July 23, 1946. M. E. BOND 2,404,359

FREQUENCY DISCRIMINATOR

Filed June 11, 1943

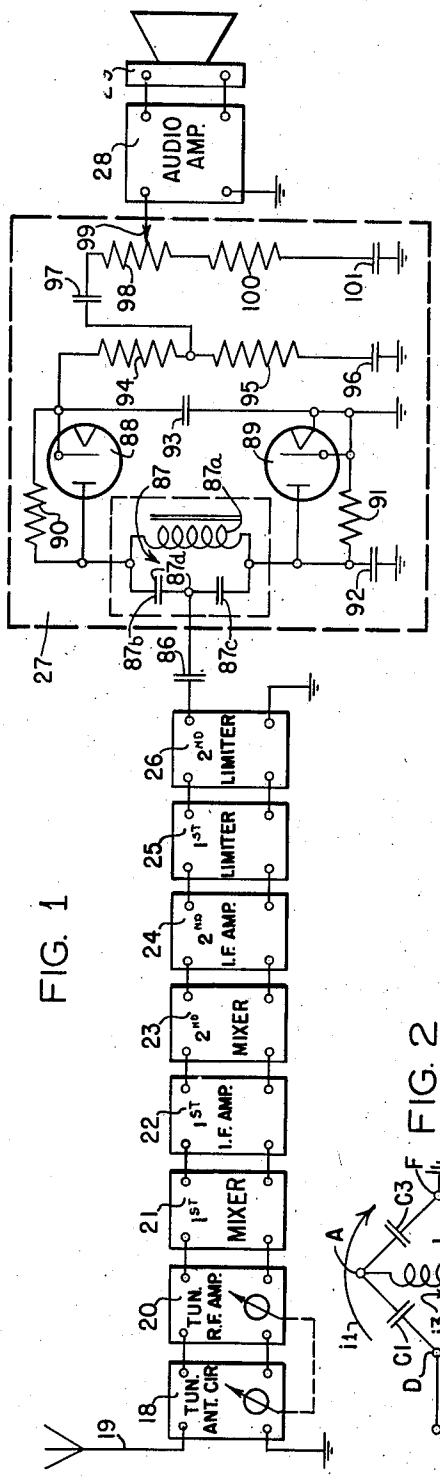

FIG. 1

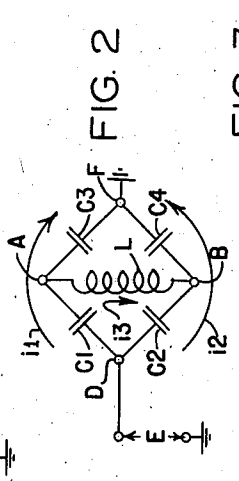

FIG. 2

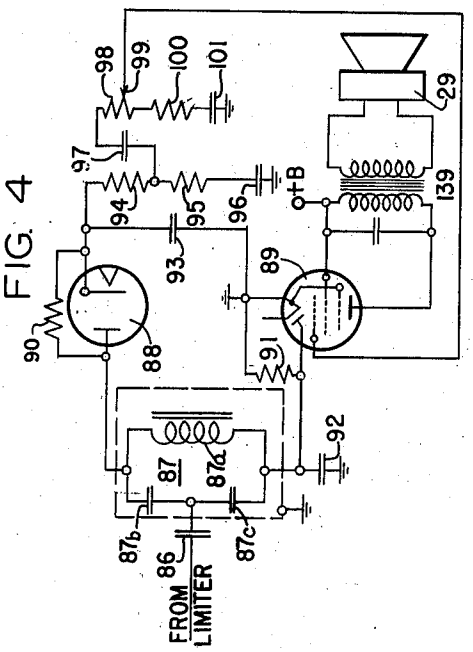

FIG. 4

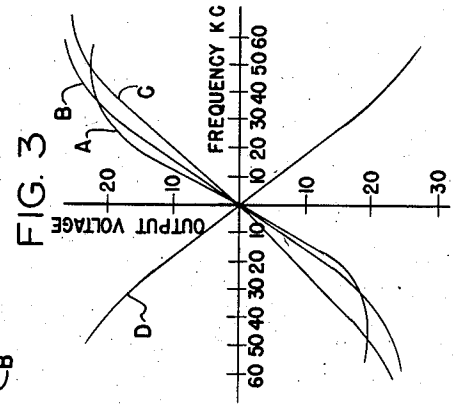

FIG. 3

INVENTOR.
MARION E. BOND

BY Mueller, Dodds & Mason

ATTORNEYS

Patented July 23, 1946 2,404,359

UNITED STATES PATENT OFFICE

2,404,359

FREQUENCY DISCRIMINATOR

Marion E. Bond, Chicago, Ill., assignor to Galvin Manufacturing Corporation, Chicago, Ill., a corporation of Illinois

Application June 11, 1943, Serial No. 490,467

7 Claims. (Cl. 250—27)

1

The present invention relates to frequency discriminators and more particularly to improvements in frequency discriminating networks of the character utilized in frequency modulated radio receiving systems for detecting the modulation components of a received frequency modulated carrier.

Conventional frequency discriminators, as used ahead of the audio frequency channel of a frequency modulated receiver for detecting the modulation components of a modulated intermediate frequency carrier, conventionally comprise a resonant circuit tuned to the intermediate frequency and designed to respond to frequencies which exceed or are less than the intermediate frequency by not more than a predetermined amount. In the usual arrangement, the signal modulated intermediate frequency carrier is introduced into the discriminating network by tapping the winding of the fixed inductance forming a part of the resonant circuit at its electrical mid-point, and connecting or coupling the output circuit of the preceding amplitude limiter tube to the center tap of the inductance element. The capacitance coupling thus provided is supplemented by inductively coupling the inductance element of the discriminator to the output inductance element of the preceding limiter stage. The tuning of the resonant circuit to the desired intermediate frequency is universally accomplished by using an adjustable condenser connected in shunt with the inductance element. The adjustable resonant circuit thus formed is combined with additional circuit apparatus which includes a pair of rectifying paths and has the function of producing an output voltage which varies in magnitude at the signal frequency rate in accordance with departures of the resonant circuit exciting frequency from the intermediate frequency and also varies in polarity, depending upon whether the exciting frequency is increased above or decreased below the intermediate frequency.

The above-described conventional arrangement is characterized by several disadvantages both from the standpoint of circuit performance and also from the standpoint of commercial reproduction of a receiver of fixed design in large quantities. Thus, in the operation of the discriminator it is essential that the resonant circuit be accurately and precisely tuned to the center intermediate frequency and that it be accurately and precisely balanced to produce no output voltage at this frequency. It is also necessary that the output voltage of the circuit accurately and faithfully respond to given departures in frequency from the intermediate frequency in either direction. These ends are difficult to achieve with typical prior art arrangements, because of the difficulties inherent in accurate condenser tuning of the resonant circuit and the difficulties inherent in accurately center tapping inductances at their electrical mid-points in commercial quantities.

2

It is an object of the present invention, therefore, to provide an improved frequency discriminator which is simple in arrangement and may be readily reproduced in production quantities to have an exact and predetermined operating characteristic.

It is another object of the present invention to provide an improved discriminator which may be easily and accurately adjusted to produce no output voltage at a particular frequency and to produce an output voltage which accurately conforms both in polarity and magnitude to deviations in the exciting frequency from the particular frequency.

It is a further object of the invention to provide a frequency modulated radio receiving system which includes an improved and exceedingly simple arrangement for accurately and faithfully detecting the audio frequency components of a received frequency modulated carrier.

It is still another object of the invention to provide an improved discriminator or network wherein condensers of fixed capacitance value and an adjustable inductance element are utilized to form the tuned circuit which determines the frequency response characteristic of the network.

According to another object of the invention, an inductance element of the adjustable permeability type is utilized to tune the resonant frequency of the discriminator network to the desired center frequency.

In accordance with still another object of the invention, a discriminator network is provided wherein the exciting voltage is introduced into the network at the junction point between two

series connected condensers which also serve to tune the resonant circuit to the desired center frequency.

According to a further object of the invention, capacitance coupling is alone utilized to introduce the exciting voltage into the discriminator network.

According to a still further object of the invention, an exceedingly simple arrangement is provided for improving the stability of the discriminator network.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawing, in which:

Fig. 1 represents a frequency modulated radio receiving system having incorporated therein an improved discriminator network characterized by the features of the invention briefly referred to above;

Fig. 2 is an equivalent circuit of the frequency discriminator network shown in Fig. 1;

Fig. 3 is a graph illustrating the different response characteristics which are obtained for the discriminator when the circuit elements of the discriminator are arranged in different manners and at least one of the circuit constants of the network is varied; and

Fig. 4 is a circuit diagram illustrating a modification of the receiving system shown in Fig. 1.

Referring now more particularly to Fig. 1 of the drawing, there is represented, partially schematically, a frequency-modulation receiving system embodying the frequency discriminator of the invention. This receiving system includes the following units, connected in cascade, in the order named: a tunable antenna circuit 18, a tunable radio frequency amplifier 20, a first mixer or converter stage 21, a first intermediate frequency amplifier 22, a second mixer or converter stage 23, a second intermediate frequency amplifier 24, a first limiter 25, a second limiter 26, a frequency discriminator 27, an audio frequency amplifier 28, and a loud speaker 29, all connected in cascade in the order named.

The frequency discriminator 27 to which the present invention more specifically relates comprises a circuit 87, a pair of diode rectifier tubes 88 and 89, the space current paths of which are respectively shunted by load resistors 90 and 91, a radio frequency by-pass condenser 93 having substantially negligible impedance to frequencies of the order of the second intermediate frequency, and a stabilizing condenser 92. More specifically, the resonant circuit 87 comprises a pair of series connected condensers 87*b* and 87*c* which are shunted by an adjustable inductance element 87*a*. Preferably the last mentioned element is of the variable permeability type being provided with an adjustable powdered ferrous metal core, the position of which may be changed to alter the inductance of the element within the desired limits. The circuit constants of the resonant circuit 87 together with the associated capacitances including condenser 92 are so chosen that this circuit is tuned to the nominal intermediate carrier frequency and sufficiently broadly tuned so that all desired signal components of a frequency modulated carrier appearing in the second intermediate frequency channel 24, 25, 26 may be detected and impressed upon the input circuit of the audio amplifier 28. The voltage appearing across the output side of the second limiter 26 is impressed upon the discriminator network 27 through a coupling condenser 86 which is connected at one side thereof to the junction point 87*d* between the two condensers 87*b* and 87*c*. Actually, the condenser 86 provides the only coupling path between the output side of the limiter 26 and the discriminator 27, a grounded conductive shielding housing being provided for enclosing the circuit elements 87*a*, 87*b* and 87*c* so that mutual inductive coupling or stray capacitance coupling between the discriminator and the preceding limiter is absolutely eliminated. Audio frequency voltages detected through operation of the discriminator 27 appear across the condenser 93 and are impressed upon the input side of the audio frequency amplifier 28 through a coupling circuit which includes radio frequency decoupling resistor 94, an audio frequency filter comprising the resistor 95 and condenser 96, an audio frequency coupling condenser 97, and a voltage dividing network comprising the two resistors 98 and 100 and a direct current blocking condenser 101. It will be understood in this regard that the proportion of the available audio frequency voltage appearing across the series connected resistors 98 and 100 which is impressed upon the input circuit of the audio frequency amplifier 28, is determined by the setting of the wiper 99 along the resistor 98.

The operation of the above described signal-receiving system, as a whole, will be clear to those skilled in the art from the foregoing description. In brief, a frequency-modulated carrier signal intercepted by the antenna circuit 19 is selected and amplified in the unit 18, further selected and amplified in the radio-frequency amplifier 20, converted in the first mixer 21 into a frequency-modulated intermediate-frequency wave which is amplified and selected in the amplifier 22, converted in the second mixer 23 to a second frequency-modulated intermediate-frequency signal of a lower frequency, further selected and amplified in the amplifier 24, limited in limiters 25 and 26 and applied through the coupling condenser 86 to the frequency discriminator 27 embodying the invention, from which it is applied through the audio-frequency amplifier 28 to the loud speaker 29 for reproduction.

Referring now more particularly to the operation of the discriminator 27, it will be noted that this circuit is essentially a four arm, four terminal bridge circuit of the character shown in Fig. 2 of the drawing. In this bridge circuit the capacitances C_1 and C_2 are of equal value and represent the condensers 87*b* and 87*c*, respectively, the capacitor C_3 represents the capacitance of the diode 88, the capacitor C_4 represents the combined capacitance of the diode 89 and the shunting condenser 92 and the inductance L represents the tuning inductance 87*a*. The diode rectifiers 88 and 89 are thus effectively individually coupled across the two adjacent capacitance arms C_3 and C_4, respectively, while the resistors 90 and 91 individually shunt the rectifiers 88 and 89, respectively. Since the load resistors 90 and 91 have impedances far in excess of the impedances of the capacitors C_3 and C_4 at the frequencies involved, they may be neglected in analyzing the circuit. Again, the capacitance of the condenser 93 is so much greater than that of either the capacitor C_3 or the capacitor C_4, that this condenser may also be neglected in analyzing the circuit. The signal modulated carrier

voltage E, which appears at the output side of the limiter **26**, is applied to the circuit solely between the terminals D and F, and the voltage appearing at the output side of the discriminator is the difference between the absolute values of the voltages to ground at the terminals A and B. From an examination of the bridge, it will be understood that if C_1 equals C_2, which it does, and C_3 equals C_4, such that the bridge is balanced, the currents i_1 i_2 respectively traversing the capacitors C_1 and C_2 are equal so that equal voltage drops e_1 and e_2 appear across these capacitors. Accordingly, no difference between the voltages to ground is developed at the points A and B, regardless of the frequency of the exciting voltage E. In the actual circuit, however, the capacitance C_3 is less than the capacitance C_4 by an amount equal to the capacitance value of the condenser **92** such that the bridge is unbalanced. Accordingly, during excitation of the circuit by the voltage E, the current i_2 exceeds the current i_1 so that a current i_3 is caused to flow through capacitors C_1 and C_2 of the inductance element L. The magnitude of this current obviously depends upon the reactive impedance of the inductance L at the particular frequency of excitation and the direction of current flow is such that the voltage drop across the capacitance C_1 is enhanced and that across the capacitance C_2 is decreased. It will be understood, therefore, that by suitably proportioning the impedance of the inductance L relative to the reactive impedances of the capacitances C_1 and C_2 at a particular center frequency, to establish a given relationship between the currents i_1, i_2 and i_3 the absolute voltages between the points A and B and ground become equal. In their relationship to each other, however, these voltages are out of phase so that a difference voltage actually exists between the points A and B. This difference voltage is, of course, equal to the vector sum of the absolute voltages from the points A and B to the ground point F. The particular frequency at which these absolute voltages become equal to balance the bridge represents the center frequency at which the voltage appearing at the output side of the discriminator between the cathode of the diode **88** and ground becomes zero. In this regard it is pointed out that when the bridge is balanced so that the voltages from the points A and B to ground are equal, equal direct voltages are produced across the load resistors **90** and **91**. These voltages are opposingly combined in a direct current path through the inductance element **87***a* so that when equal, no direct voltage appears between the cathode of the diode **88** and ground.

As the exciting voltage for the resonant circuit **87** is increased above the center frequency, due to the signal modulation thereof at an audio rate, the reactive impedances of the circuit constants change to alter the relative magnitudes of the currents i_1, i_2 and i_3 so that the voltage from the point A to ground exceeds that between the point B and ground. Accordingly a voltage which is positive with respect to ground is produced between the cathode of the diode **88** and ground. If, on the other hand, the exciting frequency for the circuit **87** is decreased below the center frequency, the reactive impedances of the circuit constants change to alter the relative magnitudes of the currents i_1, i_2 and i_3 so that the voltage between the point B and ground exceeds that between the point A and ground. As a result an output voltage which is negative with respect to ground is produced between the cathode of the diode **88** and ground.

More specifically considered the voltage between the point A and ground, mathematically expressed, is as follows:

$$V_a=\frac{EC\left[\frac{C+C4}{Q}+j\left\{(C+C4)-\frac{2}{L\omega^2}\right\}\right]}{\frac{EC^2}{Q}+j\left\{\Sigma C^2-\frac{\Sigma C}{L\omega^2}\right\}}$$

where:

$C=C_1=C_2$

$j=\sqrt{-1}$

E=exciting voltage

Q=the Q of the inductance element **87***a*

$\omega=2\pi f$

$\Sigma C=2C-C_3-C_4$

$\Sigma C^2=C^2+CC_3+CC_4+C_3C_4$

The expression for the voltage between the point B and ground is similar, viz:

$$Vb=\frac{EC\left[\frac{C+C^3}{Q}+j\left\{(C+C_3)-\frac{2}{L\omega^2}\right\}\right]}{\frac{EC^2}{Q}+j\left\{\Sigma C^2-\frac{\Sigma C}{L\omega^2}\right\}}$$

By evaluating the above voltages for different values of ω in a circuit having selected circuit constants and excited at a particular voltage, and plotting the difference voltage therebetween, it may be shown that at the center resonant frequency of the discriminator network **27** the difference voltage is zero and that this difference voltage varies linearly with frequency changes above and below the center resonant frequency.

From the above explanation it will be understood that the extent or magnitude of the discriminator output voltage varies in accordance with the departure of the exciting frequency from the center intermediate frequency to which the resonant circuit **87** is center tuned. It will also be understood that if the frequency of the carrier appearing at the output side of the limiter **26** is frequency modulated in accordance with a given audio signal, a corresponding audio frequency voltage is accurately reproduced across the condenser **93** at the output side of the discriminator **27**. To consider somewhat more fully the action of the condenser **92** in stabilizing the operation of the discriminator network **27**, it may be pointed out that if the impedances of the four legs of the bridge circuit are perfectly balanced, changes in the exciting frequency will not produce the desired differences of potential between the terminals A and B. By providing the condenser **92** connected in the manner illustrated, however, thereby to insure that the over-all capacitance between the lower terminal B of the resonant circuit **87** and ground exceeds that between the upper terminal A of this circuit and ground, the desired circulating current within the resonant circuit will always be produced to insure stability of circuit operation. In this regard it is pointed out that the unbalancing or stabilizing condenser **92** may be connected either between the lower terminal of the resonant circuit **87** and ground or between the upper terminal of this circuit and ground. In either case, the desired operation of the network is produced. It is noted, however, that when a condenser **92** of appropriate capacitance value is connected between the upper terminal A of the circuit **87** and ground, the direction of circulating current flow within the circuit is reversed. Accordingly, the polarity

of the output voltage produced across the condenser **93** incident to a given departure of the exciting frequency from the center intermediate frequency is the reverse of that which is obtained for the same frequency departure when the condenser **92** is connected between the lower terminal of the resonant circuit and ground.

It will be understood from the above explanation that the invention is not limited to any particular range of frequency detection, although it is particularly applicable to the detection of signal frequencies within a band embracing the audio frequency range. In order to illustrate the relative magnitudes of the principal circuit elements of the discriminator network **27**, when designed in accordance with the present invention, the following approximate values of its elements, together with other pertinent information, are given for a particular system of the character shown in Figs. 1 and 2 of the drawing.

Center intermediate frequency megacycles	2.515
Condenser 87*b*—micro microfarads	100
Condenser 87*c*—do	100
Condenser 93—do	100
Condenser 92—do	10
Resistor 90—ohms	220,000
Resistor 91—do	220,000
Inductance element 87*a* — adjustable from—micro henries	50
Resistor 94—ohms	100,000
Resistor 95—do	470,000
Condenser 97—microfarads	.01
Condenser 96—do	.01
Condenser 101—do	.01
Resistor 98—ohms	500,000
Resistor 100—do	39,000

The response characteristics shown in Fig. 3 of the drawing are typically representative of the improved discriminator **27** when provided with circuit elements having the approximate values indicated, but with different capacitance values for the condenser **92**. In the graph illustrated in this figure, positive and negative frequency deviations from the center intermediate frequency of 2.515 megacycles, as graduated in positive and negative frequency steps of ten kilocycles each, are plotted as a function of positive and negative voltage output across the condenser **93**. More specifically, the response curves A, B and C of this graph represent accurately reproduced test curves of a discriminator network of the character described when provided with a condenser **92** connected between the lower terminal of the resonant circuit **87** and ground. By a comparison of these curves, it will be noted that as the value of this condenser is increased from a value of 5 micro microfarads upward to a value of 9 micro microfarads, the linear portion of the resulting response characteristic of the network is substantially increased. It will also be seen from an examination of these curves that as the exciting frequency of the network is increased above the center intermediate frequency at which the resonant circuit **87** is tuned, an output voltage which is positive with respect to ground is produced at the output side of the discriminator. On the other hand, when the exciting frequency is decreased below the center intermediate frequency, an output voltage which is negative with respect to ground is produced at the output side of the discriminator. Over the linear portion of each curve, changes in the magnitude of the output voltage are obviously directly proportional to changes in the exciting frequency of the resonant circuit **87**.

The curve D, as shown in Fig. 3 of the drawing, is an accurate reproduction of the same circuit when equipped with a condenser **92** of 5 micro microfarads connected between the upper terminal of the resonant circuit **87** and ground. By a comparison of this curve with the three curves A, B and C, it will be noted that the polarity of the output voltage produced in response to increases and decreases in the exciting frequency of the resonant circuit **87** is reversed from that which obtains when the condenser **92** is connected between the lower terminal of the resonant circuit and ground. This is due to the fact, noted above, that when the position of this condenser in the network is changed from a connection between the lower terminal of the resonant circuit and ground to a connection between the upper terminal of this resonant circuit and ground, the direction of circulating current flow through the elements of the resonant circuit **87** is reversed.

If desired, one rectifying section of the improved discriminator **27** may be combined with the audio frequency amplifier **28** in the manner illustrated in Fig. 4 of the drawing, wherein reference characters corresponding to those used in Fig. 1 identify the same circuit elements. From an examination of the Fig. 4 arrangement, it will be seen that the diode section of the tube **89** is utilized as one of the rectifying paths of the discriminator, and that the cathode, anode and three grids of the tube are used to amplify the audio frequency voltage which is developed between the wiper **99** and ground during reception of a selected signal. This audio voltage is transmitted to the loud speaker **29** for reproduction through a coupling transformer **139**. The manner in which the audio section of the tube is blocked under the control of the muting oscillator **33** and mode of operation of the discriminator **27** are exactly the same as explained herein with reference to the system shown in Fig. 1. In fact, the circuit of Fig. 4 may be directly substituted for the discriminator **27** and the audio frequency amplifier **28** in the system of Fig. 1.

From the foregoing explanation with reference to the discriminator **27**, it will be understood that this circuit may be accurately reproduced according to a preconceived design to have the exact desired operating characteristics. Thus, in the manufacture of this circuit, it is unnecessary to utilize a tuning inductance element **87***a* having a center tap precisely located at the electrical mid-point of the inductance winding. This necessity is obviated by utilizing the two condensers **87***b* and **87***c* of equal capacitance values for introducing the carrier voltage into the discriminator network. Moreover, the use of fixed condensers **87***b* and **87***c* of matched capacitance values is only permissible in the circuit because an adjustable inductance element **87***a* is utilized to tune the resonant circuit to the desired center intermediate frequency. It has been found that by utilizing available commercial inductance elements **87***a* of the variable permeability type, a resonant circuit **87** may be provided which is precisely and accurately tuned to the desired frequency such that no output voltage is produced across the condenser **93** when the discriminator network is excited at the center intermediate frequency. This is an important consideration in the automatic control of the reactance modula-

tor tube 38 to maintain the system faithfully responsive to a selected signal, as will appear from the explanation which follows.

More generally considered, the discriminator network 27 is substantially more stable and less affected by stray capacitance coupling paths than the discriminators previously available in the prior art. Thus, the tuning slug of the variable inductance 87*a* may be connected to ground so that body capacity effects do not affect the circuit constants of the network in tuning the resonant circuit 87 to a desired center frequency. This makes it possible to easily tune the network with precision accuracy to the exact desired center frequency, so that the network is perfectly balanced in so far as the relationship between frequency deviations and voltage output is concerned. As contrasted with this improved arrangement, a conventional discriminator utilizes an adjustable tuning condenser having its adjustable plates above ground potential. When, therefore, a tuning tool is brought into proximity to the adjusting shaft, stray capacitance coupling to the elements of the tuned discriminator circuit is provided which makes exact tuning of the circuit to the desired center frequency practically impossible.

Also, by shielding the elements of the circuit 87 and the elements used at the output side of the limiter 26, thereby to eliminate mutual inductive coupling between the discriminator and the preceding limiter 26, and by using only the capacitive coupling of the condenser 86 between these stages, the discriminator network may be much more accurately manufactured and adjusted to operate in accordance with given design specifications. Moreover, by capacitively coupling the preceding limiter 26 into the discriminator 27 through the condensers 86, 87*b* and 87*c*, stray capacitances are minimized and the effects of those remaining may be more easily compensated for in the design and adjustment of the network. A further advantage of the disclosed discriminator 27 resides in the fact that it may be more easily and accurately compensated for temperature variations by making suitable provision for adjusting the tuning slug of the inductance element 87*a* in response to changes in the temperature to which the elements of the network are exposed.

While one embodiment of the invention has been disclosed, it will be understood that various modifications may be made therein, which are within the true spirit and scope of the invention.

I claim:

1. In a frequency discriminator network which is adapted to be excited from a voltage source of variable frequency, a pair of series connected condensers, a two-terminal adjustable inductance shunting said series connected condensers to tune said network to a particular center frequency, means including a first rectifying element for bridging one of said condensers across said source, means including a second rectifying element for bridging the other of said condensers across said source, load resistors respectively shunting said rectifying elements, and means providing unequal capacitance across said rectifying elements to unbalance said network.

2. In a frequency discriminator network which is adapted to be excited from a voltage source of variable frequency, a pair of series connected condensers, a two-terminal adjustable inductance shunting said series connected condensers to tune said network to a particular center frequency, means including a first rectifying element for bridging one of said condensers across said source, means including a second rectifying element for bridging the other of said condensers across said source, load resistors respectively shunting said rectifying elements, and an unbalancing capacitance element connected in shunt with one of said load resistors.

3. In combination with a voltage source of variable frequency, a pair of rectifying paths bridging said source and each including a rectifying element and a condenser arranged in series circuit relationship, means comprising a two-terminal tuning inductance shunting said condensers in series, means providing unequal capacitance across said rectifying elements for varying the relative magnitudes of the voltages appearing across said rectifying elements in accordance with deviations in the frequency of said voltage source from a particular value, load resistors respectively shunting said rectifying elements, and a direct current path serially including said resistors and said inductance so that a voltage is produced thereacross which varies in accordance with the extent of deviations of the frequency of said voltage source from said particular frequency.

4. In combination with a voltage source of variable frequency, a pair of rectifying paths bridging said source in parallel and each including a rectifying element and a condenser arranged in series circuit relationship, means comprising a two-terminal inductance shunting said condensers in series and a condenser shunting one of said rectifying elements for varying the relative magnitudes of the voltages appearing across said rectifying elements in accordance with deviations in the frequency of said voltage source from a particular value, load resistors respectively shunting said rectifying elements, and a direct current path serially including said resistors and said inductance so that a voltage is produced thereacross which varies with deviations in the frequency of said voltage source from said particular frequency.

5. A frequency discriminator network adapted to be excited from a variable-frequency signal source comprising, a four-arm capacitance bridge circuit including connections for excitation from said source across one diagonal thereof, a two-terminal adjustable inductor connected across the the other diagonal of said bridge circuit to tune said bridge circuit to the mean value of said variable frequency, a pair of rectifying devices individually coupled across two adjacent capacitance arms of said bridge forming a branch in parallel to said inductor, a pair of resistors individually shunting said rectifying devices, and load impedance means coupled to said resistors for deriving the differential of the unidirectional signals developed thereacross by said rectifiers.

6. A frequency discriminator network adapted to be excited from a variable-frequency signal source comprising, a four-arm capacitance bridge circuit including connections for excitation from said source across one diagonal thereof, a two-terminal adjustable inductor connected across the other diagonal of said bridge circuit to tune said bridge circuit to the mean value of said variable frequency, the adjacent capacitance arms of at least one of the bridge branch circuits in parallel to said inductor having unequal capacitance values, a pair of rectifying devices individually coupled across two adjacent capacitance arms of said bridge forming a branch in

parallel to said inductor, a pair of resistors individually shunting said rectifying devices, and means for deriving the differential of the unidirectional signals developed by said rectifiers.

7. A frequency discriminator network adapted to be excited from a variable-frequency signal source comprising, a four-arm capacitance bridge circuit including connections for excitation from said source across one diagonal thereof, a two-terminal inductor including an adjustable ferromagnetic core for adjusting the inductance value thereof, said inductor being connected across the

other diagonal of said bridge circuit to tune said bridge circuit to the mean value of said variable frequency, a pair of rectifying devices individually coupled across two adjacent capacitance arms of said bridge forming a branch in parallel to said inductor, a pair of resistors individually shunting said rectifying devices, and load impedance means coupled to said resistors for deriving the differential of the unidirectional signals developed thereacross by said rectifiers.

MARION E. BOND.