

May 26, 1936.

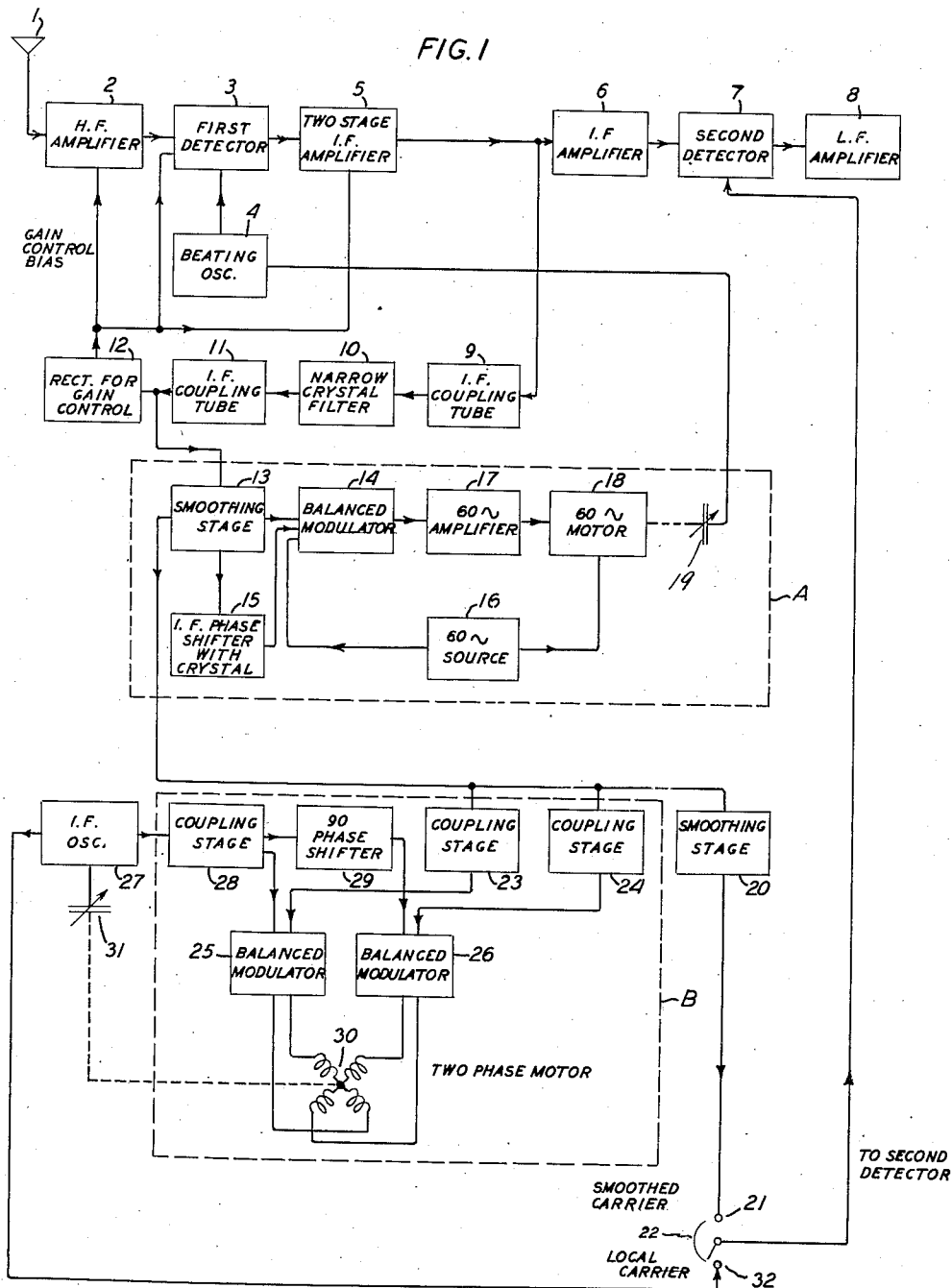
R. S. OHL

2,041,855

FREQUENCY CONTROL

Filed March 1, 1935

2 Sheets-Sheet 1



INVENTOR
R. S. OHL

BY *G. H. Stevenson*
ATTORNEY

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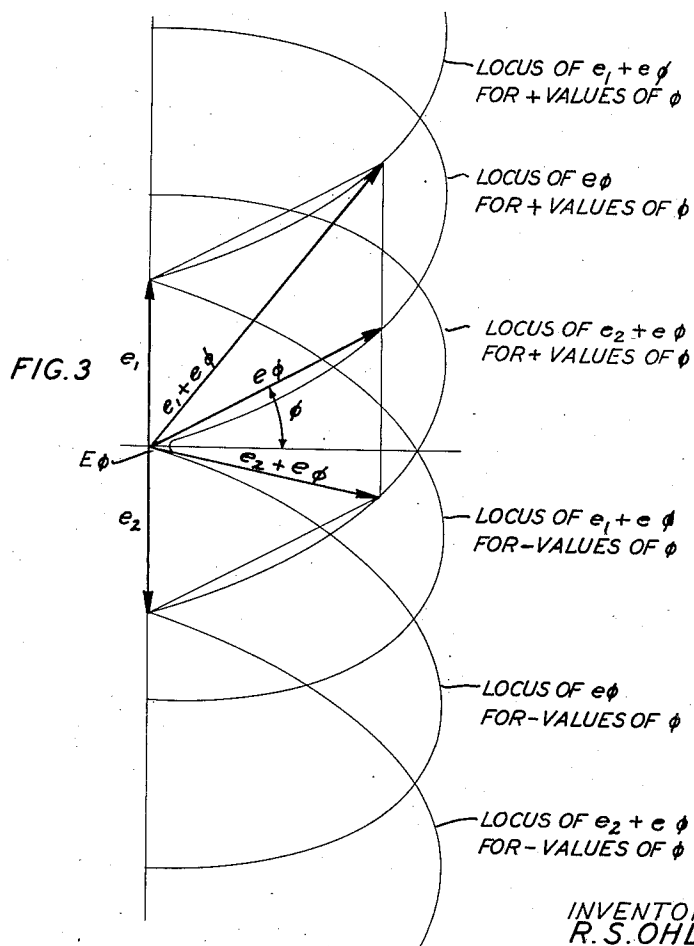
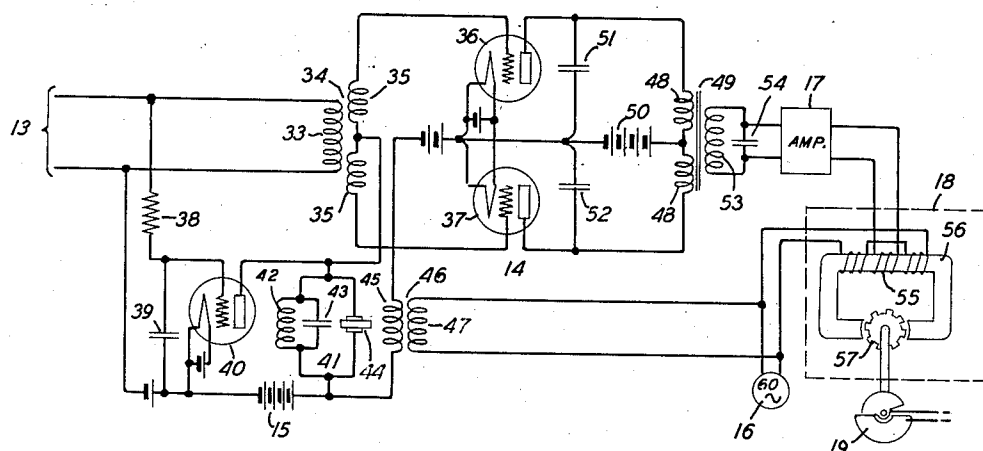
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FIG. 2



INVENTOR
R. S. OHL

BY *G. H. Stevenson*
ATTORNEY

UNITED STATES PATENT OFFICE

2,041,855

FREQUENCY CONTROL

Russell S. Ohl, Little Silver, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application March 1, 1935, Serial No. 8,816

7 Claims. (Cl. 250—20)

This invention relates to frequency control and synchronizing systems and particularly to such systems for controlling the frequency of carrier or heterodyne generators in a radio receiver.

5 An object of the invention is to improve the accuracy of operation of frequency control systems.

10 In a radio receiver it is often desirable to use a wave, the frequency of which is in fixed relationship to the carrier frequency of the received wave. It is not only necessary in systems in which only a single side-band is transmitted and the carrier resupplied at the receiver, but also in multiple detection systems in which 15 the received wave is combined with the local wave to produce a wave which may be more readily selected and amplified.

Obviously, in systems of the first type any variation between the original and resupplied carrier 20 waves will produce a distortion of the resultant signal wave. Likewise, in systems of the second type, any variation in the frequency relation of the received and locally supplied waves will produce a variation in the resultant intermediate frequency wave from the frequency for which the 25 selecting and amplifying circuits are designed which will result in a loss in output level and distortion in the signal wave. In the case of short radio waves, not only is it extremely difficult and involved to maintain constant the frequency relation of the waves at the transmitter and receiver, but also fading often produces an apparent change in the frequency of the incoming carrier, which must be compensated for by a 30 corresponding change in the frequency of the wave supplied at the receiver.

In a specific preferred embodiment, this invention comprises an automatic tuning or heterodyne oscillator frequency control for a radio 40 receiver. The control circuit comprises a balanced vacuum tube modulator which may be considered as acting as a Wheatstone bridge, two arms of which are made up of the plate circuits of the vacuum tubes. A 60 cycle alternating current is supplied across one diagonal of the bridge and the resultant current across the other diagonal is used for effecting the control as described hereinafter.

50 A portion of the intermediate frequency current is branched off to a highly selective filter, preferably of the piezoelectric crystal type, which selects the intermediate frequency carrier to the exclusion of the side-band frequencies. The output of this filter, after being smoothed out in an 55 amplitude limiting amplifier, is impressed on a

conventional type push-pull input circuit connected to the grids of the tubes forming the arms of the Wheatstone bridge so that the grids receive equal voltages of opposite sign. The input is also branched off through a network which produces a 90 degree phase shift, and through a narrow filter comprising an anti-resonant circuit and a crystal in parallel, both tuned to the intermediate carrier frequency. The output of this filter is supplied in the common grid lead of the vacuum tubes so as to add equal voltages to the inputs of the two tubes. The narrow filter will produce no phase shift and a maximum attenuation at the resonant frequency, and the amplitudes of the inputs of the two tubes will be equal. When the frequency departs from the resonant frequency there will be produced a phase shift, the sign of which is determined by the direction of the departure. This in turn causes the relative magnitudes of the tube input voltages to vary, an increase in the frequency causing the input of one tube to go up and of the other to go down, while a decrease in frequency causing an opposite effect.

As a result the impedances of the tubes will be equal and there will be no output from the bridge when the frequency of the intermediate carrier is at the desired value. At other frequencies there will be an output, the amplitude of which is dependent on the degree of variation and the phase of which is dependent on the direction of variation. In order to effect an automatic control of the frequency, the output of the bridge is supplied to one coil of a watt-hour meter type of induction motor, the other coil of which is energized by the same source which supplies the bridge. The rotor of the motor is mechanically connected to a condenser in the tuning circuit of the beating oscillator which supplies the high frequency modulator so that any variation of the intermediate frequency carrier from the desired frequency will be automatically corrected.

The invention will be more readily understood by reference to the following detailed description in connection with the attached drawings, of which

Fig. 1 is a block diagram of one embodiment of the invention in a double detection radio receiver designed for single side-band and reduced carrier reception;

Fig. 2 is a detailed schematic drawing of the portion of the circuit shown in the dashed lines A of Fig. 1; and

Fig. 3 is a vector diagram explanatory of the operation of the circuit of Fig. 2.

Referring to Fig. 1, radio frequency signal waves received in an antenna 1 are amplified by a high frequency amplifier 2 and applied to a detector 3, in which they are combined with waves from a beating oscillator 4 for the purpose of effecting a shift in the frequencies of the received carrier and side-band to frequencies of a lower, or "intermediate", value. These intermediate frequency waves are then selectively amplified by an amplifier comprising two stages 5 and a third stage 6. The output of amplifier 6 is delivered to a second or low frequency detector 7 and the resulting audio signal is amplified by a signal frequency amplifier 8.

In a branch circuit from the two-stage amplifier 5 a portion of the output is supplied through a coupling tube 9 to a narrow crystal filter 10 which allows only the carrier of the intermediate frequency band to pass. After passing through the filter the carrier is amplified by a coupling tube 11 and rectified by a linear rectifier 12, the rectified output voltage giving automatic volume control action on the high frequency amplifier 2, the first detector 3 and the two-stage intermediate frequency amplifier 5, in a manner well-known in the art.

In a branch circuit from the output of the coupling tube 11 the carrier passes through a smoothing stage 13 which serves to reduce the fluctuations that may be present on account of fading or modulation. This smoothed carrier is then branched into several paths, in one of which it is introduced in push-pull fashion onto the grids of a balanced modulator 14. In another branch circuit the same carrier is passed through a network 15 comprising a 90 degree phase shifter, an amplifier, and a narrow band suppression filter, and then applied to the grids of the modulator 14 in parallel. A small 60 cycle, or other low frequency, voltage from a source 16 is also applied to the modulator grids in parallel. These input voltages are so disposed, as will be more fully explained below, that if the carrier frequency remains at its proper value there will be no 60 cycle output from the modulator 14, but if the frequency departs in either direction from this value there will be a 60 cycle output current the phase of which will depend upon the direction of the deviation. The output current from modulator 14 is amplified by a 60 cycle amplifier 17 and applied to one winding of a 60 cycle two-phase induction motor 18, the other winding of which is connected directly to the 60 cycle source 16. The rotor of the induction motor is mechanically connected to the movable plates of a condenser 19 which is electrically connected so as to control the frequency of the beating oscillator 4. The action of the modulator and associated elements will be described in fuller detail in connection with Fig. 2.

By another path from the output of amplifier 13 the smoothed intermediate frequency carrier is passed through a second smoothing stage 20 and thence to a terminal 21 of switch 22, by which means it may be applied to the detector 7 for the purpose of demodulating the intermediate frequency side-band in order to obtain the transmitted signal.

From the path connecting the smoothing stages 13 and 20 the intermediate frequency carrier is again branched and passed through coupling amplifiers 23 and 24 to the balanced modulators 25 and 26, respectively. The output of a local oscilla-

tor 27, which is to be adjusted to the same frequency as that of the intermediate frequency carrier, is passed through a coupling amplifier 28 and by other branched circuits is introduced to the same modulators; i. e., to 25 directly and to 26 through a phase shifting network 29 which shifts the phase 90 degrees. The phases of the output voltages of these balanced modulators will therefore be in quadrature and the output frequency will be the beat frequency between the incoming intermediate frequency carrier and the locally generated carrier. These voltages operate a motor 30 which, by means of a mechanical coupling, operates a variable condenser 31 in the circuit of the local oscillator 27. The motor operates until the frequency of this oscillator is exactly the same as that of the intermediate frequency carrier produced from the incoming wave, at which point the frequency of the voltage applied to the motor becomes zero and the motor stops. The controlled output of the local oscillator 27 is connected to a terminal 32 of the switch 22 and so may be applied to detector 7 for purposes of demodulation during periods of deep fading of the carrier and low signal-to-noise ratio. Reference is made to U. S. Patent 1,959,449 to H. M. Stoller for a more detailed description of the arrangement and operation of the type of control unit just described and comprises within the dashed lines B.

We will now refer to Fig. 2 for the details of the tuning or synchronizing control A of Fig. 1. The smoothed intermediate frequency carrier from 13 is branched into two paths, by one of which it is applied to the primary 33 of transformer 34, the secondary 35 being connected to the grids of the balanced modulator tubes 36 and 37, with the mid-point of the secondary connected to a common point of the cathodes, in the manner of the well-known push-pull arrangement. By the other path the carrier is passed through a 90 degree phase shifting network consisting of a resistance 38 and a condenser 39, the voltage across 39 being nearly in quadrature with that across the resistance 38, or that across the primary winding 33. This quadrature voltage is amplified by an amplifier tube 40 and the output voltage is applied across a network 41 constituting a narrow band suppression filter. This network consists of two branches, one of which, comprising an inductance 42 and a condenser 43 in parallel, is anti-resonant to the intermediate carrier frequency and the other, comprising a quartz crystal 44, is resonant to the same frequency. The voltage developed across the network 41 is inserted in the common grid lead of the balanced modulator, between the mid-point of the secondary 35 and a common point of the cathodes of the two modulator tubes, and is thus applied to the grids in parallel. Connected in the same circuit is the secondary winding 45 of transformer 46, the primary 47 of which is connected to the 60 cycle source 16, by means of which a small 60 cycle voltage is also applied to the grids in parallel.

In the output circuit of the balanced modulator is connected the primary 48 of transformer 49, with its middle point connected through a battery 50 to a common point of the cathodes, in the conventional push-pull fashion. By-pass condensers 51 and 52 permit high frequency currents to return to the cathodes without passing through the primary windings, while the secondary winding 53 may be tuned to 60 cycles by a condenser 54 in order to augment the current

therein at this frequency. The terminals of the secondary winding 53 are connected to the input side of the amplifier 17, the output of which is connected to one winding 55 of the 60 cycle induction motor 18, which consists of a common type of watt-hour meter, the other winding 56 being connected directly to the 60 cycle source 16. The rotor 57 of the watt-hour meter is mechanically connected to one set of plates of the condenser 19, which is electrically connected in the circuit of the beating oscillator 4 of Fig. 1 in such a manner that the oscillator frequency may be controlled thereby, and hence the frequency of the intermediate frequency carrier 15 and side-band output of the detector 3.

The manner in which this frequency control is effected will now be explained. The voltages at intermediate carrier frequency applied to the grids of 36 and 37 by the secondary winding 35 are equal and opposite in phase and may be designated as e_1 and e_2 , respectively (see Fig. 3). The voltage of the same frequency developed across the filter 41 and applied to the grids in parallel may be designated as $e\phi$. When the intermediate carrier frequency is at its correct value, which is that of maximum suppression for the filter 41, the voltage $e\phi$ is at its minimum value $E\phi$ and very small, and is in quadrature with the voltages e_1 and e_2 . As the carrier shifts from its proper value, however, $e\phi$ is increased in magnitude and changed in phase, approaching the phase of e_1 or e_2 depending upon the direction of the carrier frequency deviation. The resultant high frequency voltage applied to the grid of 36 is then the vector sum of e_1 and $e\phi$ and the resultant applied to the grid of 37 is the vector sum of e_2 and $e\phi$. When the voltage $e\phi$ is at its minimum value the two tubes 36 and 37 will be operating under exactly the same conditions (grid voltages of equal magnitude and phase) and, assuming that their electrical characteristics are identical, or sensibly so, their mutual conductances will be equal. Under these circumstances, therefore, there will be equal and opposite 60 cycle currents in the two halves of the primary 49 and no voltage will be induced in the secondary 53. When the carrier frequency deviates from its correct value, $e\phi$ increases in magnitude and is no longer in quadrature with e_1 or e_2 and therefore the resultant voltage on one of the grids becomes greater than that on the other. The tubes are now unbalanced with respect to their mutual conductances and more current flows through one than the other. A 60 cycle current will now flow through the secondary 53 and the winding 55 of the watt-hour meter 18 and the rotor will begin to rotate, the direction of rotation depending upon the phase of the current in the coil 55, this in turn depending upon the direction of the deviation of the carrier frequency. The condenser 19 attached to the rotor 57 of the watt-hour meter is electrically connected in the tuning circuit of the oscillator 4 of Fig. 1 in such a manner that its rotation from the normal position either increases or decreases the oscillator frequency until the intermediate carrier frequency is restored to its correct value, whereupon the current in the coil 55 falls to zero and the rotor stops. Thus the intermediate carrier frequency is held automatically very close to its desired value.

Another way of looking at the operation of the modulator 14 is to consider it as a Wheatstone bridge, two of the arms of which comprise the primary windings 48 and the other two the an-

ode-cathode paths of the tubes 36 and 37. Due to the application of the 60 cycle voltage through transformer 46 to the common grid branch there appears in the common anode path a 60 cycle voltage which is effectively impressed across one diagonal of the bridge. In fact, this voltage could be directly applied in the plate circuit by substituting a 60 cycle source of the proper voltage in place of the battery 50 and eliminating the 60 cycle supply from the grid circuits. For some purposes this circuit variation may be substituted for the arrangement shown in the drawings. The output of the bridge is taken off the opposite diagonal through the secondary 53 of the transformer 49. The primary windings 48 being balanced, as long as the anode-cathode impedances of the tubes 36 and 37 are equal there will be no 60 cycle output from the bridge, which is the normal condition, i. e., when the intermediate carrier voltage supplied from the smoothing amplifier 13 is of the correct frequency. However, the anode-cathode paths of the tubes 36 and 37 are variable impedances being controlled by the voltages of their respective grids, in one case the vector sum $e_1+e\phi$ and in the other the vector sum $e_2+e\phi$ (Fig. 3).

Thus in the case of the correct frequency for the intermediate carrier $e\phi=E\phi$ and the two sum voltages and consequently the two anode-cathode impedances are equal, the bridge is balanced and there is no 60 cycle output therefrom. On the other hand as the intermediate carrier frequency varies from the correct value $e\phi$ varies in amplitude and phase, due to the characteristic of the network 41, and the two voltages $e_1+e\phi$ and $e_2+e\phi$ will become unequal producing a corresponding variation in the anode-cathode impedances of the tubes 36 and 37 and a consequent unbalance in the bridge. As will be observed from a consideration of the diagram, Fig. 3, $e_1+e\phi$ is greater than $e_2+e\phi$ for plus values of ϕ and $e_2+e\phi$ is greater than $e_1+e\phi$ for minus values of ϕ . The result is that in one case the anode-cathode impedance of tube 36 will be lower than that of tube 37 and in the other the opposite will be true. Thus the 60 cycle output of the bridge will be of one phase for plus values of ϕ and of the opposite phase for minus values of ϕ producing rotations of the rotor 57 in opposite directions for the two conditions. Since the sign of ϕ is in turn dependent on the direction of variation of the frequency of the intermediate carrier from normal this fact is utilized to make the proper correction capacity of the condenser 19 to restore the frequency to the desired value.

What is claimed is:

1. A frequency control system comprising a source of electrical oscillations, the frequency of which is to be controlled, an impedance network having a frequency phase shift characteristic producing a phase reversal as the frequency passes through a predetermined value, a balanced bridge circuit comprising controllable impedance elements in two corresponding arms, an alternating current source connected across one diagonal of the bridge, means for controlling the impedances of said controllable impedance elements in response to the vector sum and difference, respectively, of a voltage from said source and the voltage output of said impedance network produced by a voltage input from said source 90 degrees out of phase with the first mentioned voltage from said source, and means responsive to the phase and amplitude of the voltage across the other

diagonal of said bridge for controlling the frequency of said source.

2. A frequency control system comprising a source of oscillations, the frequency of which is to be controlled, an impedance network having a phase shift characteristic which varies with frequency, the phase shift reversing and passing through zero at a predetermined frequency, means for impressing oscillations from said source on the input of said network, means for producing two voltages, one representing the vector sum and the other the vector difference of a voltage 90 degrees out of phase with the input to said network and the voltage output of said network, a bridge network having as two arms thereof variable impedance elements, the values of which are controlled by the respective two voltages, an alternating current supply for said bridge, and means responsive to the phase of the output from said bridge for controlling the frequency of said source.

3. In combination, a source of electrical oscillations, means for controlling the frequency of said source comprising a balanced vacuum tube modulator, means for deriving from said source equal voltages of opposite phase, means for impressing said voltages on the respective grids of the vacuum tubes of said modulator, means for obtaining from said source a voltage 90 degrees out of phase with the first voltage, an impedance network having a phase shift characteristic reversing in sign and passing through zero at a predetermined frequency and an attenuation characteristic which is a maximum at said predetermined frequency and decreases rapidly as the frequency varies in either direction therefrom, means for impressing on said impedance network said 90 degrees out of phase voltage, means for impressing the output from said impedance network on the respective grids of the vacuum tubes of said modulator, a source for supplying alternating current to said vacuum tubes in parallel, and means responsive to the phase and amplitude of the push-pull output of said balanced modulator at the frequency of said alternating current for controlling the frequency of said source.

4. A combination according to claim 3 in which said impedance network comprises a circuit anti-resonant to the desired frequency for the controlled source and a piezoelectric element resonant at the same frequency connected in parallel with said circuit.

5. A frequency control system comprising a source to be controlled, a pair of electric discharge devices connected in push-pull, circuit paths for obtaining two voltages one directly from said source and the second also from said source but 90 degrees out of phase with the first, an electrical network having a frequency phase characteristic which reverses in sign at a given fre-

quency and varies rapidly at frequencies on each side of and adjacent to said given frequency and a frequency amplitude characteristic having a minimum value at said given frequency and rising rapidly for frequencies on each side of and adjacent to said given frequency, means for applying one of said two voltages to said network, means for supplying the other of said two voltages to the grids of said electric discharge devices in push-pull, means for supplying the output of said network to the grids of said electric discharge devices in parallel, a source of alternating current supplied to said electric discharge devices in parallel, and means responsive to the push-pull output of said devices at the frequency of said alternating current for controlling the frequency of the source to be controlled.

6. A frequency control system according to claim 5 in which the means for controlling the frequency of the source to be controlled comprises an induction motor having one winding supplied directly from said alternating current source and another winding supplied with the push-pull output of said electric discharge devices at the frequency of said alternating current source.

7. A radio receiver comprising an oscillator having a variable impedance element for controlling the frequency, means for combining the received waves with the output of said oscillator to produce an intermediate frequency wave, means for selectively amplifying said intermediate frequency wave, means for selecting the carrier from said intermediate frequency wave to the substantial exclusion of any side-band components, a pair of electric discharge modulators, means for supplying the selected intermediate frequency carrier wave to the inputs of said modulators in push-pull relation, a path for impressing said selected intermediate frequency carrier wave to the inputs of said modulators in parallel said path including a network for producing a 90 degree phase shift, an electrical network connected in shunt to said path and comprising a circuit anti-resonant at the desired intermediate carrier frequency connected in parallel with a piezoelectric crystal resonant at said intermediate carrier frequency, an induction motor having two windings so arranged that the direction of rotation of said motor depends upon the relative phase of the current in said windings, connections from one of said motor windings to the outputs of said modulators in push-pull, a source of alternating current, connections from said source to the other of said motor windings, other connections from said alternating current source to said modulators in parallel, and a mechanical linkage from said motor to said variable impedance element to control the frequency of the output of said oscillator to maintain the intermediate frequency constant at said desired value.

RUSSELL S. OHL.