivalent to separating the plates of the condenser thereby to decrease the capacity therebetween. Conversely, as the control grid becomes more positive, the distance between the control grid and the space charge is diminished thereby to increase the input capacity of the device.

From the foregoing explanation it is believed that the operation of the receiver of Fig. 3 will be clear. As explained hereinbefore, the frequency discriminating circuit is arranged to supply at the positive terminal of the discriminator load resistor 28 a potential which varies from a predetermined value as, for example, from ground potential either positively or negatively depending upon the variation of the mean carrier frequency from a desired value. These variations in unidirectional potential are impressed upon the control grids 88 and 89 of the discharge devices 80 and 81, respectively, through the signal frequency rejection filter 101, 102. The discharge devices 80 and 81 respond to these grid potential variations to effect changes in the grid to cathode capacitances of the discharge devices. Since these grid to cathode capacitances are connected in series circuit relation between the high and low potential terminals of the discriminator transformer secondary winding 22, changes in the grid to cathode capacitances may be arranged to effect desired changes in the tuning of the discriminator transformer secondary windings. Upon a change in carrier frequency, the grid potential variation impressed upon the discharge devices 80 and 81 is such as to change the input capacitances of the devices in a manner tending to make the resonant frequency of the tuned discriminator transformer follow the varying mean frequency of the received signal wave.

I wish to have it understood that my invention, as illustrated in Figs. 2 and 3, is not limited to the use of a pair of electronic reactance devices connected between each terminal of the transformer winding 22 and ground. The reactance of the discharge devices is in the nature of a trimming reactance only, and the necessary changes of reactance required for control are extremely small. This necessary change may be obtained from only one electric discharge device, and the other device may be replaced by a small fixed balancing capacitance connected between one terminal of the winding 22 and ground.

At Fig. 4 I have shown a further embodiment of my invention wherein the necessary number of electric discharge devices is reduced by utilizing interelectrode capacity variations within the discriminator rectifying devices themselves to retune the discriminator circuit. The conventional portions of the receiver illustrated in Fig. 4 are similar to those illustrated at Figs. 1 to 3, inclusive, and similar parts have been assigned the same reference numerals. The discriminator circuit of Fig. 4 differs from those of Figs. 1, 2 and 3 in that the unidirectional conducting devices in the oppositely connected series rectifying circuits forming part of the discriminator are grid controlled electric discharge devices 110 and 111 of the variable mu type rather than the diode discharge devices 26 and 31 of Figs. 1 to 3, inclusive.. So far as their demodulating function is concerned, however, the grid controlled discharge devices 110 and 111 operate in the same manner as the diode elements 26 and 31 by grid rectification between their control grid 112 and 113, respectively, and their cathodes 114 and 115, respectively. At Fig. 4 the positive terminal of the discriminator transformer secondary winding is connected to the control grid 112 of the discharge device 110 and the low potential terminal of the transformer winding 22 is connected to the

control grid 113 of the discharge device 111, the cathodes 114 and 115 of the discharge devices 110 and 111 being connected to electrically remote terminals of the discriminator load resistors 28 and 33 in the same manner as previously described in connection with Figs. 1, 2 and 3. The discharge devices 110 and 111 are provided with anodes 116 and 117, respectively, each of which is connected through separate current limiting resistors 118 and 119, respectively, to the positive terminal of the discriminator load resistor 28 through a signal frequency rejection filter comprising a resistor 120 and a capacitor 121.

The operation of the tuning system of Fig. 4 will be understood when it is observed that the grid to cathode capacitances of the discharge devices 110 and 111 are connected in series circuit relation through the load resistors 28 and 33 across the terminals of the discriminator transformer secondary winding 22. As previously explained, the grid to cathode capacity of a discharge device under operating conditions, or the input capacity, is known to be a function of the plate current. It will be evident that by proper selection and orientation of the tube elements the variations in the input capacitances connected across the tuned discriminator circuit 22, 23 may be made to respond to changes in unidirectional plate potential impressed through the filter 120, 121 in such a manner as to retune the discriminator transformer secondary winding and to maintain resonance at the varying mean frequency of the incoming signal wave.

While I have illustrated only certain preferred embodiments of my invention by way of illustration, many further modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a source of carrier waves signal modulated in frequency about a mean frequency subject to variation, means comprising a tuned circuit normally resonant at said mean frequency for deriving from said frequency modulated wave a wave modulated in amplitude in accordance with said signal, means including unidirectional conducting means connected in balanced relation across said tuned circuit for deriving from said amplitude modulated wave a signal wave including a unidirectional potential component variable in accordance with variation between said mean and resonant frequencies, a pair of electron discharge devices each comprising at least three electrodes and providing a space discharge path between at least two of said electrodes, means including a third electrode of each said devices for shifting the phase of current traversing said discharge paths with respect to the alternating potentials thereacross, means for connecting said discharge path in series circuit relation across said tuned circuit, and means including the third electrode of at least one of said devices for controlling the apparent reactance of the associated discharge path in accordance with said unidirectional component of signal potential to control the tuning of said tuned circuit.

2. In combination, a source of carrier waves signal modulated in frequency about a mean frequency subject to variation, means comprising a tuned circuit normally resonant at said mean frequency for deriving from said frequency modulated wave a wave modulated in amplitude in accordance with said signal, means including unidirectional conducting means connected in balanced relation across said tuned circuit for deriving from said amplitude modulated wave a signal wave including a unidirectional potential component variable in accordance with variations between said mean and resonant frequencies, an electron discharge device including an anode, a cathode and at least one control electrode, means for rendering the discharge path between said anode and cathode effectively reactive, said effective reactance being variable in accordance with the unidirectional potential applied to said control electrode, means including a serially connected balancing reactor for connecting said discharge path in parallel circuit relation with said tuned circuit to control the tuning of said circuit, and means for applying said unidirectional component of signal potential to said control electrode to retune said tuned circuit in accordance with mean frequency variations of said carrier wave.

3. In combination, a source of carrier waves signal modulated in frequency about a mean frequency subject to variation, means comprising a tuned circuit normally resonant at said mean frequency for deriving from said frequency modulated wave a wave modulated in amplitude in accordance with said signal, means including unidirectional conducting means connected in balanced relation across said tuned circuit for deriving from said amplitude modulated wave a signal wave including a unidirectional potential component variable in accordance with variations between said mean and resonant frequencies, an electron discharge device including an anode, a cathode and at least one control electrode, said electron discharge device providing between said cathode and said control electrode an input capacitance variable in accordance with the unidirectional potential of said control electrode, means including a serially connected balancing reactor for connecting said input capacitance across said tuned circuit for controlling the tuning of said circuit, and means for applying said unidirectional component of signal potential to said control electrode for maintaining resonance of said tuned circuit at the varying mean frequency of said carrier wave.

4. In combination, a pair of rectifier circuits connected in opposing balanced relation, a source of carrier waves signal modulated in frequency about a desired mean frequency subject to variation, means including an electric circuit tuned to resonance at said mean frequency for supplying to said rectifier circuits oscillations varying oppositely in amplitude with frequency modulation of said carrier waves, said rectifier circuits providing an output voltage at signal frequency having a unidirectional component proportional to variation between said mean and resonant frequencies, a pair of electron discharge devices each having a control electrode and an internal reactance proportional to the voltage upon the electrode, means for connecting said internal reactances in balanced tuning relation with said tuned circuit, and means for applying said unidirectional component of signal voltage to at least one of said control electrodes.

5. In combination, a pair of rectifier circuits connected in opposing balanced relation, a source of carrier waves signal modulated in frequency about a desired mean frequency subject to variation, means including an electric circuit tuned to resonance at said mean frequency for supply-

ing to said rectifier circuits oscillations varying oppositely in amplitude with frequency modulation of said carrier waves, said rectifier circuits providing an output voltage at signal frequency having a unidirectional component proportional to variation between said mean and resonant frequencies, a pair of electric discharge devices each comprising an anode, a cathode and at least one control electrode, said electric discharge devices providing said control electrodes and cathodes electron stream capacitances variable in accordance with the unidirectional voltage upon said control electrodes, means for connecting the discharge paths between said grids and cathodes in balanced series circuit relation across said tuned circuit, and means for applying said unidirectional component of signal voltage to said control electrodes to control the tuning of said circuit in accordance with variations of said carrier mean frequency.

6. In combination, a pair of rectifier circuits connected in opposing balanced relation, a source of carrier waves signal modulated in frequency about a desired mean frequency subject to variation, means including a parallel resonant tuned circuit tuned to said mean frequency for supplying to said rectifier circuits oscillations varying oppositely in amplitude with frequency modulation of said carrier waves, whereby said rectifier circuits provide an output voltage at signal frequency having a unidirectional component proportional to variation between said mean and resonant frequencies, an electric discharge device comprising an anode, a cathode and at least one control electrode, means including a balancing reactor in series circuit relation with said discharge device for connecting the discharge path between said anode and said cathode across said tuned circuit, means for supplying to said control electrode oscillations substantially out of phase with the voltage between said anode and cathode thereby to maintain in said discharge device a plate current substantially out of phase with said anode to cathode voltage, and means for applying said unidirectional component of signal voltage to said control electrode to control the intensity of said plate current in accordance with mistuning of said tuned circuit.

7. In combination, a pair of rectifier circuits connected in opposing balanced relation and each including a unilateral conducting device having at least three electrodes, a source of carrier waves signal modulated in frequency about a desired mean frequency subject to variation, means including an electric circuit tuned to resonance at said mean frequency for supplying to said rectifier circuits oscillations varying oppositely in amplitude with frequency modulation of said carrier waves, said rectifier circuits providing an output voltage at signal frequency having a unidirectional component proportional to variations between said mean and resonant frequencies, and means for applying said unidirectional component of signal voltage to at least one electrode of each of said unidirectional conducting devices to control the interelectrode capacities of said devices in accordance with mistuning of said tuned circuits thereby to maintain said circuits tuned to said variable mean frequency.

8. In combination, a pair of rectifier circuits



connected in opposing balanced relation and each including a unilateral conducting device, each of said devices having two electrodes connected in series with the associated rectifier circuit and including a control electrode, a source of carrier waves signal modulated in frequency about a desired mean frequency subject to variation, means including a parallel resonant circuit tuned to said mean frequency for supplying to said rectifier circuits oscillations varying oppositely in amplitude with frequency modulation of said carrier waves, said rectifier circuits demodulating said oscillations to supply an output voltage at signal frequency having a unidirectional component proportional to variations between said mean and resonant frequencies, and means for applying said unidirectional component of signal voltage to the control electrode of each of said unilateral conducting devices to control the interelectrode capacities of said devices in accordance with mistuning of said parallel resonant circuit thereby to maintain said circuit tuned to said variable mean frequency.

9. In combination, a source of carrier waves signal modulated in frequency about a mean frequency subject to variation, means comprising a tuned circuit normally resonant at said mean frequency for deriving from said frequency modulated wave a wave modulated in amplitude in accordance with said signal, means including unidirectional conducting means connected in balanced relation across said tuned circuit for deriving from said amplitude modulated wave signal wave including a unidirectional potential component variable in accordance with variation between said mean and resonant frequencies, a pair of electron discharge devices each including at least three electrodes, the discharge paths between two electrodes of each said device being connected in balanced series circuit relation across said tuned circuit, and means for applying said unidirectional potential component to at least one electrode of each of said devices to control the effective reactance of said discharge devices.

10. In combination, a source of carrier waves signal modulated in frequency about a mean frequency subject to variation, means comprising a tuned circuit normally resonant at said mean frequency for deriving from said frequency modulated wave a wave modulated in amplitude in accordance with said signal, means including unidirectional conducting means connected in balanced relation across said tuned circuit for deriving from said amplitude modulated wave a signal wave including a unidirectional potential component variable in accordance with variation between said mean and resonant frequencies, an electron discharge device including at least three electrodes, a balancing reactor connecting the discharge path between two of said electrodes across said tuned circuit, the effective reactance of said discharge path being variable in accordance with the unidirectional potential of one electrode of said discharge device, and means for applying said unidirectional potential component to said one electrode to maintain said resonant frequency substantially equal to said mean frequency.

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