

Aug. 19, 1947.

M. G. CROSBY

2,425,922

FREQUENCY DISCRIMINATOR CIRCUIT

Filed April 15, 1943

4 Sheets-Sheet 1

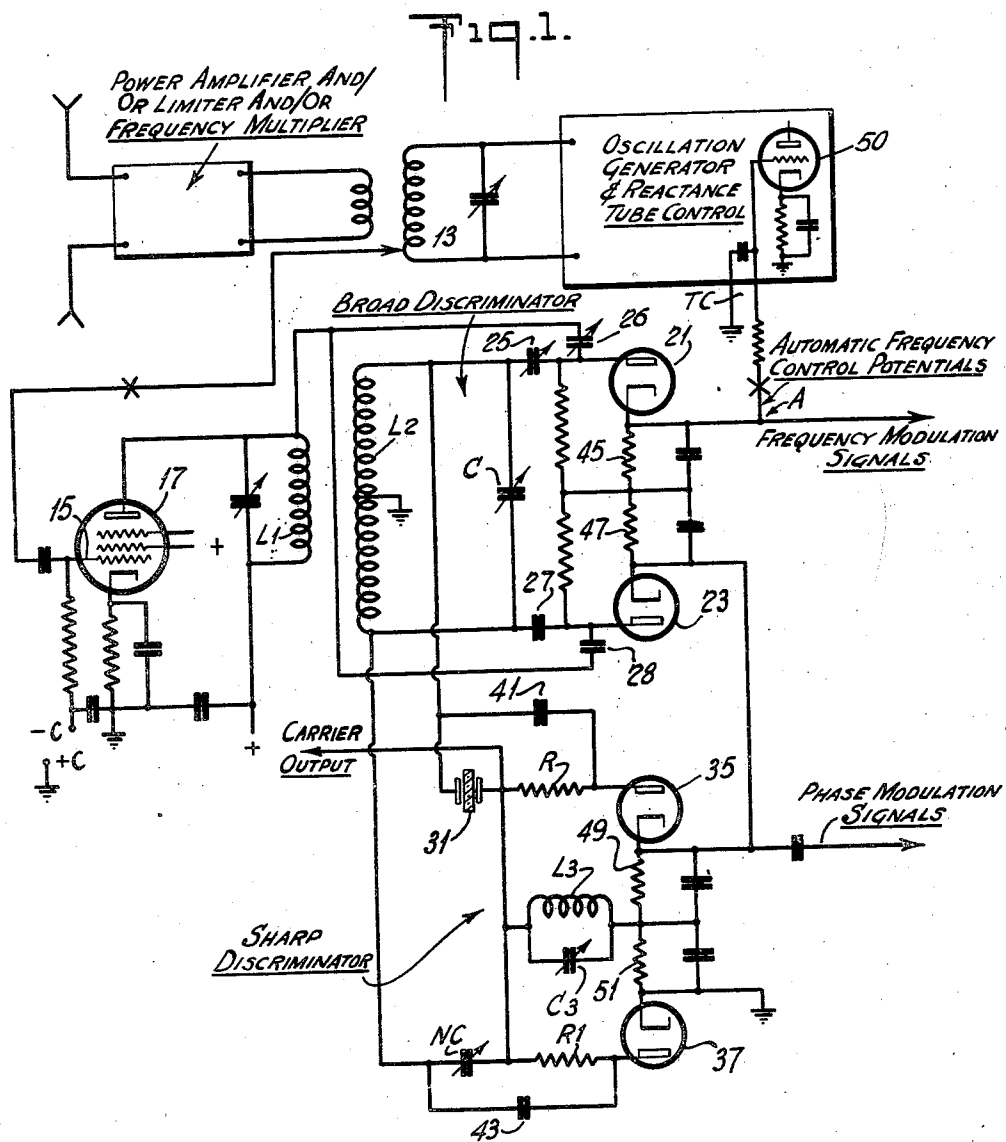
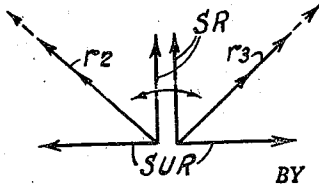
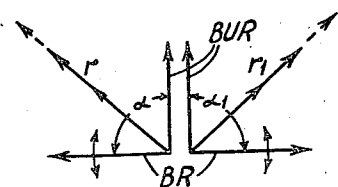


Fig. 1a.

Fig. 1b.



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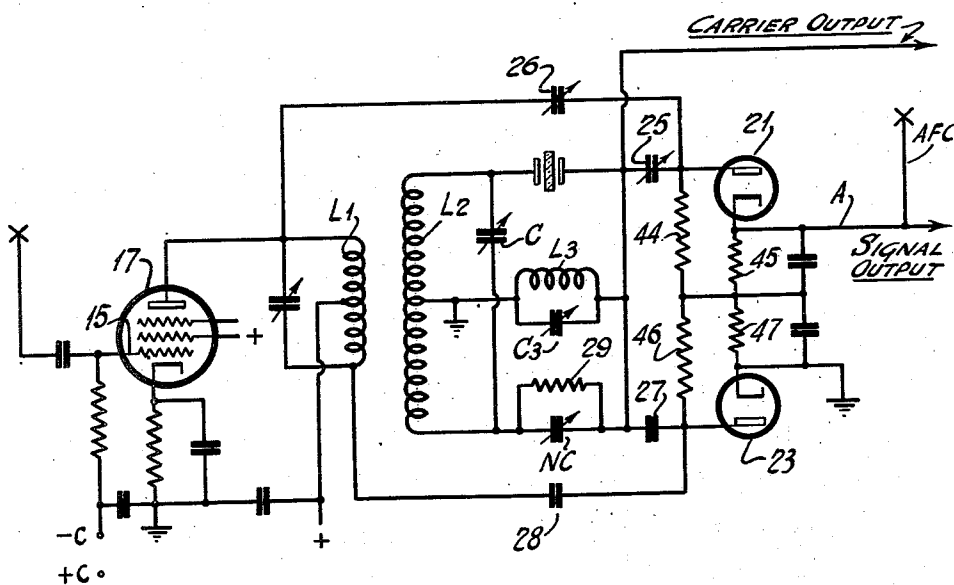


Fig. 2a.

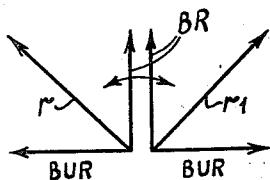
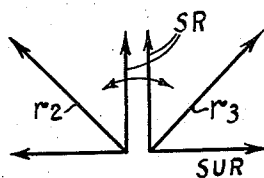


Fig. 2b.



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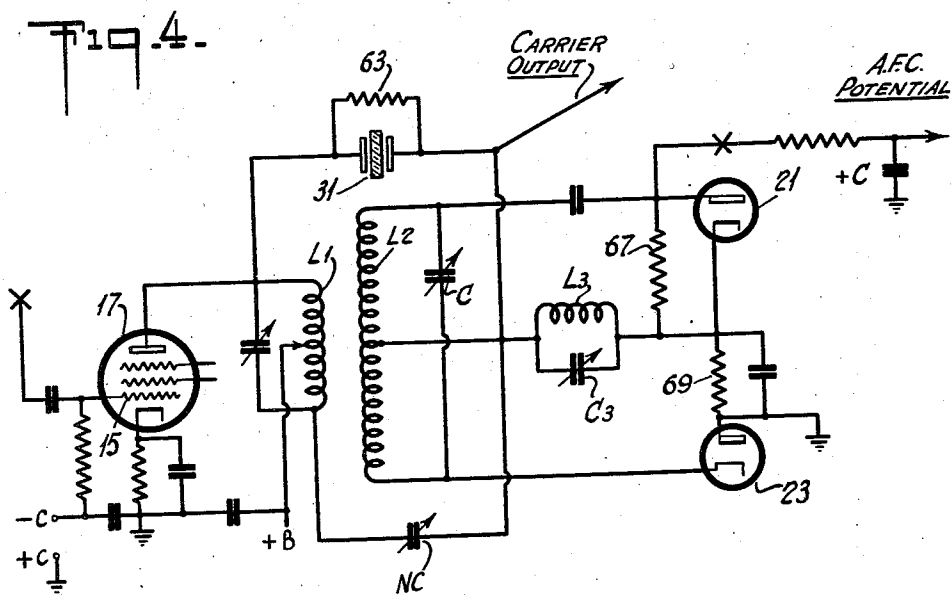
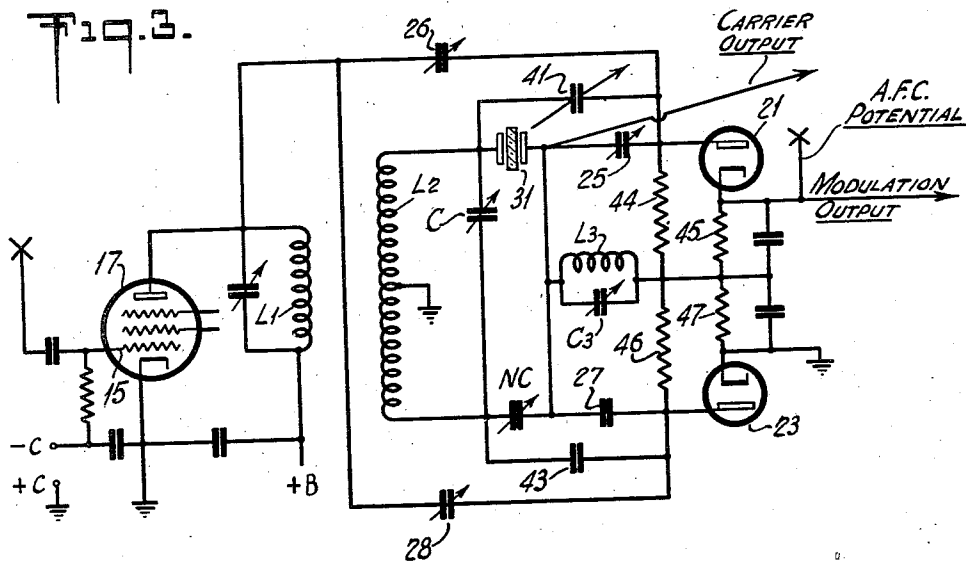
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4 Sheets-Sheet 3



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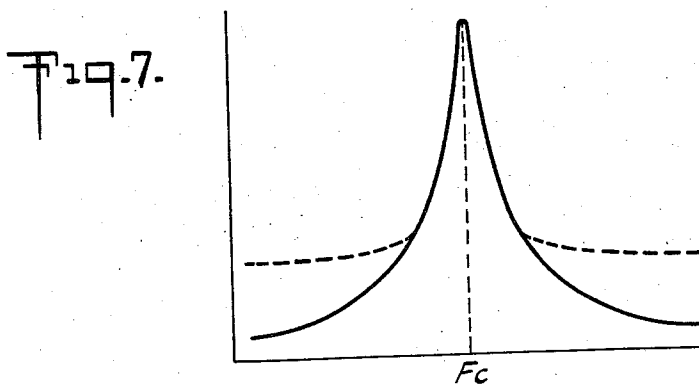
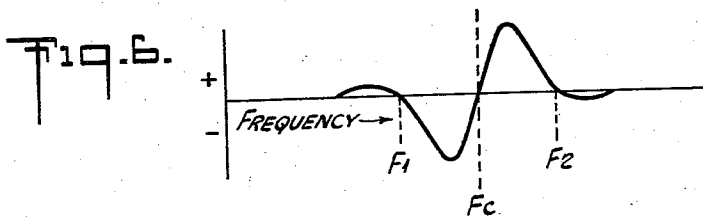
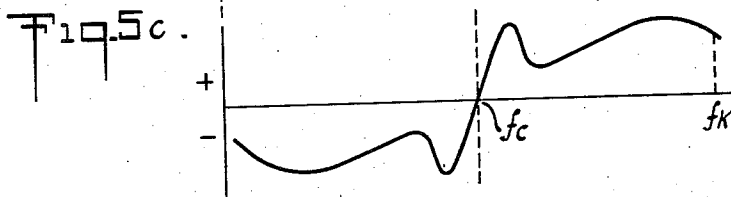
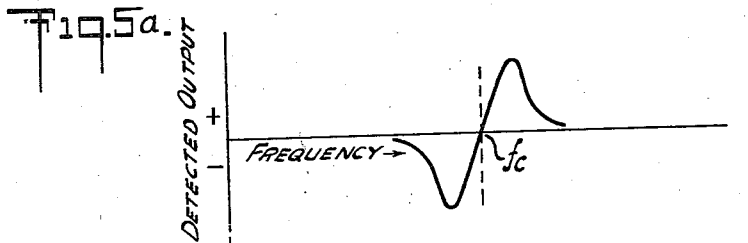
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FREQUENCY DISCRIMINATOR CIRCUIT

Filed April 15, 1943

4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,425,922

FREQUENCY DISCRIMINATOR CIRCUIT

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Application April 15, 1943, Serial No. 483,153

14 Claims. (Cl. 250—40)

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My present application relates to a new and improved frequency discriminator circuit having broad and sharp discriminating characteristics.

More in detail this application discloses a new and improved discriminator circuit which may be used in the detection and generation of frequency and phase modulated signals or modified forms of frequency and phase modulation signals.

The novelty of my system might be said to reside in means by which potentials are produced representative of coarse or large frequency changes or deviations from the mean frequency as well as potentials representative of small changes or deviations near the carrier or mean frequency. This broad and sharp discrimination is obtained by means of a combination of the broad tuning characteristics of a tuned circuit including reactance with the sharp characteristics of a tuned circuit including a piezo-electric crystal.

One of the main objects of my present invention is to provide an automatic frequency control (AFC) system employing a dual discriminator; one discriminator having a broad frequency response characteristic, the second discriminator having a relatively sharp characteristic; and the rate of development of the control voltage being a function of the sharp characteristic for small frequency shifts and of the broad characteristic for relatively wide frequency deviations.

Another important object of my present invention is to provide a method of developing AFC voltage from frequency-variable signal waves wherein relatively small values of AFC voltage are developed at a relatively rapid rate for small frequency shifts of the signal waves from a predetermined reference frequency, and larger values of AFC voltage are produced at a relatively slower rate for wide frequency shifts from said reference frequency.

Another object of my invention is to provide a crystal filter discriminator-rectifier circuit capable of deriving AFC bias from either frequency, or phase, modulated wave energy, or demodulating phase modulated wave energy; to provide a second discriminator-rectifier circuit whose response is relatively broader than the crystal circuit and which is capable of acting as a demodulator for frequency modulated wave energy; the AFC voltages produced from either of said circuits being transmitted over a common AFC line to a frequency-controllable network.

Still another object of my invention is to provide a more sensitive AFC circuit of wide frequency response for a transmitter of the type described in my U. S. Patent No. 2,279,659, granted April 14, 1942.

In one modification of my improved method and means a broad-sharp discriminator is pro-

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vided which includes two separate differential detectors, one supplied with the output of a discriminator having a broad characteristic and the other detector supplied with the output of a discriminator having a sharp characteristic with the detector outputs arranged in series, so that the resulting characteristic is a summation of the broad characteristic of one detector and the sharp characteristic of the other differential detector.

In a further modification a single differential detector is used and the broad discriminator circuit and the sharp discriminator circuit have a substantial number of elements in common so that they may be considered as composite broad-sharp discriminator circuits. In this modification the combination of the two discriminating actions takes place in the circuit of the discriminator itself, whereas it might be said that in the prior modification the summation or combination of the broad-sharp characteristics takes place in the detectors wherein the modulation components flow.

Such a broad-sharp discriminating action has advantages for use as an AFC discriminator in a phase or frequency modulation transmitter as well as for use as a combined carrier filter and AFC discriminator in a carrier-exalted phase-amplitude modulation receiver. As an AFC discriminator in a phase or frequency modulation transmitter, it may be used in the circuits of my U. S. Patent No. 2,270,659 and U. S. application No. 355,592, filed September 6, 1940, now Patent #2,312,079, dated February 23, 1943. It is particularly advantageous for use in circuits of the type in the last mentioned patent, which is a frequency modulator comprising an oscillator, a reactance tube and an AFC discriminator and detecting system. In this type of circuit the AFC potentials are obtained from a discriminator which is tuned to the master oscillator frequency without the step of heterodyning. Hence the controlled frequency is dependent directly upon the discriminator stability. In the present invention, the stability of the discriminator is as high as that of the crystal which forms a part of it. Consequently the stability of the controlled frequency has the same stability as the ordinary crystal oscillator. It also has the broad range of control affected by the coarse part of the characteristic.

For use in carrier-exalted phase and amplitude modulation reception, this type of discriminator has the advantage that the AFC system may be adjusted so that it takes control of the signal as soon as it enters the band-pass characteristic of the receiver. The usual crystal discriminator does not ordinarily do this, but takes control of the signal when it is tuned to within a few hundred cycles of the crystal frequency. Hence by the

use of the circuit of the present invention, the receiver is made more simple to tune. Such a type of control would be particularly advantageous on the broadcast type of carrier-exalted receiver since it would facilitate the design and maintenance of a push-button type of receiver and would simplify manual tuning.

In describing my invention reference will be made to the attached drawings, wherein Figs. 1 to 4 inclusive each show a different embodiment of my broad-sharp discriminator circuit. As shown in Fig. 1 the discriminator circuit may be used as the automatic frequency control means in a wave length modulation transmitter.

Figs. 1a and 1b illustrate graphically the vector relations of the voltages applied to the diodes in the arrangement of Fig. 1 to obtain the broad and the sharp characteristics respectively.

Figs. 2a and 2b illustrate graphically the vector relations of the voltages applied to the diodes in the arrangement of Fig. 2 to obtain the broad and the sharp characteristics respectively.

Fig. 5a illustrates the sharp discriminator characteristic.

Fig. 5b illustrates the broad discriminator characteristic.

Fig. 5c illustrates the combined broad-sharp filter characteristic.

Fig. 6 is a graphic illustration of the sharp discriminator characteristic used in describing the invention.

Fig. 7 illustrates the resonant characteristic of the crystal and of the same when shunted by the resistance. This graph is used in showing that pure carrier may be obtained for use in a carrier-exalted receiver.

In Fig. 1, numeral 13 denotes a source of timing modulated oscillations which may be modulated as to phase or frequency in accordance with signals, and the mean or average frequency of which may vary or drift in frequency with respect to the desired mean frequency. These oscillations are fed to the first grid 15 of an electron discharge device 17, the anode of which is coupled to the winding L1 of a frequency discriminator arrangement which may in general be said to be of the type disclosed in Seeley U. S. Patent No. 2,121,103, dated June 21, 1938, and more specifically of the type disclosed in my United States application No. 480,762, filed March 27, 1943 patented February 26, 1946, as U. S. Patent No. 2,395,725. The winding L1 is inductively coupled to a second winding L2 tuned by a variable capacity C. The voltage induced in L2 by inductive coupling is, as is well known, shifted by about 90° with respect to the inducing voltage in L1. The winding L2 has its mid-point grounded, and its terminals are coupled to the respective anodes of diodes 21 and 23 by coupling condensers 25 and 27 to impress the phase displaced (90°) voltage in phase opposition on the diode anodes. The condensers 25 and 27 impress equal voltages on the diodes, and to facilitate this condenser 25 is of larger maximum capacity than condenser 27 and is adjustable.

The phase of the voltage fed from L1 through L2 and condensers 25 and 27 to the diodes is retarded an amount which changes with changes in the frequency of the applied voltages. These voltages are represented at BR in Fig. 1a. The high potential end of inductance L1 is also coupled by equal coupling condensers 26 and 28 to the diodes. In this path the voltage is relatively unretarded because the length of the path they follow is substantially independent of frequency.

These voltages are represented at BUR in Fig. 1a. These couplings provide a sloping filter effect as described in Crosby Patent No. 2,229,640 and provide the broad discriminator and detector characteristic of the present invention. This characteristic is illustrated in Fig. 5b. As the voltages BR swing in phase due to the retarding effect of L1 and L2 the amplitude of the resultants r and $r1$, Figure 1a, on the diodes vary differentially since the angle α between the components for vector r decreases at the time when the corresponding angle $\alpha1$ for vector $r1$ increases and vice versa. The current through the opposed resistances 45 and 47 changes as does the potential drop across these resistances.

The inductance L2 also has its terminals coupled by a crystal 31 and a crystal holder capacity neutralizing condenser NC to the high potential end of a circuit L3, C3 tuned to the frequency to which the crystal 31 is ground, this also being the mean or average or carrier frequency of the wave energy supplied by L1 to L2. This circuit C3, L3 is of high impedance to the voltages fed thereto by the crystal and these voltages are fed in phase through resistances R and R1 to the diodes 35 and 37. In this path or circuit the phase of the voltages fed to the diodes 35 and 37 is retarded. The diodes 35 and 37 have their cathodes connected by by-passed resistances 49 and 51 arranged to combine the diode outputs differentially. The high potential ends of inductance L2 are also coupled by paths including coupling condensers 41 and 43 to the anodes of diodes 35 and 37. In these paths the phase of the voltages fed to the diodes is relatively unretarded. Condensers 41 and 43 effect a 90° phase shift of the unretarded voltage. Note that in this arrangement we again have a discriminating effect but its characteristic is much sharper. The last mentioned voltages fed to the diodes 35 and 37 are in phase opposition and (disregarding the retarding effect of inductance L2 and condenser C) are relatively unretarded. They may be represented by vectors SUR in Figure 1b. The voltage fed through the crystal 31 is relatively retarded and is impressed in like phase on the diodes by resistances R and R1. These voltages may be represented by vectors SR in Figure 1b and they change in phase with changes in frequency of the wave energy fed to L2. This change in phase with frequency of the retarded voltage causes the resultant voltages, $r2$ and $r3$, fed to the diodes to change differentially in amplitude causing corresponding changes in the current through resistors 49 and 51. These resistors are differentially connected as shown, so that across the diode resistors is developed a differential potential the value and sign of which depends on the extent of deviation of the carrier and the direction of such deviation. The sharp discriminator circuit and its detectors 35 and 37 has a sloping filter characteristic which may be represented by the graph in Figure 5a.

The resistors 45, 47, 49 and 51 are connected in series with the cathode of a diode 37 grounded so that at the point A there appears a potential which is the combination or summation of the potentials in the two differential diode output impedances. The broad discriminator circuit and rectifier characteristic and sharp or narrow discriminator and rectifier characteristic are combined to provide a resultant characteristic as illustrated in Figure 5c. As will be seen by inspection

tion of Figure 5c, the improved detector system will have a characteristic such that the potential produced across the series diode outputs rises rapidly in one direction or the other as the mean or carrier frequency deviates from its assigned value at f_c . This steep characteristic obtains throughout a narrow range so that if the produced potential is used for automatic frequency control purposes a strong stabilizing action is provided within a narrow range. Outside this range the slope of the characteristic is not so steep so that the action throughout the rest of the range is positive but is not so rapid. In the normal condition the sensitivity of the AFC system would be such as to maintain the signal in tune at frequency f_c . For this condition there would be little or no positive or negative voltage fed to point A. As the signal is brought into tune from, for instance, the high-frequency side of f_c , a positive potential is present as soon as the signal is lower than frequency f_k . This potential applies a correcting tuning which tunes the signal to the immediate vicinity of frequency f_c .

The discriminator system of this figure and of those which are described hereinafter may be used in a receiver for automatic frequency control purposes in a well known manner. When so used the tuned circuits 13 may represent a source of oscillations used in the receiver for heterodyning the received wave to a lower frequency and the tube 50 may represent a reactance tube with its electrodes coupled to the generating circuit in a well known manner and its control grid connected to the point A on the diode output. A time constant network TC may be included in this connection where desired.

The broad discriminator comprising L1, L2 condenser C and coupling condensers 25, 26, 27 and 28 and diodes 21, 23 and resistors 45 and 47 considered alone comprise a frequency modulation detector of the type wherein a phase retarded voltage is combined out of phase with a voltage the phase of which is unretarded in the rectifiers, and the rectifier outputs combined differentially. Thus we may use the system also for demodulation of frequency modulated waves and the modulation components are then derived from the drop across resistors 45 and 47.

Considering the sharp discriminator circuit and its rectifiers 35 and 37, it is noted that the neutralized crystal 31 supplies pure carrier wave energy across the impedance L3, C3 and thus pure carrier wave energy is supplied in phase to the electrodes of the diodes 35 and 37. The condensers 41 and 43 supply to the diodes substantially unfiltered, wave energy of unretarded phase and the voltages of this wave energy are phase opposed on the rectifiers. If this unfiltered, unretarded energy is phase modulated the modulation thereon is detected and is available across resistors 49 and 51. This is because I am supplying to each of the rectifiers a carrier and phase modulated wave energy displaced in phase with respect to the carrier so that there is in effect on each demodulator a resultant high frequency wave, the envelope of which is amplitude modulated in accordance with the phase modulation on the unfiltered, unretarded energy. When this type of discriminator is used in a carrier-exalted phase-amplitude modulation receiver, the carrier output appearing across L3, C3 is fed to a separate detecting system which recombines the filtered carrier with the unfiltered signal in the manner of my U. S. Patent No. 2,063,588, issued

December 8, 1936, or No. 2,065,565, issued December 29, 1936.

In Figure 2, I have shown an arrangement wherein a compound circuit provides a broad discriminator detector characteristic and a narrow discriminator detector characteristic. In this arrangement the circuit is, as in Figure 1, a combination of the crystal filter type of discriminator of my U. S. application Serial No. 476,052, filed February 16, 1943, and of the type of discriminator based on the principle of my U. S. Patent No. 2,229,640, issued January 28, 1941, where in one path the phase of the voltages is retarded and in another path the phase of the voltage is unretarded. This is a preferred form of discriminator and detector circuit.

The voltage, unretarded in phase, of the broad discriminator characteristic is fed by condensers 26 and 28 from opposite ends of inductance L1, a point on which is grounded for voltages of radio frequency, to the diodes in like amounts and in opposite phase. The voltage, retarded in phase, of the broad characteristic is fed through the resistance 29 shunting the crystal neutralizing condenser NC across the impedance of L3, C3 to ground. L3, C3 being tuned to the mean carrier frequency provides a high impedance output for the crystal and the resistance 29. The high potential end of this impedance provided by tuned circuit L3, C3 is coupled by condensers 25 and 27 (of which one, say 25, is adjustable) to the diodes 21 and 23 so that the same are also energized by voltages of like amplitude and like phase passed by the path of the broad discriminator circuit wherein phase retarding takes place. There is, however, a 90° phase shift in the voltage induced from L1 into L2 so that again we have on each of the rectifiers voltage of unretarded phase and voltage of retarded phase in phase displaced relation. The relation of these voltages are shown in Figure 2a where BR represents the phase retarded voltage supplied to the two diodes by resistance 29 and BUR represents the voltage of unretarded voltage phase supplied by condensers 25 and 27. Again we have resultant (r and r') high frequency energy the amplitude of which changes differentially with change in phase or frequency of the voltage in L1 to provide across 45 and 47 differential potentials, and the system has a sloping characteristic as illustrated in Figure 5b. The maximum value of the positive or negative voltage occurs at a frequency separation approximately equal to the band width which the tuned transformer would have had if it were tuned as a band pass filter.

The crystal holder neutralization condenser NC also supplies to diodes phase retarded voltages which are of like phase but are phase displaced about 90° with respect to the voltages of unretarded phase supplied by condensers 26 and 28. Thus are applied to each of the diodes phase displaced phase retarded voltages of like phase passed by the crystal and voltages of unretarded and opposed phase passed by the condensers 26 and 28. The vector relation of the voltages on the diodes for the narrow characteristic is shown in Figure 2b.

As to the sharp filter the same principle is applied but the selective action of the crystal filter is utilized to produce the phase retarding action. Due to its high selectivity the output of the crystal filter varies more rapidly in phase as the frequency of the output is varied. This produces a steeper and narrower automatic frequency control characteristic as shown in Figure 5a. Fre-

quency separation of the maximum positive and negative voltage varies with the relative amplitudes of the phase retarded and unretarded voltages but for equality of the two components is approximately equal to the width of the crystal filter at 3 db (decibels) down.

In the circuit of Figure 2 a combination is effected between the voltage of unretarded phase and the voltage of retarded phase in such a manner that the retarded voltage contains two components. One of these components is passed by the crystal filter and produces a sharp discriminator action in the vicinity of the carrier frequency while the other component is passed through the tuned transformer to produce a broad discriminator action. Note that this combination takes place in the voltages applied to the diodes for rectification purposes. In the arrangement of Figure 1 the phase retarded and unretarded components of the broad and of the sharp discriminator action are set up separately on pairs of diodes and the outputs of the diodes combined in series to get the composite effect.

The circuit of Figure 2 consists of a crystal filter type of discriminator if the resistor 29 is omitted. Voltage unretarded in phase is fed to the diode anodes from the primary of the tuned transformer through condensers 26 and 28. Phase retarded voltage is fed through the transformer (90° shift) and crystal filter to appear across L3, C3 and be fed to the anodes of the diodes through condensers 25 and 27. Note that here as in Figure 1 the voltage fed to the crystal to be phase retarded thereby is retarded by the action of the tuned transformer L1, L2, but this phase retarding action is so small as compared to the phase retarding action of the crystal that it may be disregarded. The 90° phase shift between the phase retarded and unretarded voltages is effected by the transformer L1 and L2. The relation of these voltages on the diodes will be apparent to those skilled in the art when the voltage relations involved in the arrangement of Figure 1 as illustrated in detail in Figures 1a and 1b and described in the specification is understood and it is believed unnecessary to further discuss the relation of the voltage vectors at this point. Circuit L3, C3 as before is tuned to the crystal frequency and may be damped by resistance to increase selectivity of the crystal filter.

With the addition of the resistance 29 the crystal filter is bypassed so that unfiltered phase retarded energy is passed by resistor 29 unaffected by the crystal filter. If desired resistor 29 may be connected across the crystal terminals as well as across the neutralizing condenser NC. Whether it is connected across the crystal or the neutralizing condenser depends upon the polarity of the broad discriminating action with respect to the sharp discriminating action. This relative polarity may also be regulated by reversing the terminals of the transformer windings of L1, L2. Thus for one transformer connection the resistance might be across the crystal and for the opposite it might be across the neutralizing connection. The object is to have the two discriminator characteristics aid, as shown in Figure 5c, instead of oppose.

It is thus seen that the crystal passes the highly selective component of phase retarded energy and the resistance 29 passes the broad component. I have found experimentally that this combination of voltages of unretarded and retarded phase produces a discriminator which has an overall characteristic that is a combination of the two

separate characteristics of the broad and sharp filters as shown in Figure 5c. By varying the value of resistor 29 the relative magnitudes of the two characteristics may be regulated. For low values of resistor 29 the broad characteristic predominates and for high values the sharp characteristic predominates.

In the case of the crystal filter type of discriminator, where only the sharp discrimination is desired, it has been found that as the frequency is shifted away from the carrier frequency the detected output of the discriminator falls down to zero and for the extreme frequency deviations assumes a small value of opposite polarity. This is shown in Figure 6. Such a characteristic produces reversed frequency control tending to detune the signal in the frequency region below f_1 and above f_2 . I have found that this effect can be eliminated by connecting a rather high value of resistance 29 across either the crystal or the neutralizing condenser. This introduces a slight amount of the broad characteristic which opposes and cancels the cross-over effect of Fig. 6.

Where the discriminator is to be used for carrier-exalted reception, it might be felt that bypassing the crystal filter with resistance might impair the selective characteristic of the carrier filter. This is true where the value of resistance 29 is made low so that the broad characteristic predominates, but for the higher values of resistance 29, in which there is more of a balance between the broad and sharp characteristics, the result is to change the crystal filter characteristic, appearing at the carrier output terminal, from the solid line of Figure 7 to the dotted-line characteristic. The change is thus symmetrical and the carrier-exalting effect remains although somewhat reduced in degree.

Figure 3 shows another embodiment which produces the same combination of phase retarded and unretarded voltages by a somewhat different arrangement. The voltages of unretarded phase are fed in like amounts and of like phase to the anodes of the diodes through condensers 26 and 28. These condensers are made variable so that the degree of broad discriminator action may be controlled with respect to the sharp discriminator action. The broad discriminator phase retarded energy is fed in opposed phase relation to the anodes of diodes 21 and 23 through condensers 41 and 43, of which one, say condenser 41, is variable for matching the couplings.

The sharp discriminator phase retarded energy is fed in phase to the anodes of the diodes 21 and 23 through condensers 25 and 27 as in Figure 2. The unretarded energy for the sharp discriminator characteristic is fed to the anodes of the diodes 21 and 23 by condensers 41 and 43. Here again the retarding actions of the tuned transformer may be disregarded. Condensers 41 and 43 in this arrangement have the dual purpose of supplying the retarded energy for the broad characteristic and the unretarded energy for the sharp characteristic. The required 90° phase relation between the unretarded and retarded voltages for both characteristics is produced by the transformer. Condenser 41 and 43 thus serve to bypass the crystal filter to a sufficient degree to pass the desired amount of phase retarded energy for the broad characteristic and also energy unretarded in phase for the sharp characteristic. The vector relation of the voltages on the diodes will be apparent to those skilled in the art and it is believed unnecessary to show the same here.

In this embodiment the sharp-broad effects or characteristics are combined as fed to the diodes as in Figure 2, rather than in the diode outputs as in Figure 1.

The circuit of Figure 4 employs a mid-tapped primary coil to obtain energy for neutralizing the crystal holder capacity. For the sharp characteristic of the discriminator, voltage relatively unretarded in phase is fed through the transformer L1, L2 to the diodes in opposed phase relation and phase retarded voltage is fed through the crystal which has as its output load the impedance of L3, C3 tuned to the crystal frequency, to appear across L3, C3 and be impressed on the diodes in like phase relation. For the broad characteristic voltage relatively unretarded in phase is fed through resistor 63 to the electrodes of the diodes in like phase relation while the phase retarded voltage is fed to the diodes through the transformer L1, L2 in phase opposed relation. In this circuit, if the diodes were arranged as in Figures 2 and 3, this would produce a strong second harmonic across L3, C3 at the carrier output. This can take place since the mid-tap of L2 is not grounded, but has L3, C3 connected between mid-tap and ground. The effect is eliminated by arranging the diodes as shown with the load resistor 67 between the anode of diode 21 and the low potential radio frequency end of L3, C3, so that both diodes draw their current pulse at the same instant and produce a cancellation of the second harmonic in L3, C3. In a circuit such as shown in Figures 2 and 3, the diodes draw their currents alternately. In these circuits, however, the mid-tap of the transformer secondary is grounded so that there will be no full-wave rectified voltage built up. The second harmonic is not filtered and therefore detracts from the filtering action of the crystal filter. With the connection of diodes as in Figure 4, the diode input impedances are no longer equal. This can be compensated for by altering the relative magnitudes of resistances 67 and 69 so that the two diode outputs properly balance.

In the systems of Figures 2, 3 and 4, the broad-sharp discriminator effect can be obtained in a single rectifier. For example, in Figure 2, I may open the circuit through condenser 28, condenser 27 and remove tube 23 and its cathode resistance 47 and bias resistance 46. The lower end of resistance 44 is now grounded and the sharp-broad effects appear at point A. Corresponding changes may be made in the circuits of Figures 3 and 4.

In my system pure carrier may be obtained in all of the modifications at the crystal output and taken from the lead designated "Carrier output" in the figures. This pure carrier may be used in carrier-exalted phase or amplitude modulated receivers of the type wherein a pure carrier and a modulated wave is fed to the detector. A preferred form of the receiver of the exalted carrier phase-amplitude modulation type has been disclosed in my U. S. Patent No. 2,063,588, dated December 8, 1936.

I claim:

1. In a frequency discriminator system having dual frequency versus amplitude characteristics, input terminals across which voltages of changing frequency appear, output terminals, a frequency responsive circuit having a sharp frequency versus amplitude characteristic coupling said input terminals to said output terminals, a frequency responsive circuit having a broad frequency versus amplitude characteristic coupling said input terminals to said output terminals, and

a circuit independent of frequency coupling said input terminals to said output terminals.

2. In a frequency discriminator system having dual frequency versus voltage characteristics, input terminals across which voltages of changing frequency appear, output terminals, a frequency discriminator circuit and a rectifier coupling said input terminals to said output terminals said circuit and rectifier having a sloping frequency versus voltage characteristic the slope of which is relatively steep, and a frequency responsive circuit and a rectifier coupling said input terminals to said output terminals, said last circuit and rectifier having a sloping frequency versus voltage characteristic, the slope of which is relatively gradual, and means connected to said output terminals to provide a resultant rectified voltage which is the summation of the rectified potentials of said rectifiers.

3. In a frequency discriminator system having dual frequency versus amplitude characteristics, input terminals across which voltages of changing frequency appear, output terminals, a differential rectifier system coupled to said output terminals, a frequency responsive circuit having a sharp frequency versus amplitude characteristic coupling said input terminals to said rectifier system, a frequency responsive circuit having a broad frequency versus amplitude characteristic coupling said input terminals to said rectifier system, and a circuit independent of frequency coupling said input terminals to said rectifier system.

4. In a frequency discriminating system having a broad characteristic and a sharp characteristic, an output impedance wherein potentials are to be produced representative of said broad and sharp characteristics, a rectifier connected to said output impedance, a source of wave energy of varying frequency, a relatively broadly tuned circuit the electrical length of which changes with wave frequency coupling said source to said rectifier to feed wave energy thereto, a circuit the electrical length of which is substantially independent of frequency coupling said source to said rectifier to feed wave energy thereto, a relatively sharply tuned circuit the electrical length of which changes with frequency coupling said source to said rectifier to feed wave energy thereto, and means for providing phase displacement between the wave energy fed to said rectifier by said circuit the electrical length of which is independent of frequency and the wave energy fed to said rectifier by said other two circuits.

5. In a frequency discriminator system having dual frequency versus amplitude characteristics, input terminals across which voltages of changing frequency appear, output terminals, a first pair of rectifiers having their outputs connected differentially by a pair of impedances, a frequency responsive circuit having a sharp frequency versus amplitude characteristic coupling said input terminals to said first pair of rectifiers, a second pair of rectifiers having their outputs connected differentially by a pair of impedances, a frequency responsive circuit having a broad frequency versus amplitude characteristic coupling said input terminals to said second pair of rectifiers, a circuit independent of frequency coupling said input terminals to both of said pairs of rectifiers, and a circuit connecting said pairs of impedances in series across said output terminals.

6. In a frequency discriminator system having dual frequency versus voltage characteristics, input terminals across which voltages of changing frequency appear, output terminals, a first pair of rectifiers having their outputs connected differentially by a pair of impedances, a frequency responsive circuit including a crystal the natural frequency of which is the same as said voltages in series between said input terminals and said pair of rectifiers, a second pair of rectifiers having their outputs connected differentially by a pair of impedances, a circuit tuned to the frequency of said voltages coupling said input terminals to said second pair of rectifiers, circuits substantially independent of frequency coupling said input terminals to both of said pairs of rectifiers, and a circuit connecting said pairs of impedances in series across said output terminals.

7. In a frequency discriminating system having a broad characteristic and a sharp characteristic, a pair of output impedances in series, a pair of rectifiers having electrodes coupled by said impedances, a source of wave energy of varying frequency, a relatively broadly tuned circuit the electrical length of which changes with wave frequency coupling said source to said rectifiers, a circuit the electrical length of which is substantially independent of frequency coupling said source to said rectifiers, a relatively sharply tuned circuit the electrical length of which changes with frequency coupling said source to said rectifiers and connections for deriving the differential output of said impedances.

8. In a frequency discriminator system having dual frequency versus voltage characteristics, input terminals across which voltages of changing frequency appear, output terminals, a pair of rectifiers having their outputs connected by a pair of impedances, a frequency responsive circuit including a crystal the natural frequency of which is the same as said voltages in series between said input terminals and said pair of rectifiers, a circuit tuned to the frequency of said voltages coupling said input terminals to said pair of rectifiers, a circuit substantially independent of frequency coupling said input terminals to said pairs of rectifiers, and a circuit connecting said pair of impedances in series across said output terminals.

9. In a wave tuner, output terminals, a frequency responsive circuit, having a sloping frequency versus voltage characteristic the slope of which is relatively steep, coupling said tuner to said output terminals, said circuit including a crystal operating at the tuner frequency, a frequency responsive circuit having a sloping frequency versus voltage characteristic the slope of which is relatively gradual, coupling said tuner to said output terminals, a phase shifting transformer tuned to the tuner frequency included in said last named circuit and a control circuit coupling said output terminals to said generator.

10. In a frequency control system, a tunable circuit wherein wave energy the instantaneous frequency of which is to be controlled flows, output terminals, a frequency responsive circuit having a sloping frequency versus amplitude characteristic the slope of which is relatively steep and a frequency responsive circuit having a sloping frequency versus amplitude characteristic the slope of which is relatively gradual, coupling said tunable circuit to said output terminals, means for deriving from said output terminals a voltage representative of the summation of the currents flowing through the two frequency respon-

sive circuits, and a control circuit responsive to said representative voltage for adjusting the frequency of said tunable circuit.

11. In signalling frequency control apparatus, a pair of rectifiers having their electrodes coupled by differentially arranged impedances, a source of wave energy the frequency of which may change, a path the electrical length of which is substantially constant with frequency coupling said source to said rectifiers, a crystal filter sharply resonant at the frequency of said wave energy coupling said source to said rectifiers, a tuned circuit comprising inductance and capacity coupling said source to said rectifiers, phase displacing means in at least one of said couplings, and resistive means electrically connected in one of said couplings and of such magnitude as to impart to the entire system a predetermined relation of broad and sharp discrimination.

12. In a frequency correction system, a source of modulated wave energy the frequency of which may change, a pair of rectifiers having their outputs connected differentially by a pair of impedances, a sharp frequency responsive circuit including a crystal the natural frequency of which is the same as said voltages in series between said source and said pair of rectifiers, means in circuit with the crystal and rectifiers for providing a predetermined relation of sharp and broad frequency discrimination for said frequency responsive circuit, a circuit tuned to the frequency of said voltages coupling said source to said pair of rectifiers, a circuit substantially independent of frequency over the range through which the frequency of the modulated wave of said source may change coupling said source to said pair of rectifiers, and a frequency control circuit connected across said impedances and coupled to said source to stabilize the frequency thereof.

13. In apparatus for producing potentials which vary in accordance with variations in the frequency of wave energy relative to a reference frequency, a transformer having a primary winding excited by wave energy the frequency of which may change, a resonant circuit tuned to said reference frequency, said transformer having a secondary winding providing the induction of said resonant circuit, a pair of rectifiers having anode electrodes and having cathode electrodes connected by output impedances at which said potentials appear, capacitative coupling between the terminals of said primary winding and the anode electrodes of said rectifiers, a piezo-electric crystal tuned to the reference frequency coupling one terminal of said secondary winding to the anode electrodes of said rectifiers, alternating current impedance coupling the anodes of said rectifiers to the cathodes of said rectifiers, and a resistance of predetermined value coupling the opposite terminal of the secondary winding to said anodes.

14. In apparatus for producing potentials which vary in accordance with variations in the frequency of wave energy relative to a reference frequency, a transformer having a primary winding excited by said wave energy the frequency of which may change, a resonant circuit tuned to said reference frequency, said transformer having its secondary winding included in said resonant circuit as the inductance thereof, a pair of rectifiers having anode electrodes and having cathode electrodes connected by output impedances wherein said potentials are developed, a coupling between the terminals of said second-

ary winding and the anode of one rectifier and the cathode of the other rectifier, a piezo-electric crystal coupling one terminal of said primary winding to the anode of one rectifier and the cathode of the other rectifier, a resistor of a predetermined magnitude in shunt with the crystal for controlling the effective frequency discrimination action, and an alternating current impedance coupling the anodes of the rectifiers to the cathodes of the rectifiers.

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REFERENCES CITED

The following references are of record in the file of this patent:

	Number
15	103,505
	469,077

UNITED STATES PATENTS

	Number	Name	Date
	2,282,971	Koch	May 12, 1942
5	2,243,417	Crosby	May 27, 1941
	2,266,052	Lindner	Dec. 16, 1941
	2,129,085	Foster	Sept. 6, 1938
	2,172,732	Crosby	Sept. 12, 1939
	2,320,175	Dennis et al.	May 25, 1943
10	2,233,199	Donley	Feb. 25, 1941
	2,376,127	Crosby	May 15, 1945

FOREIGN PATENTS

	Country	Date
	Australia	Mar. 17, 1938
	Great Britain	July 12, 1937