

Nov. 5, 1940.

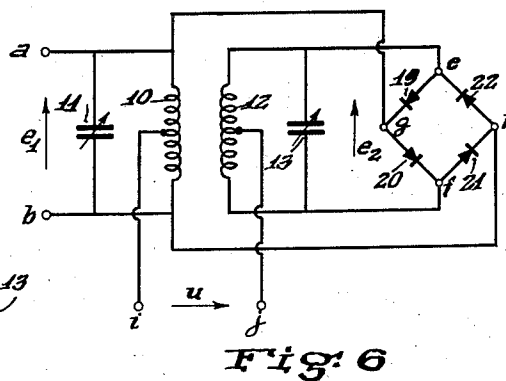
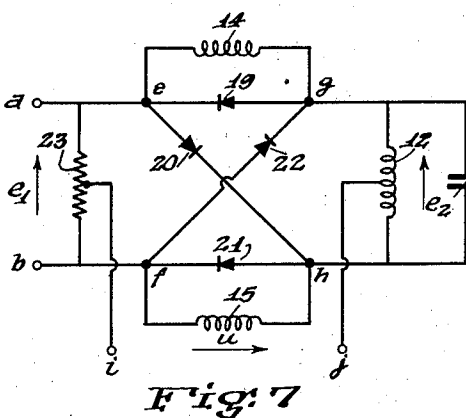
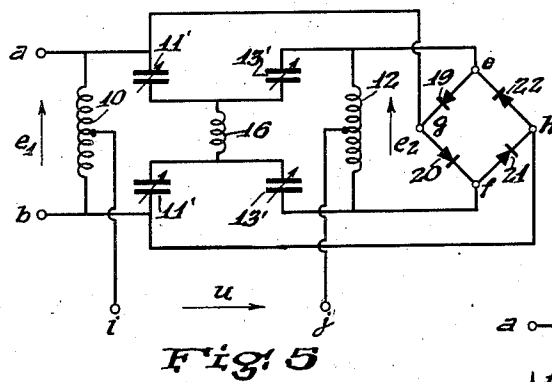
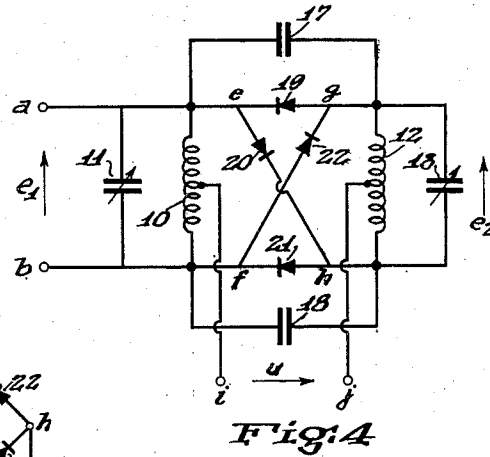
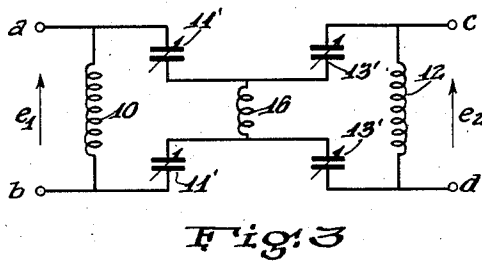
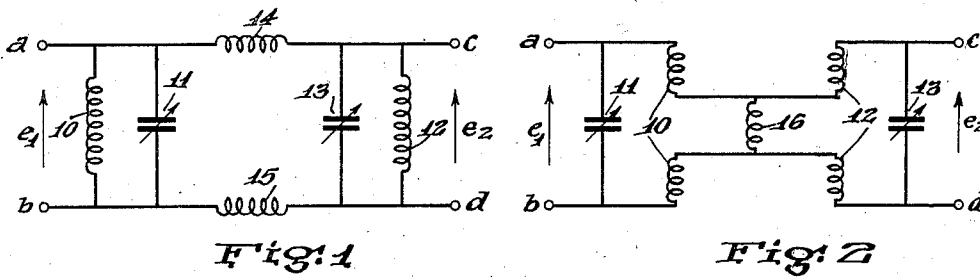
G. GUANELLA

2,220,098

FREQUENCY VARIATION RESPONSE CIRCUIT

Filed June 1, 1938

2 Sheets-Sheet 1



INVENTOR.
Gustave Guanella
BY *Art Mann*
ATTORNEY.

Nov. 5, 1940.

G. GUANELLA

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FREQUENCY VARIATION RESPONSE CIRCUIT

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2 Sheets-Sheet 2

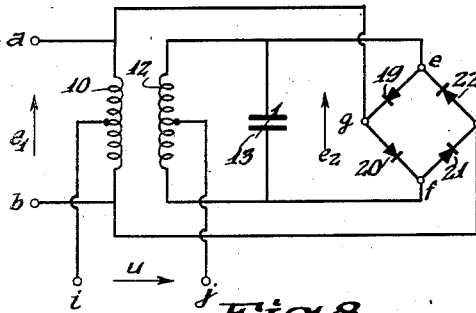


Fig. 8

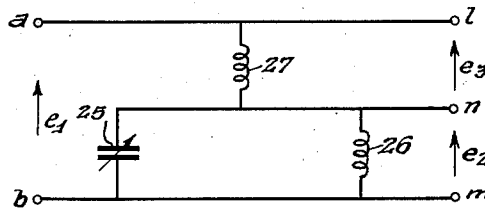


Fig. 9

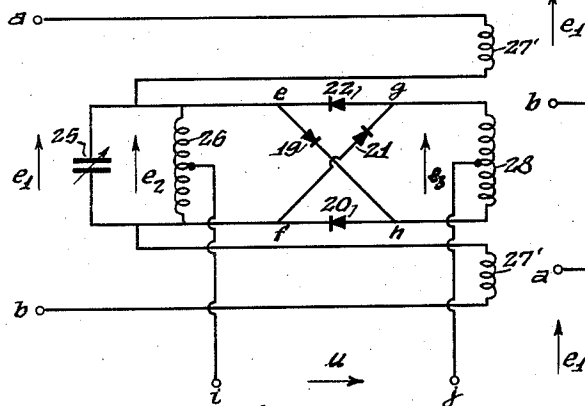


Fig. 10

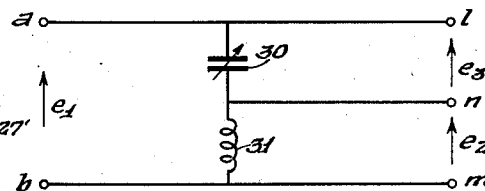


Fig. 11

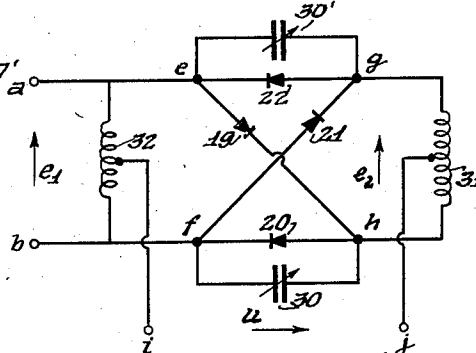


Fig. 12

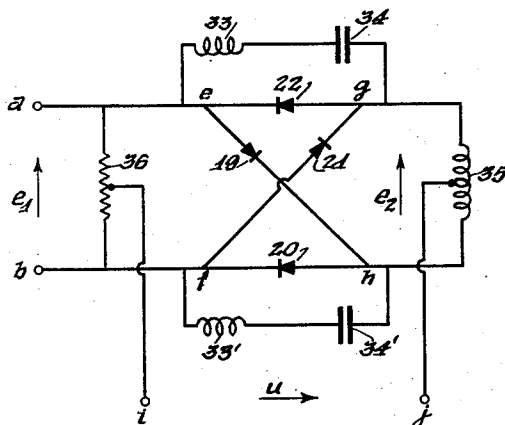


Fig. 13

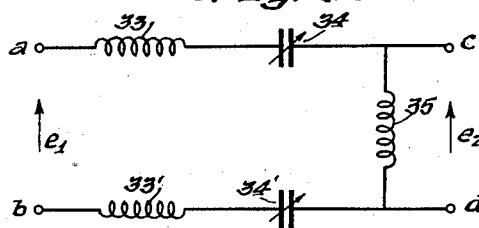


Fig. 14

INVENTOR.
Gustave Guanella
BY *W. H. M. M.*
ATTORNEY.

UNITED STATES PATENT OFFICE

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FREQUENCY VARIATION RESPONSE
CIRCUIT

Gustav Guanella, Zurich, Switzerland, assignor
to Radio Patents Corporation, New York, N. Y.,
a corporation of New York

Application June 1, 1938, Serial No. 211,158
In Switzerland July 11, 1937

8 Claims. (Cl. 250-20)

The present invention relates to improvements in and a method of operating radio circuits and the like, more particularly to a tuning discriminator arrangement for generating a potential of varying polarity and magnitude in dependence upon the sense and amount of detuning of a resonant circuit or network relative to the frequency of a high frequency signal wave impressed thereon, for either direct tuning indication or automatic frequency control (AFC) in a radio receiver, transmitter, or other electrical system.

In the copending application, Ser. No. 146,555, filed June 5, 1937, by applicant and Max Lattmann, as a joint application, there is described an arrangement for generating a tuning responsive potential by utilizing the variations of the mutual phase angle between energies or potentials derived from different points of a resonant circuit or network and depending upon the sense and amount of detuning of the circuit relative to the frequency of an impressed carrier frequency. The derived potentials of varying mutual phase angle are combined and rectified to obtain therefrom a tuning responsive direct potential varying both in polarity and magnitude in dependence upon the sense and in proportion to the amount of deviation of the tuning frequency of the circuit or network from the impressed signal frequency. This tune responsive potential may serve to operate a suitable indicator to assist in the operation and correct tuning adjustment of the receiver or it may be applied to a tuning control device to effect an automatic tuning or frequency control of a resonant circuit such as the oscillatory circuit of a self-excited oscillator such as the local oscillator in a superheterodyne receiver.

An object of the present invention is to provide an improved discriminating circuit of the above general type which insures increased efficiency and stability compared with the known arrangements serving for a similar purpose.

Further objects and aspects of the invention will become more apparent from the following detailed description taken with reference to the accompanying drawings forming part of this specification and wherein:

Figures 1 to 3 show resonant networks suited for the purpose of the invention,

Figures 4 to 8 show practical embodiments of discriminating circuits employing networks of the type according to the preceding figures,

Figures 9, 11 and 13 show further resonant networks suited for the purposes of the invention, and

Figures 10, 12 and 14 illustrate discriminating systems embodying networks of the type shown in Figures 9, 11 and 13, respectively.

Similar reference characters denote similar parts throughout the different views of the drawings.

Referring to Figure 1, there is shown a band-pass filter comprising primary and secondary tuned circuits coupled with each other. The primary circuit in the example illustrated comprises an inductance 10 shunted by a capacity 11 which may be fixed or variable as shown. The secondary circuit similarly comprises an inductance 12 shunted by a capacity 13. The primary and secondary circuits are coupled through series coupling reactances such as inductances 14 and 15 inserted in the upper and lower connecting leads as shown in the example illustrated. As is well known, according to the theory of electric filters, the voltage e_2 developed across the secondary circuit, terminals $c-d$, has a phase which differs from the phase of the primary voltage e_1 applied to terminals $a-b$ by 90° if the medium or central frequency of the response characteristic of the filter corresponds to the frequency of the impressed input potential. This phase difference deviates in either direction from 90° in dependence upon the sense and amount of deviation of the impressed frequency relative to the medium or central frequency of the filter response characteristic, these phase variations comprising a range from 0 to 180° . By comparing the phases of the potentials e_1 and e_2 , a tuning responsive or control potential is generated as will be described in detail hereafter.

In place of the coupling shown in Figure 1, the circuits 10, 11 and 12, 13 may be coupled by a small inductive or capacitive impedance such as an inductance coil 16 forming a common element of the primary and secondary inductances 10 and 12 as shown in Figure 2. Alternatively, the common coupling inductance 16 may be connected in series and symmetrically between a pair of condensers 11' and 13', respectively, replacing the condensers 11 and 13, as shown in Figure 3. Furthermore, the circuits 10, 11 and 12, 13 may be inductively coupled to form a band-pass filter of well known construction as shown in Figure 6.

In all circuits of the type according to Figures 2 and 3, and similar arrangements, the output voltage e_2 has a phase relative to the input voltage e_1 which varies from a normal relative phase angle of 90° at resonance condition in either direction according to the sense and in proportion

to the amount of deviation of the tuning of the circuit in respect to the frequency of an impressed carrier wave. Similar phase variations occur if the inductances 10 and 13 are directly coupled with each other or if a mixed coupling is employed.

Referring to Figure 4, there is shown a frequency discriminator or tune detecting system embodying a band-pass filter of the type according to Figure 1. There is provided according to the invention for the comparison of the phases of the input and output voltages e_1 and e_2 a rectifier or modulator bridge comprising four rectifier elements 19, 20, 21 and 22 connected in series in like sense to form a closed circuit. The potentials e_1 and e_2 whose phase is to be compared are each applied to the opposite corners $e-f$ and $g-h$, respectively, of the rectifier or modulator bridge.

In Figure 4, the tuned circuits 10, 11 and 12, 13 are coupled through series coupling condensers 17, 18 replacing the inductances 14 and 15 shown in Figure 1. The operation of this circuit will be more fully understood from the following. Since the inductances 10 and 12 offer no appreciable resistance for direct current, it may be assumed that terminals e, f, i and terminals g, h, j are directly connected together or that the rectifiers 19, 20, 21 and 22 are arranged in parallel to each other with alternate reversal of polarities as far as the direct output potential u is concerned, which direct current component is derived from the center taps of the inductances 10 and 12. As a result of this connection of the rectifiers whereby the direct potential developed by the rectifiers 20 and 22 opposes the direct potentials developed by the rectifiers 19 and 21, the polarity of the output potential set up between the terminals i and j will depend upon the ratio of the amplitudes of the alternating potentials existing across the rectifiers 19, 21 and 20, 22, respectively.

Thus, if in case of extreme detuning the primary potential e_1 is in phase with the secondary potential e_2 , the alternating voltage across the rectifier 19, points e and g , as well as that across the rectifier 21, points f and h , is smaller than the alternating potential across the rectifier 20, points h and e , as well as the alternating potential across the rectifier 22, points g and f . As a result, the potential u between i and j is of positive polarity. If, on the other hand, in the case of extreme detuning in the opposite sense, the potential e_2 is in counter-phase to the potential e_1 , the alternating potential across the rectifiers 19 and 21 will be greater than the alternating potential across the rectifiers 20 and 22. As a result, the control potentials produced between i, j will be of negative polarity. If the mutual phase for the medium response frequency of the band-pass filter is 90° in case of resonance, the amplitudes of the alternating potentials will be equal for all rectifiers. As a result, the direct current component in the control potential u will disappear or the control or tuning responsive potential become zero. If inductances are used as coupling elements in place of the condensers 17 and 18 (see Figure 1), the latter should offer sufficient impedance to direct current to prevent excessive equalizing currents therethrough set up by the output potential u .

There is thus produced in the above described manner between terminals i and j a potential u having a polarity depending upon the sense of detuning and which is direct proportional to the amount of detuning of the resonant circuit or

band-pass filter relative to an impressed carrier frequency as long as the tuning remains within predetermined limits.

For large amounts of detuning the mutual phase angle between e_1 and e_2 varies only slightly in dependence upon the frequency. On the other hand, the potential e_2 decreases with increase of the amount of detuning. For this reason the control potential u will again gradually approach zero after the degree of detuning has exceeded a predetermined limit. The range of linear relation of u in dependence upon the detuning and the values of detuning determining the operating range or limit values of u are governed by the damping of the resonant circuit 10, 11 and by the degree of coupling or the size of the coupling impedances 14, 15 or 17 and 18, respectively. The operating range increases for loose coupling and with increased damping of the circuits.

In addition to the direct current component of the potential u responsive to the tuning deviations, the latter also contains harmonics of the potential e_1 impressed upon the terminals $a-b$ and depending upon the characteristics of the rectifiers. The fundamental frequency is suppressed due to the symmetrical arrangement of the circuit in the case of exact equality of the four rectifiers and by reason of the center tap connections from the inductances 10 and 12 for deriving the tuning responsive potential.

The generation of a tuning responsive potential by phase comparison of the primary and secondary potentials by means of a modulator bridge can be carried out in an analogous manner by employing band-pass filters of the type shown in Figures 2 and 3. An arrangement of this type is shown in Figure 5 which corresponds substantially to Figure 3 and wherein the primary circuit is connected to the corners $g-h$ and the secondary circuit is connected to the corners $e-f$ of the rectifier or modulator bridge, while the output or tuning responsive potential is derived from the center taps of the primary and secondary inductances 10 and 12, respectively, in a manner similar to the preceding exemplification.

Referring to Figure 6, there is shown a similar arrangement employing a band-pass filter comprising a primary tuned circuit 10, 11 and a secondary tuned circuit 12, 13 coupled by an inductive coupling relation between the primary and secondary inductances 10 and 12 and connected to a modulator bridge 19, 20, 21, 22 in a manner similar to the above.

In arrangements of the aforescribed type, it is easily seen that the input impedance between terminals $a-b$ is determined substantially by the tuning and the losses of the primary circuit 10, 11. This input impedance is a maximum at or near resonance, that is the energy absorption from an impressed potential e_1 is extremely small for slight amounts of detuning. As a result, the damping imposed upon a preceding voltage or potential source or circuit is comparatively small for slight amounts of detuning as is the case in a system for automatic frequency control (AFC). This fact accounts for the advantage of tuning of the primary circuit.

On the other hand, as is understood, the phase difference between e_1 and e_2 is in no way affected by the tuning of the primary circuit which latter accordingly is of no importance as far as the generation of the tune responsive potential by the phase comparing method is concerned. Accordingly, the tuning condenser 11 in Figures 1

or 4 may be omitted and a large ohmic or inductive resistance may be provided in place of the tuning inductance 10 with a center tap connection for deriving the tune responsive or output potential.

An arrangement of this type is shown in Figure 7 which differs from Figure 4 by the provision of a high ohmic impedance 23 in place of the primary tuned circuit 10, 11 having a center tap connected to the output terminal *i* for deriving the tune responsive potential *u*. Also in the case of circuits of the type according to Figure 2, the tuning condenser 11 may be omitted in which case the inductive impedance 10 should be large relative to the impedance 16 to effect a phase rotation between e_1 and e_2 which is equal to 90° for the average or tuning frequency passed by the filter.

Referring to Figure 8, there is shown a band-pass filter with inductive coupling of the primary and secondary circuits wherein the primary tuning condenser 11 is omitted. The circuit otherwise corresponds substantially to the circuit according to Figure 6. Finally also in arrangements according to Figure 5, the inductance 10 may be replaced by an inductive or ohmic impedance with a center tap for deriving a tune responsive or control potential.

According to a further modification of the invention, the tuned secondary circuit 12, 13 may be constructed in the form of a series resonant circuit in place of a parallel resonant circuit shown in the previous exemplifications. In the latter case, the output potential *u* is derived from the center tap of a special impedance permeable to direct current and connected in parallel to the tuned circuit.

A circuit of this type is shown in Figure 9. In the latter a parallel tuned circuit comprising a variable capacity 25 shunted by an inductance 26 is connected in series with a further inductance 27. The input potential e_1 is impressed upon the tuned circuit and the series inductance and compared with either of the potentials e_2 or e_3 developed across the tuned circuit or series inductance, between terminals *m*, *n* or *n*, *l*, respectively. For the resonance frequency the circuit 25, 26 represents an ohmic or non-reactive impedance in which case the voltage developed across this circuit is phase shifted by 90° compared with the voltage developed across the inductance 27. If detuning occurs the relative phase angle will vary in either direction from 90° in dependence upon the sense and in proportion to the amount of detuning in a manner substantially similar to the circuits shown in the preceding figures. In place of the inductance 27 a capacity may be substituted as is readily understood.

Figure 10 shows a circuit arrangement for producing a tune responsive potential *u* embodying a resonant circuit arrangement of the type according to Figure 9. In this embodiment, the impedance 27 is represented by a pair of inductance coils 27' connected symmetrically to and in series with the parallel tuned circuit 25, 26 and being inductively coupled with a secondary winding 28 having a center tap connection leading to the output terminal *j*, the output terminal *i* being connected to the center tap of the inductance 26 of the parallel tuned circuit. The potential e_3 across the secondary 28 has a phase corresponding to the phase of the primary potential across the inductance 27', that is corresponding to the potential e_3 across the reactive impedance 27 of

Figure 9. The output potential *u* is produced in an analogous manner to the previous arrangements by comparing the phases of the potentials e_2 and e_3 by means of the modulator bridge 19, 20, 21, 22.

Referring to Figure 11 there is shown a further resonant circuit suited for the purpose of the invention. According to this modification a series tuned circuit comprising a variable capacity 30 and inductance 31 is connected across the input terminals *a*—*b*. This circuit offers a pure ohmic resistance to the impressed potential e_1 in case of resonance whereby the potentials e_2 developed across the inductance 31 or the potential e_3 developed across the capacity 30 are in phase quadrature to the impressed potential e_1 . In dependence upon the sense and amount of detuning the mutual phase angle will deviate from 90° in a similar manner as in the previous arrangement thereby making it possible to derive an output or control potential by comparing the phases of the potentials e_2 and e_1 or e_3 and e_1 , respectively.

A complete discriminating system of this type is shown in Figure 12. According to the latter, the phase of the voltage e_2 developed across the inductance 31 is compared with the phase of the impressed potential e_1 by mutual modulation in a modulator bridge 19, 20, 21, 22 to produce a tune responsive or control potential *u* at the output terminals *i*, *j* connected to the center taps in a high ohmic or inductive impedance 32 connected across the input terminals *a*—*b* and the inductance 31, respectively. In order to maintain complete symmetry of the system, the tuning condenser 30 according to Figure 9 is divided into two condensers 30' connected symmetrically to and in series with the inductance 31.

Referring to Figure 13, there is shown a further modification of a resonant circuit suited for the purpose of the invention. According to this embodiment a pair of series resonant circuits comprising inductances 33 and 33' and capacities 34 and 34' tuned to the same frequency are arranged serially between the input and output terminals *a*—*c* and *b*—*d*, respectively. Since these circuits at resonance represent ohmic resistances, the potential e_2 developed across a small inductive or capacitive impedance 35 across the output terminals is phase shifted relative to the input potential e_1 by 90° . If the circuits are detuned relative to the impressed frequency, the relative phase angle will vary in either sense in a manner similar to the preceding arrangements. The potentials e_1 and e_2 may be compared and combined in a rectifier arrangement of the type described hereinbefore and illustrated in Figure 14. In the latter the output potential *u* is derived from the center tap of the reactive impedance 35 and an additional reactive or non-reactive impedance such as a high ohmic resistance 36 placed across the input terminals *a*—*b* as shown. In place of the series resonant circuits 33, 34 and 33', 34' in Figures 13 and 14 corresponding parallel resonant circuits may be employed in which case the inductances 33 and 33' should offer sufficient resistance to direct current to avoid a short circuit of the output voltage *u*.

The rectifiers 19, 20, 21, 22 may impose an appreciable damping upon the tuned circuits. It is advisable for this reason to employ rectifiers having an impedance for alternating current which remains above a definite minimum during operating conditions. The applied load resistance which the rectifiers present to the applied high

frequency potentials (such as the primary and secondary potentials e_1 and e_2 of the band-pass filter) varies depending on the characteristics of the rectifier used. If this resistance is low, the damping imposed upon the tuned circuits by the rectifiers may become too high so that excessive energy drawn from the preceding amplifiers on the one hand will greatly impair the effective phase rotation depending on the frequency in the neighborhood of the resonance point. In order to increase the load resistance in such cases, it is advisable to place an additional ohmic resistance in series with each of the rectifiers. These ohmic resistances may have an equal value or they may be adjusted in such a manner as to equalize slight deviations of the resistances presented by the associate rectifiers thereby insuring a favorable balance of the rectifier bridge. By means of these additional resistances, the damping can be reduced considerably without inadmissibly decreasing the amount of the resulting control potential. It is advisable, however, to keep the ohmic load resistance of the circuit energized by the control potential at a high value relative to the above additional resistances.

The rectifiers employed in connection with the invention may be dry rectifiers preferably having an electrical capacitance as low as possible for high frequencies. A slight capacity of these rectifiers which cannot be avoided may be compensated in most cases by a corresponding decrease of the tuning capacities. In certain cases valve rectifiers may be employed in place of dry rectifiers such as diode rectifiers with electrically isolated cathodes.

The circuits described above are in general of a symmetrical character, that is the terminals of the input potential e_1 are electrically equivalent. For this purpose it is desirable that the input potential as a rule should be symmetrical relative to ground or any other reference potential. This is the case if the preceding amplifiers are push-pull operated. If only asymmetrical potentials are available such as in the case of straight amplifiers, it is advisable to provide a symmetrizing arrangement at the input of the discriminator system.

In special cases an asymmetrical input voltage may be applied in such a manner that the invariable potential of this voltage is applied to the center tap of an inductance placed between the input terminals preferably the tuning inductance according to Figures 4, 5, 6, 10 or a large inductance or impedance as shown in Figures 8 and 14, while the other variable potential of this asymmetrical input voltage is applied to one of the input terminals provided for a symmetrical input voltage e_1 . In this case, a symmetrical voltage is produced by the inductance 10 or impedances 23 or 36.

One of the input terminals may ordinarily be connected to ground for a fixed reference potential point whereby an asymmetrical output potential is obtained as required in most cases for influencing tuned circuits in accordance with variations of an inductance or capacity. This control potential should be sufficiently filtered or smoothened to suppress the high frequency components and to prevent hunting effects in an automatic frequency control system.

It will be evident from the above that the invention is not limited to the specific embodiments and methods disclosed herein for illustration but that the principle and novel concept of the invention are susceptible of numerous variations

and modifications coming within the broad scope and spirit of the invention as defined in the appended claims. The specification and drawings are to be regarded accordingly in an illustrative rather than a limiting sense.

I claim:

1. A frequency variation response circuit comprising a resonant circuit tuned to a predetermined frequency, means for impressing thereon a high frequency potential, a rectifier bridge comprising four rectifying elements connected in series in like sense to form a closed circuit, circuit means for impressing high frequency potential derived from a predetermined portion of said resonant circuit upon one pair of diagonal points of said bridge, further circuit means for impressing high frequency potential derived from a different predetermined portion of said resonant circuit upon the other pair of diagonal points of said bridge, and an output circuit connected between points of said first and second circuit means.

2. A frequency variation response circuit comprising a resonant circuit tuned to a predetermined frequency, means for impressing thereon a high frequency potential normally having a frequency equal to the resonant frequency of said circuit, means for deriving a pair of high frequency potentials from different predetermined portions of said resonant circuit, whereby the phase relation between the derived potentials varies according to the sense and in proportion to the amount of detuning of said resonant circuit relative to the impressed frequency in respect to a predetermined normal phase angle between the derived potentials when the impressed potential is in tune with said resonant circuit, a rectifier bridge comprising four rectifying elements connected in series in like sense to form a closed circuit, circuit means for impressing one of said derived potentials upon one pair of diagonal points of said bridge, further circuit means for impressing the other of said derived potentials upon the other pair of diagonal points of said bridge, and an output circuit connected between points of said first and second circuit means.

3. A frequency variation response circuit comprising a network having primary and secondary circuits coupled with each other, at least one of said circuits being a resonant circuit tuned to a predetermined frequency, means for impressing a high frequency potential upon said primary circuit normally having a frequency equal to said predetermined frequency, a rectifier bridge comprising four rectifier elements connected in series in like sense to form a closed circuit, means for impressing high frequency potential derived from one of said circuits upon one pair of diagonal points of said bridge, further means for impressing high frequency potentials derived from the other of said circuits upon the other pair of diagonal points of said bridge, and an output circuit connected between points of said circuits.

4. A frequency variation response circuit comprising a series network comprising a pair of circuit elements, the first element being constituted by a resonant circuit tuned to a predetermined frequency and the second element being constituted by an impedance, means for impressing a high frequency potential upon said network, a rectifier bridge comprising four rectifier elements connected in series in like sense to form a closed circuit, means for impressing a high frequency potential derived from one of said elements upon one pair of diagonal points of said

bridge, means for impressing a high frequency potential derived from the other of said elements upon the other pair of diagonal points of said bridge, and an output circuit connected between points of said elements to derive a resultant potential varying in sense and magnitude according to the sense and amount of detuning of said resonant circuit relative to the frequency of the impressed potential.

5. A frequency variation response circuit comprising a rectifier bridge comprising four rectifying elements connected in series in like sense to form a closed circuit, circuits connected to both pairs of opposite diagonal points of said bridge, means for impressing high frequency potentials of like frequency and varying relative phase relation upon said circuits, and an output circuit connected between points of said first mentioned circuits.

6. A frequency variation response circuit comprising a rectifier bridge comprising four rectifier elements connected in series in like sense to form a closed circuit, circuits connected to both pairs of diagonal points of said bridge, at least two of said circuits constituting a resonant network tuned to a predetermined band of frequencies, means for impressing a high frequency po-

tential upon said network, and means connected between points of said circuits for deriving a rectified output potential.

7. A frequency variation response circuit comprising a rectifier bridge comprising four rectifier elements connected in series in like sense to form a closed circuit, circuits connected to both pairs of diagonal points of said bridge, at least one of said circuits being a resonant circuit and coupled with the other circuit to form a band-pass filter tuned to a predetermined band of frequencies, and an output circuit connected between points of said first mentioned circuits.

8. A frequency variation response circuit comprising a rectifier bridge comprising four rectifier elements connected in series in like sense to form a closed circuit, a pair of circuits each arranged in coupling connection with one pair of diagonal points of said bridge, coupling means between and tuning means for said circuits to form a band-pass filter tuned to a predetermined band of frequencies, means for impressing a high frequency potential upon said band-pass filter, and an output circuit connected between points of said circuits.

GUSTAV GUANELLA.