Nov. 14, 1944. R. B. DOME **2,362,806**

FREQUENCY MODULATION RECEIVER

Filed April 27, 1943 2 Sheets-Sheet 1

Fig.1.

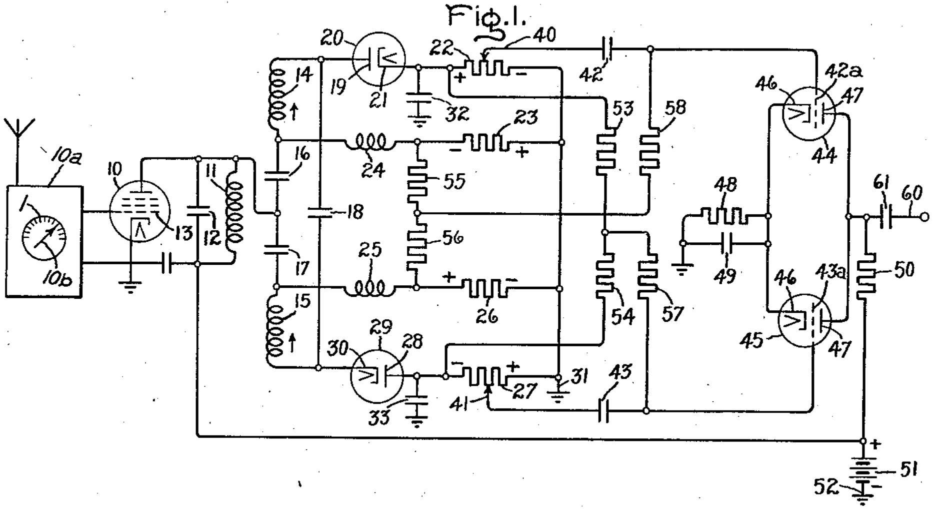

Fig.2.

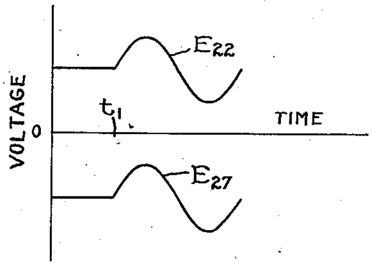

Fig.3.

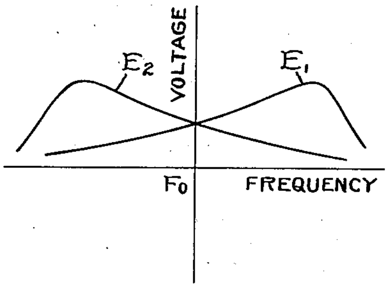

Fig.4.

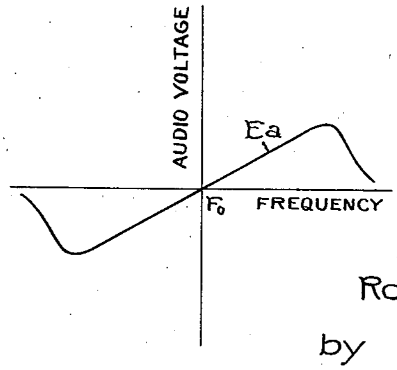

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Fig. 5.

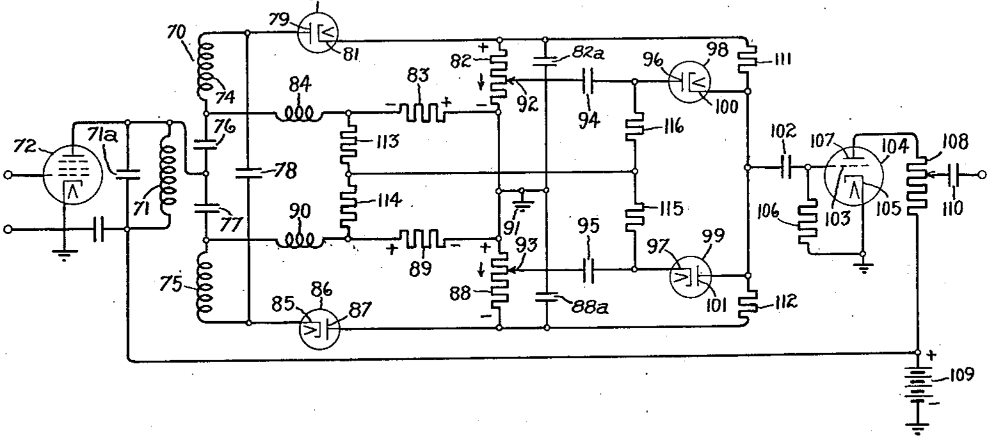
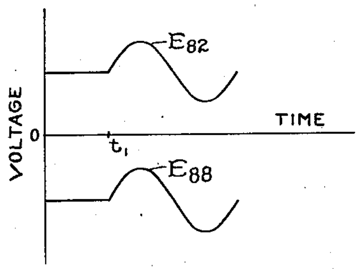


Fig. 6.



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Patented Nov. 14, 1944

2,362,806

UNITED STATES PATENT OFFICE

2,362,806

FREQUENCY MODULATION RECEIVER

Robert B. Dome, Bridgeport, Conn., assignor to General Electric Company, a corporation of New York

Application April 27, 1943, Serial No. 484,718

16 Claims. (Cl. 250—20)

My invention relates to frequency modulation receivers and more particularly to improvements in detectors or demodulators for frequency modulated carrier waves.

In the tuning of amplitude modulation radio or television receivers it is a characteristic that as the channel is tuned through, for example, in a superheterodyne receiver as the intermediate frequency approaches and then recedes from the resonant frequency of the intermediate frequency channel, the signal gradually increases in intensity to a maximum and then gradually decreases in intensity and fades out. This single maximum in the signal response is a highly desirable tuning characteristic, since it enables an unskilled operator readily to select the proper position of the tuning control for the reception of any desired broadcasting station.

It is equally well recognized, however, that detector or demodulator circuits which are currently in common use for the detection of frequency modulated carrier waves possess a tuning characteristic which exhibits three definitely distinguishable maxima of signal response. That is, as the channel is tuned through a fairly good signal is first observed, then a period of high distortion, then a range of good reception, then a second period of high distortion, then a second period of fairly good reception, and finally the signal fades out. While it is well known to those skilled in the art that the central of these three maxima is the optimum tuning position, it is also well recognized that this characteristic is confusing to unskilled operators who are not familiar with the cause of the three maxima and therefore unable to select the proper tuning position. This tuning characteristic whereby three maxima in signal response are presented is a function of the relative values of the resonant frequency of the signal channel and the mean frequency of the frequency modulated carrier wave being transmitted through the channel. Accordingly, the same characteristic will be observed in sets where the resonant frequency of the channel is to be tuned to the mean frequency of the incoming carrier and also in superheterodyne sets in which the mean intermediate frequency is to be tuned to the fixed resonant frequency of the intermediate frequency channel. It will be evident from the following description that my invention avoids both the distortion and the maxima of signal response on both sides of the optimum tuning position.

It is a general object of my invention to provide a new and improved discriminator or demodulator for frequency modulated carrier waves.

It is a further object of my invention to provide a frequency discriminator or demodulator for frequency modulation receivers which shall be readily tunable to the desired coincidence of mean frequency and channel resonant frequency without evidencing undesired tuning indications upon either side of the desired position and without severe distortion at any tuning position.

It is a still further object of my invention to provide a frequency discriminator or demodulator for a frequency modulation receiver which evidences tuning characteristics similar to that of a conventional amplitude modulation receiver in so far as the signal response gradually approaches a single maximum and then slowly fades out if the channel is tuned through.

It is a specific object of my invention to provide in a balanced discriminator circuit biasing means for substantially preventing signal response from a discriminator diode which is producing distortion in its output.

In carrying out my invention I provide a discriminator circuit comprising a pair of diode rectifier circuits interconnected to provide in-phase signal voltages at selected points in the circuits. The signal voltages thus obtained are supplied through a pair of parallel connected channel-separating electric discharge devices to a suitable signal reproducing device such as a headphone, loudspeaker, cathode ray tube or the like. Ordinarily it is desirable to introduce signal amplifying apparatus intermediate the channel-separating devices and the signal reproducing device. From suitable points in the rectifier circuits I obtain biasing potentials which, when applied to the channel-separating discharge devices, serve to diminish the signal response from that rectifier circuit which is producing signal distortion upon mistuning in one sense. Preferably, also, the signal response from the undistorted rectifier circuit is enhanced.

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 frequency modulation discriminator embodying my invention; Figs. 2, 3 and 6 are graphical representations of certain of the electrical characteristics of my discriminator; Fig. 4 is a graphical representation of certain of the characteristics of a conventional frequency discriminator upon which my invention is an improvement; and Fig. 5 is a schematic circuit diagram of a frequency modulation discriminator embodying my invention in a modified form.

Referring now to the drawings and particularly to Fig. 1, I have shown that portion of a frequency modulation receiver preferably of the superheterodyne type, which is essential to a full understanding of the invention. The circuit shown at Fig. 1 is that portion of a frequency modulation receiver which serves to derive, from a carrier wave modulated in frequency about a mean frequency in accordance with a desired signal, a signal voltage proportional in instantaneous magnitude to the instantaneous deviations of the carrier from the mean frequency. The receiver comprises an electric discharge device **10** which may serve either as the last intermediate frequency amplifier, or, if desired, as a limiter. The discharge device **10** comprises an anode and a cathode connected to an output circuit including the primary winding **11** of a discriminator input transformer which is tuned to resonance at an intermediate frequency by a suitable shunt capacitor **12**. The discharge device **10** also includes a control electrode or grid **13** which is arranged to be connected to a suitable source **10**a of frequency modulated carrier waves. Such a source of waves may be the intermediate frequency channel of a superheterodyne radio receiving apparatus, and the signal modulation may represent music, voice or the like. The intermediate frequency channel **10**a is provided with suitable manually controllable tuning means **10**b for adjusting the mean frequency of the intermediate frequency carrier wave to a desired value. It is understood that when the tuning is correct for optimum response the mean frequency of the carrier coincides with the resonant frequency of the channel.

Although it will be clear from the following description that my invention is not limited to a superheterodyne receiver, such a receiver commonly comprises a signal channel tuned to a fixed intermediate frequency, such as 2 to 5 megacycles, and including suitable amplifying and limiting devices preceding the discharge device **10**. It will be understood that in a superheterodyne receiver the incoming frequency modulated carrier wave at radio frequency, for example 42 to 50 megacycles, is reduced in frequency by mixing the frequency modulated carrier wave with an unmodulated wave from a local oscillator to obtain a signal modulated intermediate frequency carrier wave at the difference frequency. Tuning of the set to receive carrier waves of different radio frequencies is effected by changing the frequency of the local oscillator so that the difference frequency between the received carrier and that of the local oscillator is made equal to the fixed resonant frequency of the intermediate frequency channel terminating in the electric discharge device **10**.

The primary winding **11** of the tuned discriminator input transformer is magnetically coupled to a pair of secondary windings **14** and **15**, and the high potential terminal of the primary winding **11** is electrically connected to the adjacent inner or low potential terminal of the secondary windings **14** and **15** through suitable coupling capacitors **16** and **17** respectively. The secondary windings **14** and **15** are tuned as a unit to the intermediate frequency by means of a shunt capacitor **18**. Since at any instant the outer ends of the windings **14** and **15** are at the greatest difference of potential with respect to their midpoint, the polarities of the outer terminals being opposite with respect to the mid-point, the outer ends will be hereinafter referred to as the high potential terminals of the secondary windings. Each secondary winding **14** and **15** of the discriminator input transformer is connected to a series diode rectifier circuit comprising a two-element electric discharge device, a load resistor and an intermediate frequency choke coil connected in series circuit relation. Specifically, the high potential terminal of the secondary winding **14** is connected to the anode **19** of a diode **20**, the cathode **21** of which is connected through a pair of load resistors **22** and **23** and an intermediate frequency choke coil **24** in series circuit relation to the low potential terminal of the winding **14**. The other rectifier circuit is oppositely connected in that the low potential terminal of the secondary winding **15** is connected through an intermediate choke coil **25** and a pair of load resistors **26** and **27** in series circuit relation to the anode **28** of a diode rectifier **29**, the cathode **30** of which is connected to the high potential terminal of the secondary winding **15**. The resistors **22** and **27** are of equal resistance, and the resistors **23** and **26** are of equal resistance. Preferably, the resistances of all four resistors are equal. The common terminal of the resistors **22** and **23** is connected to the common terminal of the resistors **26** and **27** and grounded at **31**. The cathode **21** of the diode **20** and the anode **28** of the diode **29** are bypassed to ground for intermediate and higher frequencies by capacitors **32** and **33** respectively.

Referring now only to the connections thus far described, it will be evident that equal voltages of opposite phase are induced in the transformer secondary windings **14** and **15**. When the carrier frequency is the same as the resonant frequency of the signal channel these induced voltages are each 90 electrical degrees out of phase with the voltage across the transformer primary winding **11** by reason of the fact that both the primary and secondary windings of the transformer are tuned to resonance at that frequency. Furthermore, the connection of the high potential side of the primary winding to the midpoint of the secondary winding superposes upon each diode rectifier circuit the voltage of transformer primary winding **11**. Thus the total voltage supplied to each diode rectifier circuit is the vector sum of the transformer primary voltage and the phase displaced voltage induced in the associated secondary winding. When the mean frequency of the carrier wave is the same as the resonant frequency and no signal modulation is present the induced voltages are 90 electrical degrees out of phase with the primary voltage in opposite senses, so that the net voltages applied to the two diode rectifier circuits are equal at all times. Therefore, with proper tuning and no signal only unidirectional currents of equal scalar magnitude flow in the rectifier circuits, and the voltage drops across the resistors **22** and **27** and across the resistors **23** and **26** are equal. As the carrier frequency deviates instantaneously from the mean center frequency in accordance with signal modulation, the induced voltages in the transformer secondary windings **14** and **15** remain equal and opposite but are shifted in phase with respect to the primary voltage applied to the secondary winding midtap, the direction of the phase shift depending upon the direction of the instantaneous frequency deviation of the carrier wave. Thus signal modulation of the carrier wave changes in opposite senses the instantaneous magnitudes of the net voltages supplied to the diode circuits, the direction of the frequency deviation determining the direction of the voltage change. Accordingly, the instantaneous scalar magnitudes of the rectified currents in the load resistors 22 and 27 vary in opposite senses at the signal frequency of modulation of the carrier wave, thereby to give rise to signal frequency components of voltage across the resistors 22 and 27.

At Fig. 2 I have shown a graphical representation of the voltage drops across the resistors 22 and 27 with respect to time upon the occurrence of signal modulation of the carrier wave. It will be observed from Fig. 1 that the diodes 20 and 29 are so arranged that the rectified currents in the resistors 22 and 27 flow in opposite directions with respect to ground. Accordingly, with no signal modulation of the carrier, the potentials of electrically remote terminals of the equal resistors 22 and 27 are equal and opposite with respect to ground, as indicated in Fig. 2 up to a time t_1. If now at the time t_1 the carrier wave is modulated in frequency to produce a signal voltage E_{22} across the resistor 22, the signal voltage across the resistor 27 will be represented by E_{27}. It will be noted from Fig. 2 that while the instantaneous scalar magnitudes of the voltages E_{22} and E_{27} change in opposite senses with modulation, the voltages are in phase with respect to ground potential; i. e., the instantaneous values of E_{22} and E_{27} change in like phase with respect to ground potential.

The signal voltages appearing across the load resistors 22 and 27 are tapped at suitable points, as by potentiometer arms 40 and 41, respectively, and applied through a pair of blocking capacitors 42 and 43, respectively, to the control electrodes 42a and 43a of a pair of parallel connected grid controlled electric discharge devices 44 and 45, respectively. The blocking capacitors 42 and 43 remove the unidirectional components of the signal voltages shown at Fig. 2 and apply to the grids 42a and 43a only the in-phase alternating components of the signal voltages. The electric discharge tubes 44 and 45 each includes a cathode 46 and an anode 47. The cathodes 46 are connected together and to ground through a grid bias resistor 48 and a signal frequency bypass condenser 49 in parallel circuit relation. The anodes 47 are connected together and through a load resistor 50 to the positive terminal of a suitable source of direct electric current supply, such as a battery 51, the negative terminal of which is connected to ground at 52.

According to my invention the usual distortion and undesired maxima of audio response upon both sides of the optimum tuning position are avoided by providing suitable biasing potentials for the control electrodes 42a and 43a of the discharge devices 44 and 45 respectively. For this purpose the electrically remote terminals of the load resistors 22 and 27 are interconnected through a pair of serially connected and preferably equal voltage dividing resistors 53 and 54. Similarly the electrically remote terminals of the resistors 23 and 26 are interconnected through a pair of serially connected and preferably equal voltage dividing resistors 55 and 56. The midpoint of the resistors 53 and 54 is connected through a high resistance grid leak resistor 57 to the grid 43a of the channel-separating discharge tube 45. The midpoint of the resistors 55 and 56 is connected through a high resistance grid leak resistor 58 to the grid 42a of the channel-separating discharge device 44.

Let it first be assumed that the carrier wave is unmodulated and that its frequency is equal to the resonant frequency. Under such conditions the direct current components of the rectified currents in the circuits of the diodes 20 and 29 are equal and flow in opposite directions with respect to ground through the load resistors 22 and 27. For proper operation the potentiometer arms 40 and 41 should be positioned upon the load resistors 22 and 27 at points of equal potential above and below ground potential, respectively. However, due to the blocking capacitors 42 and 43, no bias potential is supplied to the grids 42a and 43a from the resistors 22 and 27, respectively. Furthermore, with proper tuning and no signal modulation the voltage dividing resistors 53 and 54 and the voltage dividing resistors 55 and 56 produce no biasing effect upon the grids 42a and 43a. This is evident from the fact that, with equal direct currents flowing in the diode rectifier circuits, the electrically remote terminals of the similar resistors 22 and 27 are at equal potentials above and below ground, respectively, and the electrically remote terminals of the similar resistors 23 and 26 are at equal potentials below and above ground, respectively. Accordingly, the midpoint of the resistors 53 and 54 and the midpoint of the resistors 55 and 56 are both at ground potential and thus exert no biasing effect upon the grids 42a and 43a. Therefore, under the conditions described above the channel-separating triodes 44 and 45, being unbiased, provide parallel paths for the passage of a predetermined direct current through the signal output resistor 50.

If now it is assumed that the carrier wave is modulated in frequency in accordance with a signal, it will be clear from the foregoing description in connection with Fig. 2 that the alternating or signal components of the potentials appearing at the potentiometer brushes 40 and 41 experience in-phase variations of instantaneous magnitude in accordance with the signal modulation of the carrier wave. For example, when the signal modulation is such as to produce an instantaneous increase in the rectified current through the diode 20 and a decrease in the rectified current through the diode 29, the instantaneous potential at both potentiometer brushes 40 and 41 changes in a positive sense with respect to ground potential. Similarly, signal modulation in the opposite sense produces an in-phase change in potential at the brushes 40 and 41 with respect to ground potential. The signal frequency potential thus developed is supplied to the grids 42a and 43a of the channel-separating discharge devices 44 and 45, respectively, and produces in-phase changes at signal frequency in the instantaneous value of current passed through both of the devices 44 and 45. Since these devices are connected in parallel circuit relation, they, under these conditions, contribute equally to the supply of an alternating component of current at signal frequency in the signal output resistor 50. It will be observed that the triodes 44 and 45 serve as amplifiers of the signal voltage as well as serving as channel-separators in a manner which will be hereinafter described.

The alternating component current at signal frequency in the resistor 50 produces across the resistor a voltage at signal frequency which may be applied to any suitable signal reproducing device. For this purpose I have shown a lead 60 connected to the high potential side of the load resistor 50 through a suitable blocking capacitor 61. The capacitor 61 serves to separate the unidirectional and alternating components of the current through the resistor 50, so that the signal voltage appearing at the terminal 60 is independent of the unidirectional component of current through the resistor 50. It will be understood that the lead 60 may be connected to any suitable loudspeaker, earphone or the like.

To illustrate the manner in which may invention avoids distortion and undesired maxima of the signal response upon opposite sides of the correct tuning position, I have shown at Figs. 3 and 4 a group of curves graphically illustrating certain characteristics of a balanced double diode discriminator in which the signal voltage is taken off directly across equal portions of the diode load resistors. At Fig. 3 is shown a pair of voltage characteristic curves E_1 and E_2. These curves represent the manner in which the scalar magnitude of diode load resistor voltage varies with carrier frequency in a circuit such as that of Fig. 1 where a pair of diode rectifier circuits are connected to similar secondary windings of a tuned discriminator input transformer. For example, the voltage E_1 may represent the drop across the load resistor 22 of Fig. 1 as the carrier frequency deviates from the center or mean frequency F_0, and the voltage E_2 may represent the voltage drop across the resistor 27 as the carrier frequency deviates from the mean frequency F_0. Now if a pair of rectifier circuits having these characteristics were connected in balanced opposition so that the unidirectional components of current through the load resistors flowed in the same direction with respect to the grounded midpoint, it is well understood that a signal voltage such as E_a of Fig. 4 could be obtained directly across electrically remote points of the load resistors. The reason for the distortion and undesired maxima in signal response which is common in such a balanced double-diode discriminator circuit will now be apparent from Fig. 4. The signal voltage curve E_a of Fig. 4 is substantially linear in the central region so that in this region the signal response is a maximum. However, at the maximum and minimum points of the curve E_a it will be observed that any modulation of carrier frequency, either an increase or a decrease in instantaneous frequency, produces a decrease in the instantaneous magnitude of signal voltage. Such a condition produces maximum distortion in the signal output. It will also be noted that the curve E_a of Fig. 4 is characterized by substantially linear portions on each side of the maximum and minimum points as the signal voltage fades out. These small linear portions produce undesired maxima in the signal response upon opposite sides of the center frequency.

According to my invention the side band distortion and undesired maxima in signal response on opposite sides of the proper tuning position are avoided by biasing toward cutoff that one of the channel-separating amplifying tubes 44 and 45 which is associated with the diode rectifier producing distortion. The diode rectifier producing distortion is that one which is conducting the greater, and particularly a maximum, unidirectional current component. It will be recalled that to provide demodulation the grids of the channel-separating amplifying tubes 44 and 45 are controlled by in-phase signal potentials obtained from the load resistors 22 and 27. The resistors 22 and 27 are not connected in balanced or back-to-back relation to provide the characteristic of Fig. 4, but are so connected that the direct current components of rectified current flowing through these resistors flow in opposite directions with respect to ground.

Let it now be assumed that a condition of mistuning exists such that the resonant frequency of the intermediate frequency channel and the mean frequency of the carrier waves do not coincide. In the illustrated example of the invention the resonant frequency is fixed, and it will be assumed that the mean frequency of the carrier wave is displaced therefrom and lies in the region of maximum conduction of one of the diode rectifiers, for example, the diode 20. Without the benefit of my invention the diode 20 would now be producing distortion in the signal response by reason of the fact that any modulation of the carrier wave, either an increase or decrease in instantaneous frequency, would produce a decrease in the voltage drop across the resistor 22. However, under these conditions the direct current components of the rectified currents in the diode rectifier circuit are not equal, so that the unidirectional potentials of electrically remote terminals of the resistors 23 and 26 are unequally displaced from ground potential. Qualitatively, the negative terminal of the resistor 23 is farther below ground potential than is the positive terminal of the resistor 26 above ground potential. Accordingly, the midpoint of the resistors 55 and 56 has a net unidirectional component of potential which is negative with respect to ground. This negative biasing potential is superposed upon the grid 42*a* of the channel separating discharge device 44 through the high resistance grid resistor 58, and biases the device 44 toward cutoff. Preferably the resistance of the resistor 58 is so high that the alternating component of potential appearing at the midpoint of the resistors 55 and 56 upon signal modulation of the carrier wave is sufficiently attenuated so that substantially no alternating current component appears upon the grid 42*a*. In this manner, the amplifying discharge device 44 is substantially disabled whenever the direct current component of rectified current through the diode 20 is in the region of its maximum value, and almost the entire audio response is conducted through the channel-separating amplifier 45. A like effect in lesser degree is present whenever one diode rectifier circuit conducts a greater unidirectional component than the other circuit, even though the unidirectional component does not attain its maximum value.

It will now be noted that the negative biasing potential superposed upon the grid 42*a* of the tube 44 is accompanied by a positive biasing potential upon the grid 43*a* of the tube 45 derived from the voltage dividing resistors 53 and 56. This positive biasing potential upon the grid 43*a* increases the conduction of the tube 45 to compensate for the decreased conduction of the tube 44. Under the conditions assumed, that is, with the diode 20 conducting in the region of its maximum unidirectional component of rectified current, the unidirectional components of potential at the electrically remote terminals of the resistors 22 and 27 are unequally spaced with respect to ground. Specifically, the positive terminal of the resistor 22 is higher in unidirectional potential above ground than is the negative terminal of the resistor 27 below ground. Therefore, the midpoint of the resistors 53 and 54 has a net positive unidirectional component of potential which is superposed upon the grid 43a of the device 45 through the high resistance resistor 57. The resistor 57 is of sufficiently high resistance to attenuate any alternating components of potential and prevent their reaching the grid 43a. In this manner the conduction through the undistorted channel-separating triode 45 is increased upon decrease of conduction through the distorted triode 44. By thus maintaining the total current through the signal load resistor 50 substantially constant decrease in the volume of the signal upon the occurrence of a cutoff bias in one of the channel-separating tubes is avoided.

It will be appreciated from the foregoing explanation that mistuning in the opposite sense, such that the diode 28 tends to produce distortion, results in a negative bias upon the grid 43a of the triode 45 and a compensating positive bias upon the grid 42a of the triode 44. It will now be clear that upon mistuning, that is, upon relative displacement of the resonant and carrier mean frequencies in either direction, a squelch bias is applied to one of the channel-separating devices 44 or 45 to decrease the effectiveness of that rectifying diode which is conducting the larger unidirectional component of current. Simultaneously the effect of the other diode, which is undistorted, is enhanced by the imposition of a positive bias upon the channel-separating tube associated therewith.

As explained above distortion is avoided by reducing, or eliminating, the response from the distorted diode and enhancing the response from the undistorted diode by means of a positive bias upon the associated channel-separating amplifier. It will be appreciated that such positive bias must be maintained within predetermined limits so that distortion of the audio output will not result from driving the positively biased channel-separating triode into a region of poor gain. The cathode resistor 48 provides protection against such excessive positive bias. For example, let it be assumed that the triode 45 is biased positively. This causes the direct component of the plate current to increase, thereby causing the potential drop across resistor 48 to increase. The direction of the potential across resistor 48 is such as to give negative bias to the grid of triode 45; hence, the net bias on the grid does not increase as fast as the positive potential applied from the junction of resistors 53 and 54 increases. The effect of this degenerative action on bias changes is to greatly extend the bias variations tolerable before grid current flows. However, let it be assumed that a condition of very high positive potential is present between the grid of triode 45 and ground. When such positive bias reaches a predetermined limit the positive peaks of the signal voltage appearing on the grid 43a are rectified in the grid-cathode circuit of the tube 45. This circuit includes the condenser 43 and the resistor 57. Such rectification leaves a negative charge upon the grid side of the condenser 43, thereby tending to decrease the positive bias of the grid 43a. The condenser 43 is shunted through the resistors 57, 54, and a portion of the resistor 27. However, the resistance 57 is very high, so that the decay of charge upon the condenser 43 is very slow. Therefore, only a small grid current is required to maintain the negative charge upon the condenser 43.

At Fig. 5 I have shown another embodiment of my invention in which diodes rather than triodes amplifiers are used as channel-separating devices. Fig. 5 shows a discriminator circuit for a frequency modulated carrier wave comprising a discriminator input transformer 70 having a primary winding 71 connected to the output circuit of a grid controlled electric discharge device 72. By means of a capacitor 71a the winding 71 is tuned to resonance at a predetermined frequency which, under proper tuning conditions, coincides with the mean frequency of the received intermediate frequency carrier wave. As previously explained in connection with Fig. 1 the discharge device 72 is preferably either the last intermediate frequency amplifier stage or the limiter stage of a frequency modulation radio receiving apparatus of the superheterodyne type. The discriminator transformer 70 is similar to the discriminator transformer shown in Fig. 1 and comprises a pair of similar secondary windings 74 and 75 having their inner or low potential terminals connected to the high potential terminal of the primary winding 71 through suitable coupling capacitors 76 and 77, respectively. The secondary windings 74 and 75 are tuned as a unit to the resonant frequency of the intermediate frequency channel by means of a shunt capacitor 78.

The discriminator transformer secondary windings of Fig. 5 are connected to a pair of diode rectifier circuits in the same manner as previously described in connection with Fig. 1. Specifically, the high potential terminal of the winding 74 is connected to an anode 79 of a diode 80, the cathode 81 of which is connected through a pair of serially connected load resistors 82 and 83 and a high frequency choke coil 84 to the low potential terminal of the winding 74. The high potential terminal of the secondary winding 75 is oppositely connected to the cathode 85 of a diode 86, the anode 87 of which is connected through a pair of serially connected load resistors 88 and 89 and through a high frequency choke coil 90 to the low potential terminal of the winding 75. The midpoint of the resistors 82 and 83 is connected to the midpoint of the resistors 88 and 89 and to ground at 91. The load resistors 82 and 88 are of equal resistance, and the resistances of the load resistors 83 and 89 are likewise equal. The resistors 82 and 88 are by-passed for intermediate frequencies by condensers 82a and 88a, respectively.

Thus far I have described only a pair of series diode rectifier circuits connected to similar secondary windings of a tuned input transformer in the same manner heretofore described in connection with Fig. 1. The diode rectifier circuits are also interconnected in the same manner as the rectifier circuits of Fig. 1 in that the unidirectional components of current through the load resistors 82 and 88 of Fig. 5 flow in opposite directions with respect to ground, as indicated by the polarity marks upon the drawings. It will, therefore, be understood that the alternating voltage components at signal frequency appearing across the load resistors 82 and 88 upon signal modulation of the carrier wave are in phase for the reasons heretofore explained in connection with Fig. 2.

At Fig. 6 I have shown curves similar to those of Fig. 2 and graphically illustrating the instantaneous voltages across the load resistors 82 and 88 in the absence of and also in the presence of signal modulation of the carrier wave. From the explanation of Fig. 2 it will be recognized that up to the time t_1 at Fig. 6 the carrier wave is unmodulated. The curve E_{82} represents the combined D. C. and A. C. potential across the resistor 82, and the curve E_{88} represents the combined D. C. and A. C. potential across the resistor 88.

The in-phase signal potentials appearing at similar electrically spaced points of the resistors 82 and 88 are tapped off through suitable potentiometer brushes 92 and 93 and supplied through direct current blocking capacitors 94 and 95, respectively, to a pair of channel-separating diodes 98 and 99. The brush 92 is connected through the condenser 94 to the anode 96 of the diode 98, and the brush 93 is connected through the condenser 95 to the cathode 97 of the diode 99. It will be understood that the blocking capacitors 94 and 95 serve to separate out the unidirectional components of the potentials appearing across the load resistors 82 and 88, so that only the alternating components of potential at signal frequency are supplied to the channel separating diodes 98 and 99. The diode 98 includes a cathode 100 which is connected directly to an anode 101 of the diode 99 and through a suitable blocking capacitor 102 to the control electrode or grid of a suitable signal amplifying discharge device 104. The amplifying device 104 includes also a cathode 105 which is connected to ground and through a grid leak resistor 106 to the grid 103. The anode 107 of the discharge device 104 is connected through a signal output resistor 108 to the positive terminal of a suitable source of unidirectional current supply, such as a battery 109. As is well understood by those skilled in the art the signal frequency component of potential appearing across the resistor 108 may be supplied through a suitable blocking capacitor 110 to any signal reproducing device such as a headphone, loudspeaker or the like.

According to the modification of Fig. 5 of my invention, the usual distortion and undesired maxima of signal response on both sides of the optimum tuning position are avoided by providing suitable differential biasing potentials for the anodes and cathodes of the channel-separating discharge devices 98 and 99. For this purpose the electrically remote terminals of the load resistors 82 and 88 are connected, respectively, through high resistance resistors 111 and 112 to the cathode 100 of the channel-separating diode 98 and to the anode 101 of the diode 99. Also, the electrically remote terminals of the load resistors 83 and 89 are interconnected through a pair of voltage dividing resistors 113 and 114, the midpoint of which is connected through high resistance resistors 116 and 115, respectively, to the anode 96 of the diode 98 and to the cathode 97 of the diode 99. Preferably the resistors 111, 112, 115 and 116 are of sufficiently high resistance to attenuate any alternating components of potential which may be impressed upon them from the diode rectifier circuits.

In view of the foregoing description of the circuit arrangement of Fig. 5, the mode of operation of the discriminator circuit there illustrated will be understood from the following brief description. The demodulating action of the apparatus under proper tuning conditions will first be described. It will be understood that by proper tuning it is meant that the mean frequency of the carrier wave coincides with the resonant frequency of the intermediate frequency channel. Under such conditions the direct current components of current in the load resistors 82 and 88 are equal, and signal modulation of the carrier wave produces signal voltages, such as E_{82} and E_{88} of Fig. 6, between the potentiometer brushes 92 and 93, respectively, and ground. Now it may be noted that the channel-separating diodes 98 and 99 are connected in parallel circuit relation between the ground connection 91 and the blocking capacitor 102. These parallel circuits may be traced from the ground connection 91, through adjacent portions of the load resistors 82 and 88, the potentiometer brushes 92 and 93, the blocking capacitors 94 and 95, and the diodes 98 and 99 to the blocking capacitor 102. An output circuit for the parallel connected diodes 98 and 99 is completed through the blocking capacitor 102 and the grid resistor 106 to the grounded cathode 105 of the signal amplifier 104. When signal frequency potentials are generated in the load resistors 82 and 88 by signal modulations of the carrier wave, the signal frequency currents passed by the diodes 98 and 99 are in like phase relation and are combined in the grid resistor 106 to produce across the resistor 106 a signal voltage which is applied to the amplifying device 104. An amplified signal voltage thus appears across the load resistor 108.

Let it now be assumed that a condition of mistuning exists such that the resonant frequency of the intermediate frequency channel no longer coincides with the mean frequency of the carrier wave. For the purpose of illustrative analysis let it be further assumed that the carrier mean frequency is displaced from the resonant frequency in such a direction that the direct current component of current in the load resistor 82 of Fig. 5 is greater than the direct current component of current in the load resistor 88. In such a case the unidirectional potential of the high potential terminal of the resistor 82 is greater than normal, so that a positive bias potential is impressed upon the cathode 100 of the separating diode 98 through the resistor 111. Similarly the potential of the low potential terminal of the resistor 88 is less negative, or more positive, than normal so that the unidirectional potential of the anode 101 of the separating diode 99 is raised in a positive sense through the resistor 112. The resistors 111 and 112 are very high in comparison to the resistance of the grid resistor 106, so that alternating potentials at signal frequency appearing at the resistors 111 and 112 are attenuated by voltage division between these resistors and the resistor 106. Therefore, very little, if any, alternating potential is impressed upon the electrodes of the channel separating tubes 98 and 99 through the resistors 111 and 112. The resistors 111 and 112 may be regarded as voltage dividing resistors connected between the remote terminals of the resistors 82 and 88 with their midpoint connected to the anode 101 and the cathode 100.

Under the conditions assumed the separating diode 98 is biased further toward cutoff and the conductivity of the diode 99 is further increased by impressing a suitable potential upon the anode 96 of the diode 98 and upon the cathode 97 of the diode 99. This potential is derived from the midpoint of the voltage dividing resistors 113 and 114 which are connected between electrically remote terminals of the load resistors 83 and 89. When the direct current component of current in the load resistor 83 is greater than normal, as assumed, the negative potential of the low potential terminal of the resistor 83 is greater than normal and the positive potential of the high potential terminal of the resistor 89 is less than normal. Accordingly, the potential of the midpoint of the resistors 113 and 114, which is normally at ground potential, is now appreciably below ground potential. This negative bias potential is impressed through the resistor **115** upon the cathode **97** of the discharge device **99** and through the resistor **116** upon the anode of the diode **98**.

It will now be observed that under the condition of mistuning in the sense assumed, the channel separating diode **98** is differentially biased toward cutoff by increasing the positive bias of its cathode through the resistor **111** and increasing the negative bias of its anode through the resistor **116**. To compensate for the decreased conductivity of the diode **98**, an opposite differential bias is impressed upon the diode **99**. The cathode **97** of the diode **99** is biased negatively through the resistor **115**, and the anode **101** of the diode **99** is biased positively through the resistor **112**. In this manner the effectiveness of the channel-separating diode **98** is decreased and the greater part of the signal response is obtained through the separating diode **99**. In a manner similar to that previously described in connection with Fig. 1 the increased conductivity of the diode **99** occurring upon decrease in the conductivity of the diode **98** serves to prevent a diminution in the volume of the signal output as a result of disabling the diode **98**.

From the foregoing description it will be clear that upon mistuning in the opposite sense the separating diode **99** will be disabled or its conductivity materially decreased, and the diode **98** will be so biased as to increase its conductivity to compensate for the cutoff bias of the diode **99**. Therefore, it appears that from the electrically remote terminals of the load resistors **82** and **83** and from the electrically remote terminals of the load resistors **83** and **89** differential biases are impressed upon the channel-separating diodes **98** and **99** in such a sense that that separating diode associated with the diode rectifier **80** or **86** which is conducting the greater unidirectional component of current is biased toward cutoff, while the other separating diode experiences a compensating increase in its conductivity.

It will be clear from the foregoing description that my invention not only eliminates undesired distortion and maxima in signal response as the signal channel is tuned through to receive a desired signal wave, but also serves to prevent distortion if the mean frequency of the received signal wave drifts from the resonant frequency of the signal channel after tuning.

While I have shown and described only certain preferred embodiments of my invention by way of illustration, many other modifications will doubtless occur to those skilled in the art. For example, it will be understood that my invention is not limited to receivers of the superheterodyne type, but that receivers of this type have been referred to in the illustrative embodiments only because of the current extent of their use and the convenience of reference to a pretuned intermediate frequency channel. Furthermore, it will be understood that neither illustrative embodiment of my invention is limited to inverse connection of the diode rectifiers to the transformer secondary windings, but that, if desired, the diode rectifying circuits may be connected in back-to-back or balanced opposition. It is only necessary that points of proper potential on the load resistors be selected for deriving the desired bias potentials for the channel-separating discharge tubes. Accordingly, I 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 a discriminator for electric oscillations, means for supplying a carrier wave signal modulated in frequency about a desired mean frequency, means including a pair of rectifier circuits for deriving from said carrier wave signal potentials having mean values varying oppositely and linearly in intensity within a predetermined range of frequencies with variation of said carrier frequency from said mean frequency and having peak values of intensity at the limits of said range, means including a pair of signal channels controlled by said signal potentials respectively, and means for reducing the transmission of one or the other of said channels when the mean value of the controlling signal potential attains an intensity in the region of its peak value.

2. In combination, a pair of unilateral conducting devices, a source of oscillations having its frequency modulated in accordance with desired signals about a desired average frequency, means tuned to said average frequency for supplying said oscillations to said unilateral conducting devices with intensity varying oppositely on said two devices with variations in the frequency of said oscillations whereby currents flow in said devices varying oppositely in intensity and at signal frequency as the frequency of said oscillations varies, an output circuit, a pair of electron discharge devices, means for supplying the signal frequency variations in current flowing through said unilateral conducting devices through a respective one of said pair of electron discharge devices to said output circuit in aiding relation, and means responsive to variations between the average frequency of said wave and the frequency to which said first means is tuned to decrease the conductivity of one or the other of said electron discharge devices in dependence upon the direction of said variation.

3. In combination, a pair of unilateral conducting devices, a source of oscillations signal modulated in frequency about a desired mean frequency, means tuned to resonance at said mean frequency for supplying to said devices oscillations from said source varying oppositely in intensity with frequency modulation of said oscillations, a signal channel having a separate portion associated with each of said devices, means including said devices for supplying to said portions of said channel in-phase potentials at signal frequency to control said channel, and means responsive to a variation between said mean and resonant frequencies for reducing the transmission of one or the other portions of said channel in dependence upon the direction of said variation.

4. In combination, a pair of unilateral conducting devices, a source of oscillations signal modulated in frequency about a desired mean frequency, means tuned to resonance at said mean frequency for supplying to said devices oscillations varying oppositely in intensity with frequency modulations of said oscillations about said mean frequency whereby currents varying oppositely in intensity with said modulations flow through said devices, a signal channel including a pair of electric discharge devices, means for supplying to said discharge devices in-phase control potentials at signal frequency derived from

said currents respectively, and means responsive to a variation between said mean and resonant frequencies for inversely controlling the conductivity of said electric discharge devices.

5. In combination, a pair of rectifier circuits including load resistors, a source of oscillations signal modulated in frequency about a desired mean frequency, means tuned to resonance at said mean frequency for supplying to said circuit oscillations from said source varying oppositely in intensity with frequency modulations of said oscillations about said mean frequency, said load resistors being arranged to derive thereacross in-phase potentials of signal frequency, a pair of electric discharge devices having a common output circuit, means for applying said signal potential to said discharge devices respectively to control said output circuit, and means responsive to a difference between said mean and resonant frequency for inversely controlling the conductivities of said electric discharge devices.

6. In combination, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, means including a pair of unilateral conducting devices for deriving from said carrier waves in-phase signal potentials proportional to frequency modulations of said carrier waves, a pair of electric discharge devices having a common output circuit, means for applying said signal potentials to said discharge devices respectively to control said output circuit, and means responsive to a difference between said mean and resonant frequencies for decreasing the conductivity of one of said electric discharge devices.

7. In a discriminator for electric oscillations, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, means including a pair of unilateral conducting devices for deriving from said carrier waves in-phase signal potentials proportional within a predetermined band of frequencies to frequency modulations of said carrier waves, a pair of electric discharge devices having a common output circuit, means for supplying said signal potentials to said discharge devices respectively to control said output circuit, and means responsive to a difference between said mean and resonant frequencies for inversely controlling the conductivities of said electric discharge devices to reduce the transmission through the discharge device controlled by a non-proportional signal potential.

8. In a receiver for electric oscillations, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean and resonant frequencies, means including a pair of rectifier circuits for deriving from said carrier wave in-phase signal potentials proportional to signal modulations of said waves, a pair of parallel-connected electric discharge devices having a common output circuit, means for supplying one of said signal potentials to each of said devices to control said output circuit, and means responsive to a variation between said mean frequency and resonant frequencies for decreasing the conductivity of one or the other of said electric discharge devices in dependence upon the direction of said variation.

9. In a receiver for electric oscillations, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and resonant frequencies, means including a pair of diode rectifier circuits for deriving from said carrier waves signal potentials including unidirectional components and in-phase alternating components at signal frequency, said unidirectional components being equal when said mean and resonant frequencies coincide, a pair of parallel-connected electric discharge devices having a common output circuit, means for supplying one of said alternating components of potential to each of said discharge devices to control said output circuit, and means differentially responsive to said unidirectional components of potential for controlling the conductivity of said discharge devices.

10. In a receiver for electric oscillations, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and resonant frequencies, means including a pair of diode rectifier circuits for deriving from said carrier waves signal potentials including unidirectional components and in-phase alternating components at signal frequency, said unidirectional components being equal when said mean and resonant frequencies coincide and varying in opposite senses upon relative displacement of said frequencies, a pair of electric discharge devices having a common output circuit, means for supplying said in-phase components of signal potential to said devices to control said output circuit, and means differentially responsive to said unidirectional components of potential and operable upon relative displacement of said mean and resonant frequencies to bias toward cutoff the discharge device controlled by the signal potential having the greater unidirectional component.

11. In a receiver for electric oscillations, means tuned to resonance at a desired frequency for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean and resonant frequencies, means including a pair of rectifier circuits connected to said signal channel for deriving from said carrier waves signal potentials including unidirectional components and in-phase alternating components at signal frequency, said unidirectional components being equal when said mean and resonant frequencies coincide and varying in opposite senses upon relative displacement of said frequencies, a pair of electric discharge devices having a common output circuit, means including said in-phase components of signal potential for controlling said discharge devices, and means differentially responsive to said unidirectional components of potential and operable upon relative displacement of said mean and resonant frequencies to bias toward cutoff the discharge device controlled by the signal potential having the greater unidirectional component and simultaneously to increase the conductivity of the other electric discharge device.

12. In a receiver for electric oscillations, a tuned signal channel for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and the resonant frequency of said channel, a pair of diode rectifier circuits connected to said signal channel and including separate load resistors having a common point of fixed potential, said rectifier

circuits being arranged to provide across adjacent portions of said load resistors signal potentials of opposite polarity with respect to said fixed potential, said signal potentials including in-phase alternating components at signal frequency and unidirectional components, a pair of parallel-connected electric discharge devices controlled by said alternating potentials and arranged jointly to supply a common output circuit, and means differentially responsive to the unidirectional potentials at electrically spaced points of said load resistors for controlling the conductivity of at least one of said discharge devices.

13. In a discriminator for electric oscillations, a tuned signal channel for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and the resonant frequency of said channel, a pair of diode rectifier circuits connected to said signal channel and including separate load resistors having a common point of fixed potential, said rectifier circuits being arranged to provide across adjacent portions of said load resistors signal potentials of opposite polarity with respect to said fixed potential, said signal potentials including in-phase alternating components at signal frequency and unidirectional components of equal magnitude when said mean and resonant frequencies coincide, a pair of parallel-connected electric discharge devices controlled by said signal potentials and arranged jointly to supply an output signal to a common output circuit. and means differentially responsive to the unidirectional potentials at electrically remote points of said load resistors and operable upon relative displacement of said mean and resonant frequencies to decrease the conductivity of that discharge device controlled by the signal potential having the greater unidirectional component and simultaneously to increase the conductivity of the other discharge device.

14. In a receiver for electric oscillations, a tuned signal channel for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and the resonant frequency of said channel, a pair of diode rectifier circuits connected to said signal channel and including separate and equal load resistors having like intermediate points connected together and to a point of fixed potential, means for deriving from said resistors signal potentials of opposite polarity with respect to said fixed potential, said signal potentials including in-phase alternating components at signal frequency and unidirectional components which are of equal magnitude when said mean and resonant frequencies coincide, a pair of parallel-connected electric discharge devices controlled by said signal potentials jointly to supply to a common output circuit an output signal voltage, and voltage dividing means connected between terminals of opposite polarity on separate load resistors to provide biasing potentials operable upon relative displacement of said mean and resonant frequencies to reduce the conductivity of the discharge device controlled by the signal potential having the greater unidirectional component and to increase the conductivity of the other discharge device.

15. In combination, a signal channel for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and the resonant frequency of said channel, a pair of diode rectifier circuits connected to said channel and including separate load resistors having a common point of fixed potential, said rectifier circuit being arranged to provide across adjacent portions of said load resistors signal potentials of opposite polarity with respect to said fixed potentials, said signal potentials including in-phase alternating component of said signal frequency and unidirectional component, a pair of parallel connected grid-controlled electric discharge devices having a common output circuit, means for supplying said alternating components of signal potential to the control grids of said discharge devices to provide in said output circuit an amplified signal voltage, and means differentially responsive to said unidirectional components of potential for supplying to said control grids biasing potentials varying oppositely in response to variations between said mean and resonant frequencies thereby inversely to control the conductivities of said discharge devices.

16. In combination, a tuned signal channel for supplying carrier waves signal modulated in frequency about a mean frequency, manually controllable means for effecting coincidence of said mean frequency and the resonant frequency of said channel, a pair of diode rectifier circuits connected to said signal channel and including separate load resistors having a common point of fixed potential, said rectifier circuits being arranged to provide across adjacent portions of said load resistors signal potentials of opposite polarity with respect to said fixed potential, said signal potentials including in-phase alternating components at signal frequency and unidirectional components, a pair of parallel connected diodes having a common output circuit, means for supplying one of said alternating components of signal potential to each of said diodes to provide in said output circuit an output voltage, and means differentially responsive to said unidirectional component of potential for supplying to said diodes differential bias potentials varying oppositely in response to variations between said mean and resonant frequencies thereby inversely to control the conductivities of said diodes.

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