Dec. 9, 1941. K. RATH 2,265,744

FREQUENCY VARIATION RESPONSE NETWORK

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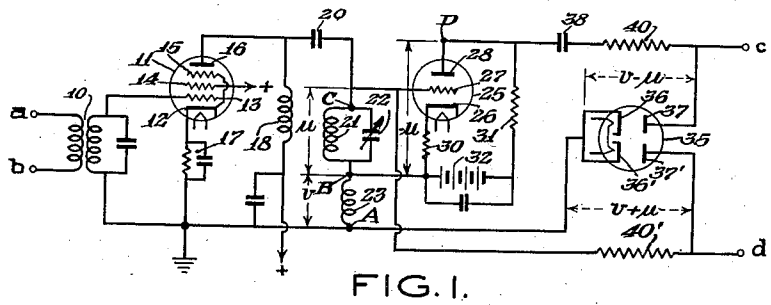


FIG. 1.

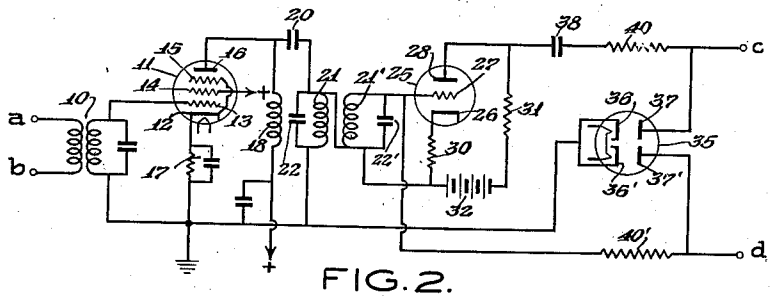


FIG. 2.

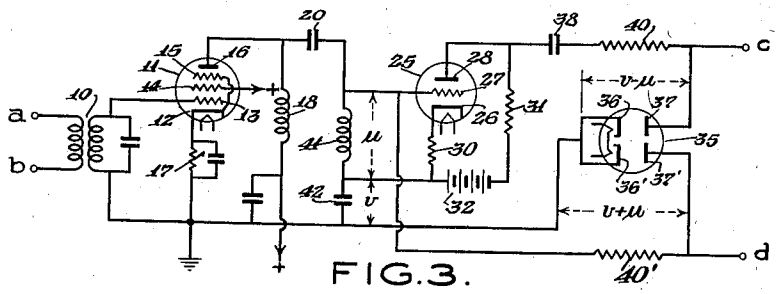


FIG. 3.

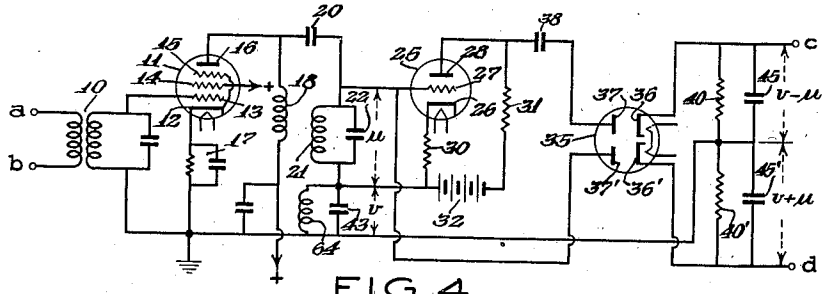


FIG. 4.

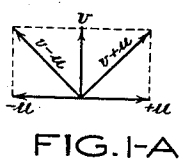


FIG. 1-A

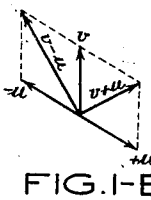


FIG. 1-B.

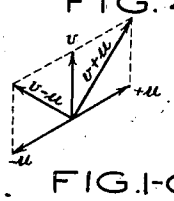


FIG. 1-C.

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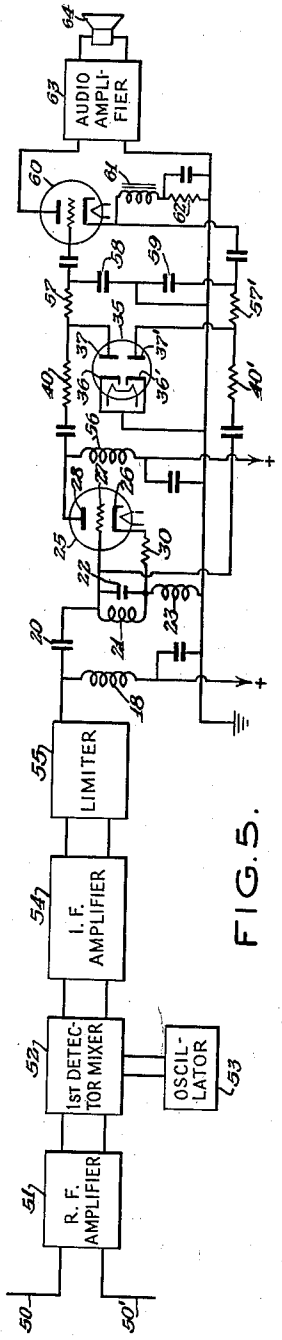


FIG. 5.

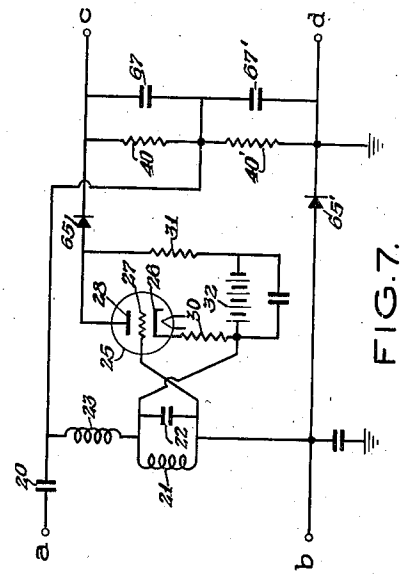


FIG. 7.

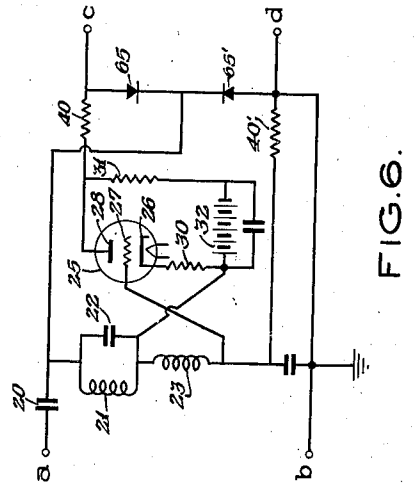


FIG. 6.

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FREQUENCY VARIATION RESPONSE NETWORK

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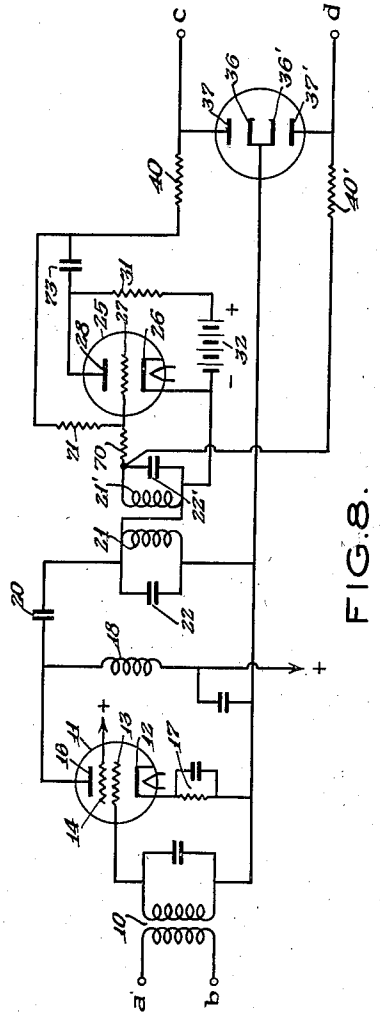


FIG. 8.

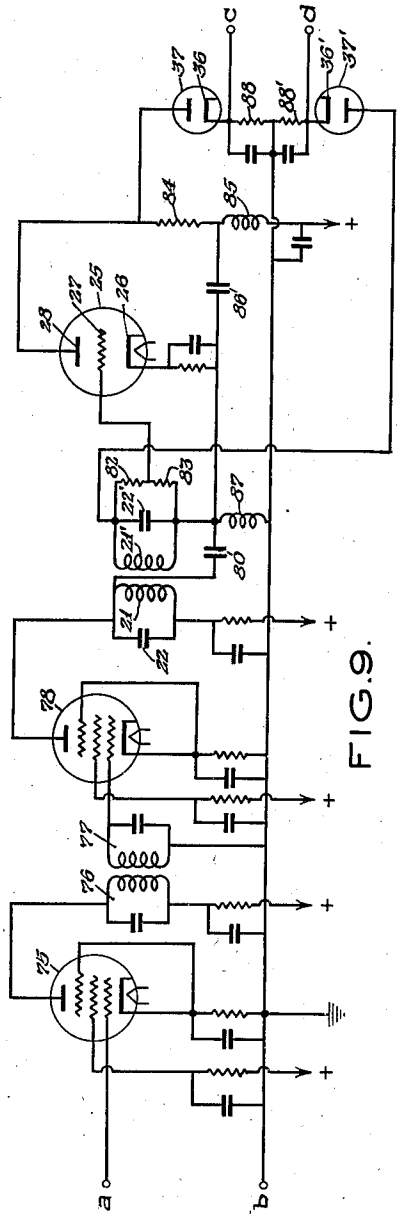


FIG. 9.

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Patented Dec. 9, 1941

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UNITED STATES PATENT OFFICE

2,265,744

FREQUENCY VARIATION RESPONSE NETWORK

Karl Rath, New York, N. Y., assignor to Radio Patents Corporation, a corporation of New York

Application June 1, 1940, Serial No. 338,431

6 Claims. (Cl. 250—20)

The present invention relates to electrical frequency sensitive devices or frequency variation response networks of the type in which the amplitude and sign of an output current or voltage depends upon the departure of the frequency of an alternating input signal from some predetermined frequency.

Among other applications, devices or systems of the above character are employed in automatic frequency control systems for radio transmitters or automatic tuning control (AFC) systems for radio receivers to produce a discriminating potential or current as a result of and in proportion to deviations of the transmitting frequency from its assigned value or a detuning of the receiver, respectively, said potential or current serving to readjust the frequency or correct the tuning to the desired value.

Another use of frequency sensitive devices or circuits is to serve as a demodulator in frequency modulation receivers to convert a frequency modulated carrier signal into a direct current varying in amplitude proportionately to the variations of the sound signals or other intelligence being imparted upon the received signal by frequency modulation of the carrier oscillations.

More particularly the invention is concerned with frequency variation response circuits of the type comprising a retarding network such as a resonant transformer, band-pass circuit or the like upon which the alternating signal of varying frequency is impressed to produce a pair of voltages at predetermined points of said network or circuit, said voltages having a relative phase varying proportionately to the frequency deviation of the impressed signal to be detected. The thus established voltages of varying relative phase are compared with each other or combined to produce sum and difference voltages thereof and the latter are rectified separately and in turn combined differentially in a balanced rectifier, whereby the differential rectified output potential or current obtained will vary in amplitude proportionately to the frequency departure of the impressed signal from a predetermined, such as the carrier frequency to which the retarding circuit or network is resonant.

Thus, in the case of a double tuned transformer or band-pass circuit, the primary and secondary voltages will be 90° out of phase if the impressed signal frequency is equal to the resonant frequency to which the circuit is tuned. This resonant frequency may represent the carrier frequency of a received radio signal and this carrier frequency may vary in either direction from the assigned or normal value either spuriously or in accordance with the amplitude of a sound signal, picture signal or other intelligence being transmitted. If the impressed frequency deviates in either direction from the resonant frequency of the circuit, the phase angle of the primary and secondary voltages will increase beyond or decrease below, respectively, the normal 90° angle depending upon the sense and in proportion to the frequency deviation. Since the numerical value of the sum and difference of two vectors in quadrature i. e. relatively dephased by 90° are alike, the differential rectified output will be zero for the resonant or carrier frequency and increase in either direction proportionately as the frequency deviates from the normal or carrier frequency.

In order to produce sum and difference voltages in systems of the aforedescribed type, one of the voltages to be compared has to be reversed in polarity or inverted and the customary method has been to employ a center tapped transformer for this purpose. Such a transformer besides being expensive suffers from several disadvantages that seriously impair its efficiency. Thus, the center tap has to be adjusted accurately or correct balancing of the sum and difference voltages applied to the rectifiers for resonant input (carrier) frequency is not obtained. This disadvantage is of special importance in receiving frequency modulated signals in which case lack of balance will result in substantial distortion of the sound signals or other intelligence being received.

The object of the present invention is to substantially eliminate the above defects and drawbacks inherent in a center tapped winding or special transformer employed in frequency variation response circuits of the type heretofore known and to provide a novel method for and system of frequency conversion or detection ensuring highly stabilized and efficient performance over a prolonged operating period.

Other objects and advantages 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 4 are circuit diagrams illustrating various modifications of frequency variation detecting or response circuits embodying the principle of the invention,

Figure 5 illustrates, partly in block diagram form, a frequency modulation receiving circuit embodying a demodulator or frequency variation detector constructed in accordance with the invention,

Figures 6 to 8 illustrate further modifications

of variable frequency response circuits designed in accordance with the principle of the invention, and

Figure 9 is a diagram of a frequency variation detecting circuit suited for embodiment in the intermediate frequency section of a radio receiving system.

Like reference characters identify like parts in the different views of the drawings.

Referring to Figure 1 there is shown a simple circuit diagram of a system according to the invention with customary elements such as power supply sources, etc., not forming a part of the invention having been omitted for simplicity's sake. The circuit shown comprises an amplifier for pre-amplifying an alternating input signal and a frequency detecting network to produce output energy having an amplitude varying proportionately to the frequency variations of the input signal to be converted or detected. The input signal potential which may have a varying frequency is impressed by way of input terminals *a*—*b* and a tuned transformer **10** upon the grid **13** and cathode **12** of an electron tube amplifier **11** of known design further comprising in the example shown a screen grid **14**, a suppressor grid **15** connected internally to the cathode **12** and an anode or plate **16**. Item **17** is a biasing network comprising a resistance bypassed by a condenser in the cathode lead of the tube to provide proper grid operating bias in a manner well understood by those skilled in the art. The plate **16** is connected to the positive pole of a suitable space current source indicated by the + sign through a suitable coupling impedance such as a choke coil **18** designed to develop amplified signal potential on the plate **16** which is impressed through a blocking condenser **20** upon the retarding or phase shifting network of the frequency detector or discriminator.

The retarding network in the example shown is comprised of a parallel tuned circuit **21—22** in series with a suitable reactance in the embodiment shown an inductance coil **23**. In an arrangement of this type, if the impressed signal frequency is in tune with the resonant frequency of the circuit **21—22**, the voltage *v* developed by the inductance **23**, that is, between points A and B will be in quadrature to the voltage *u* developed by the circuit **21—22**, that is, between points B and C as shown in the drawings. If the impressed frequency deviates from the tuning frequency of the circuit **21—22**, the phase angle between the voltages *v* and *u* will increase beyond or decrease below the normal 90° angle in proportion to the relative departure between the impressed signal frequency and the tuning frequency to which the circuit **21—22** is resonant. Thus, if the impressed frequency is relatively higher than the tuning frequency of the circuit **21—22**, the phase angle between the voltages *u* and *v* will become less than 90° and vice versa, if the impressed frequency becomes smaller than the tuning frequency of the circuit **21—22** the phase angle between the voltages *u* and *v* will increase beyond 90°.

In the example shown, the potential drop or voltage *u* is applied to the grid **27** and cathode **26** of a three element electron tube **25** having an anode or plate **28**. This tube serves as a phase inverter and in order to stabilize its operation and to obtain an inverted voltage $-u$ of proper amplitude an inverse feedback impedance such as an inductance coil or an ohmic resistance **30** according to the embodiment shown is provided in the cathode lead forming a common return path for both the grid and plate circuits of the tube. Any other type of inverter tube and inverse feedback arrangement known such as shown in Figure 8 may be employed for the purpose of the invention as will be understood. The plate **28** is connected to the cathode through a load resistance **31** which may be replaced by an induction coil and a source of space current in the example shown a battery **32**.

There is produced by the action of the tube **25** an inverted potential $-u$ between the cathode and plate of the tube, that is between points B and D in the diagram. Point D is connected to the output terminal *c* through a blocking condenser **38** and a smoothing impedance such as a resistance **40** and point C is connected to the output terminal *d* through a smoothing resistance **40'**. Terminals *c* and *d* are further connected to the plates or anodes **37** and **37'**, respectively, of a double diode rectifier having cathodes **36** and **36'** which are connected together and to the point A of the phase shifting network **21—22—23**. There are thus provided two rectifying paths traced as follows: First rectifying path from the cathode **36'** to point A, through inductance **23**, injecting voltage *v*, through the tuned circuit **21—22** injecting voltage *u*, through resistance **40'**, anode **37'** back to the cathode **36'**; second rectifying path from cathode **36** to point A, through inductance **23**, injecting voltage *v*, through tube **25** injecting voltage $-u$, condenser **38**, smoothing resistance **40**, anode **37** and back to the anode **36**. Thus, the effective voltage in one of the rectifying circuits will be equal to the sum $v+u$ and the voltage effective in the other rectifying circuit will be equal to the difference $v-u$ between the phase shifted voltages established by the resonant network **21—22—23**. Since the two diode paths are connected in opposition with respect to the output terminals *c*—*d*, differential of the rectified sum and difference voltages will appear across the output. This differential output will have an amplitude varying proportionately to the relative frequency departure of the impressed input signal from the tuning frequency to which the circuit **21—22** is resonant as will be further understood by reference to the vector diagrams shown in Figures 1A to 1C discussed in the following.

Assuming the two voltages *v* and *u* to be equal which condition can be fulfilled by the proper design of the circuit, it is seen from Figure 1A showing the condition of the input frequency being equal to the tuning frequency of circuit **21—22**, that the vector sum and difference $v+u$ *and* $v-u$ are of equal magnitude resulting in a complete balance of the rectified potentials and zero output response between the terminals *c*—*d*; that is, in other words, if the input signal is in resonance with the tuned circuit as in the case of the carrier frequency of a frequency modulated signal, no output energy will be delivered from the terminals *c*—*d*. If the signal frequency decreases below the resonant frequency of the circuit **21—22**, the phase shift between the voltages *u* and *v* will increase beyond 90° as shown in Figure 1B resulting in the difference voltage $v-u$ exceeding the sum voltage $v+u$, thus causing a rectified voltage response between terminals *c*—*d* in one direction from zero. Vice versa, if the input signal frequency increases beyond the resonant frequency of the

circuit 21—22, the phase shift between the voltages v and u will become less than the normal 90° angle as shown in Figure 1C resulting in a sum voltage $v+u$ exceeding the difference voltage $v-u$ and causing a response in the opposite direction at the terminals c—d. It is seen, therefore, that relative frequency variations of the impressed signal are converted into proportionate amplitude variations of a direct potential or current derived from the output of the system.

It will be evident that an arrangement according to the invention may serve to convert or detect both frequency variations of an alternating signal such as a frequency modulated signal as well as variations of the natural tuning frequency of the circuit 21—22. In the latter case, the impressed signal frequency is fixed and preferably equal to the resonant frequency of the circuit 21—22. If now the tuning of the latter is varied as by varying the inductance 21 or condenser 22 which for this purpose has been shown as being variable in the diagram, the relative frequency variations and in turn the inductance or capacity changes will be translated into current variations in substantially the same manner as described hereinbefore.

Referring to Figure 2, there is shown a system similar to Figure 1 embodying a different kind of phase shifting or retarding circuit. The retarding circuit according to this modification consists of a double tuned transformer or band-pass filter having a primary circuit comprised of an inductance 21 shunted by a condenser 22 and a second circuit comprised of an inductance 21' shunted by a condenser 22'. The high potential side of the primary circuit is coupled such as by a direct connection with the low potential side of the secondary circuit, whereby the primary and secondary voltages will be added and subtracted and rectified in a manner substantially similar to that according to Figure 1. Here again, if the circuits 21—22 and 21'—22' are in exact resonance with the impressed signal frequency, the voltages developed across the primary and secondary will be in quadrature phase relation and this phase angle will vary in either direction in proportion to the departure of the impressed signal frequency from the resonant frequency of the circuits resulting in a direct output current or potential having an amplitude varying proportionately to the frequency deviation to be detected.

Referring to Figure 3, there is shown a diagram similar to Figures 1 and 2 embodying a phase shifting or retarding circuit in the form of a series resonant network comprising an inductance 41 and a condenser 42. The potential drop v across the condenser and the potential drop u across the inductance are again added and subtracted and applied to the differential rectifier in substantially the same manner as in the preceding embodiments. In a system of this type the response at terminals c—d will be a maximum for the carrier or resonant frequency and fall off rapidly as the frequency deviates in either direction in the manner of a normal resonance curve. This circuit is especially suited as a tuning indicator by connecting a suitable direct current indicating instrument across the terminals c—d for supervisory frequency control, alignment of tuned circuits and similar purposes.

Referring to Figure 4, there is shown a further modification of a retarding or phase shifting circuit comprising a parallel tuned circuit 21—22 similar to that in Figure 1 and a series reactance in the form of a condenser 43, the latter being shunted by a choke coil 44 to provide a direct current ground return for the tube 25. In this embodiment there is furthermore shown a modified rectifying circuit wherein the plates 37 and 37' of the double diode 35 are connected to the blocking condenser 38 and the grid 27 (point C), respectively, and the cathodes 36 and 36' of the double diode 35 are connected to the output terminals c—d, respectively. The latter are shunted by a pair of smoothing resistors 40 and 40' in series, each by-passed by a condenser 45 and 45', respectively. The low potential end of the condenser 43 of the phase retarding network is connected to the junction of the resistors 40 and 40'. As will be understood from the foregoing, there will be obtained by an arrangement of this type an output response varying both in sign and magnitude in dependence upon the relative frequency departure of an impressed alternating signal from the tuning frequency to which the circuit 21—22 is resonant.

Referring to Figure 5, there is shown partly in block diagram form a complete receiver for frequency modulated radio signals embodying a detector of the type according to the invention. The signals received by a pair of dipole antennae 50—50' are impressed by way of a radio frequency amplifier 51 upon a first detector or mixer 52 wherein the received signals are combined with local signals generated by an oscillator 53 to produce signals of intermediate frequency amplified in an intermediate frequency amplifier 54 designed for selective and efficient amplification of the fixed intermediate frequency of the receiver. The amplified intermediate frequency signals are applied to a limiter 55 of any known type to remove any spurious amplitude modulation due to noises and other interference and to cause pure frequency modulated signals to be impressed from the output of the limiter upon the frequency detecting or demodulating circuit constructed in accordance with the invention. The latter comprises a retarding circuit 21—22—23, a phase inverting tube 25, and a balanced double diode rectifier 35 substantially as shown in Figure 1. In the embodiment shown the load impedance for the inverter 25 has the form of an inductance coil 56. The demodulated or output signals developed across the anodes 37 and 37' of the double diode 35 is additionally filtered and freed from radio frequency components by the aid of series resistors 57 and 57' and a pair of shunt condensers 58 and 59, the latter arranged in series and having their junction point connected to ground and their outer ends connected to the resistors 57 and 57'. The demodulated signals are impressed upon the grid and cathode of an audio amplifier tube 60 by way of coupling condensers or in any other desired manner. The cathode of the tube 60 is connected to ground through a choke coil 61 forming a load impedance and a biasing resistance 62 by-passed by a condenser. Thus, the cathode of tube 60 is at floating (signal) potential, while the grid is grounded for alternating potential through condenser 58, resulting in a control of the space current and an amplified output current in the plate circuit. This output current may be further amplified in an audio amplifier serving to energize a suitable translating device such as a loud speaker 64.

Referring to Figure 6, there is shown another modification of a frequency variation response circuit embodying the principle of the invention.

According to this modification, the voltage u is inverted and combined with the voltage v and for this purpose the grid 27 of the inverter tube is grounded for alternating potential and the cathode maintained at floating (control) potential to effect plate current control. Figure 7 is substantially the same as Figure 6 with the exception that the voltage v is inverted by the tube 25 to obtain sum and difference voltages effective in both rectifying paths.

Figure 8 shows a system similar to Figure 2 embodying a modified inverter circuit. According to this modification the high potential side of the secondary circuit 21', 22' is connected to the output terminal c (by way of smoothing resistor 40) through a voltage divider comprising a pair of resistors 70 and 71 in series. The junction between the resistors 70 and 71 is connected to the grid 27 of the inverter tube 25 to obtain an inverted output potential of the proper amplitude. There is further provided a condenser 73 connected between the plate 28 and the output terminal c serving both as a blocking condenser and a means to impress inverse feedback potential upon the grid 27 from the plate circuit. This system was found to ensure both high operational stability and conversion fidelity.

Referring to Figure 9 there is shown a modified variable frequency conversion circuit especially, though not limitatively, suited for use in the I. F. section of a superheterodyne receiver. Input signals of varying frequency applied by way of terminals a—b are pre-amplified in a two stage amplifier comprising radio frequency pentodes 75 and 78 intercoupled through a double tuned transformer 76—77. The amplified signal potential is impressed upon a doubled tuned transformer type phase shifting network 21—22, 21'—22', resonant to the intermediate frequency. The high potential side of the primary circuit 21—22 is connected to the low potential end of the secondary circuit 21'—22' through a blocking condenser 80. Proper amplitude of the inverted potential is secured by a potential divider comprising a pair of resistors 82, 83 in series and connected across the secondary circuit 21'—22'. The grid 27 of the inverter tube is directly connected to the junction of resistors 82, 83. Furthermore, the grid 27 is properly biased with respect to the cathode by the provision of a biasing network in the cathode return and the cathode is further returned to ground for direct current through a radio frequency choke coil 87. The plate 28 of the inverter tube is connected to a suitable space current source through a resistor 84 in series with choke coil 85 with the junction point therebetween by-passed to cathode through condenser 86. The output is derived from the cathodes 36 and 36' of the diodes 37 and 37' by the provision of suitable load resistors 88 and 88' by-passed by condensers being connected between the cathodes and ground or any other potential reference point of the system. The function and operation of this system will be readily understood from the foregoing being substantially identical to the embodiments described hereinbefore. The circuit has been proven to operate satisfactorily and to ensure stable and faithful performance by experiments. The rectifiers in the balanced detector circuit are preferably of the linear type such as diode rectifiers to ensure faithful reproduction of the sounds or other signals in a frequency modulated receiver.

As is understood, the circuit proposed by the invention has many uses whenever a potential or current is required of varying amplitude representing relative frequency deviation both of an alternating signal or the resonant frequency of a tuned circuit from some particular frequency. Thus, in addition to the use of a frequency modulation detector as described in connection with Figure 5, the frequency sensitive or detecting circuit of the invention may be employed as a discriminator in radio transmitting or receiving systems to control a frequency determining element for automatically maintaining the frequency of an oscillation being generated or the tuning frequency of a circuit at a desired constant value.

It will be evident from the foregoing that the invention is not limited to the specific details and arrangement of parts and circuits shown and disclosed herein for illustration but that the underlying principle and novel inventive thought are susceptible of numerous variations and modifications coming within the broader scope and spirit of the invention as defined in the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than a limiting sense.

I claim:

1. A frequency variation response circuit comprising an input circuit, a first resonant impedance tuned to a predetermined frequency and reactively coupled with said input circuit, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from said resonant impedance and embodying a third impedance in its output circuit to develop a voltage of opposite phase to the voltage developed by said resonant impedance, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying means and a load resistance, said circuit paths having one end thereof connected to the same open end of one of said impedances and having their other ends each connected to one of the remaining open ends of said impedances, and an output circuit connected between points on the load resistances of said circuit paths to develop a voltage varying in sense and magnitude in accordance with and substantially in proportion to the departure of an impressed input frequency from said predetermined frequency.

2. A frequency variation response circuit comprising an input circuit, a first parallel-tuned impedance resonant to a predetermined frequency and reactively coupled with said input circuit, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from said first impedance and embodying a third impedance in its output circuit to develop a voltage of opposite phase to the voltage developed by said first impedance, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying and load resistance means, said circuit paths having one end thereof connected to the same open end of one of said impedances and having their other ends each connected to one of the remaining open ends of said impedances, and an output circuit including smoothing means connected between electrically symmetrical points of the load resistance means of said paths to derive

a voltage varying in sense and magnitude in accordance with and substantially in proportion to the departure of an impressed input frequency from said predetermined frequency.

3. A frequency variation response circuit comprising a parallel-tuned input circuit resonant to a predetermined frequency, a first parallel-tuned impedance also resonant to said predetermined frequency and being reactively coupled with said input circuit, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from said first impedance and embodying a third impedance in its output circuit to develop a voltage of opposite phase to the voltage developed by said first impedance, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying and load resistance means, said circuit paths having one end thereof connected to the same open end of one of said impedances and having their other ends each connected to one of the remaining open ends of said impedances, and an output circuit including smoothing means connected between electrically symmetrical points of the load resistance means of said circuit paths, to derive a voltage varying in sense and magnitude in accordance with and substantially in proportion to the departure of an impressed input frequency from said predetermined frequency.

4. A frequency variation response circuit comprising a parallel-tuned input circuit resonant to a predetermined frequency, a first parallel tuned impedance also resonant to said predetermined frequency and inductively coupled with said input circuit to develop voltages across said input circuit and said impedance having a relative phase varying in either direction from a normal phase relation in accordance with and substantially in proportion to the departure of an impressed input frequency from said predetermined frequency, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from said first impedance and embodying a third impedance in its output circuit to develop a voltage of opposite phase to the voltage developed by said first impedance, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying and load resistance means, said circuit paths having one end thereof connected to the same open end of one of said impedances and having their other ends connected each to one of the remaining open ends of said impedances, and an output circuit including smoothing means connected between electrically symmetrical points to the load resistance means of said circuit paths.

5. A frequency variation response circuit comprising an input circuit, a first resonant impedance tuned to a predetermined frequency and reactively coupled with said input circuit, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from said first impedance and embodying a third impedance in its output circuit to develope a voltage of opposite phase to the voltage developed by said first impedance, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying and load resistance means, each of said circuit paths having one end thereof connected to the open end of said second impedance and having their other ends connected each to one of the open ends of said first and third impedances, and an output circuit including smoothing means connected between points of the load resistance means of said circuit paths electrically symmetrical with respect to the open end of said second impedance, to derive a voltage varying in sense and magnitude in accordance with and in proportion to the departure of an impressed input frequency from said predetermined frequency.

6. A frequency variation response circuit comprising an input circuit, a first resonant impedance tuned to a predetermined frequency and reactively coupled with said input circuit, a second substantially non-resonant impedance coupled with said input circuit, an electron tube phase inverter having its input excited from one of said impedances and embodying a third impedance in its output circuit, said first, second and third impedances having one end thereof coupled to a common point, a pair of circuit paths each including rectifying and load resistance means, said circuit paths having one end thereof connected to the same open end of one of said impedances and having their other ends each connected to one of the remaining open ends of said impedances and an output circuit connected between points on the load resistance means of said circuit paths to develop a voltage varying in sense and magnitude in accordance with and substantially in proportion to the departure of an impressed input frequency from said predetermined frequency.

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